Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

BY

UZMA SAEED

DEPARTMENT OF ZOOLOGY
QUAID-I-AZAM UNIVERSITY
ISLAMABAD, PAKISTAN
2024

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

Ph.D. Dissertation

A dissertation submitted in partial fulfillment of requirements for the degree of Doctor of Philosophy in Zoology

BY

UZMA SAEED

DEPARTMENT OF ZOOLOGY

Faculty of Biological Sciences

Quaid-i-Azam University, Islamabad, Pakistan

2024

<u>Author's Declaration</u>

I **Ms. Uzma Saeed** hereby state that my PhD thesis titled "Assessment of Climate Change Vulnerability and Ecosystem Services in Snow Leopard Habitat in Pakistan" is my own work and has not been submitted previously by me for taking any degree from Quaid-i-Azam University, Islamabad, Pakistan.

At any time if my statement is found to be incorrect even after my Graduate the University has the right to withdraw my Ph.D. degree.

Ms. Uzma Saeed

Date: 12.01.2024

Plagiarism Undertaking

I solemnly declare that research work presented in the thesis "Assessment of Climate Change Vulnerability and Ecosystem Services in Snow Leopard Habitat in Pakistan" is solely my research work with no significant contribution from any other person. Small contribution/ help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Quaid-i-Azam University towards plagiarism. Therefore I as an Author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/ cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of Ph.D degree, HEC and the University has the right to publish my name on the HEC/University Website on which names of students are placed who submitted plagiarized thesis.

Student / Author Signature: Uzma Saeed

Name: **Ms. Uzma Saeed**

Certificate of Approval

This is to certify that the research work presented in this thesis, entitled "Assessment of Climate Change Vulnerability and Ecosystem Services in Snow Leopard Habitat in Pakistan" was conducted by **Ms. Uzma Saeed** under the supervision of **Muhammad Ali Nawaz**. No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Department of Zoology of Quaid-i-Azam University, Islamabad in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Field of Wildlife Ecology.

Student Name: **Ms. Uzma Saeed** Signature:____________

Examination Committee:

a) External Examiner 1: Signature:____________

Dr. Jahangir Arshad Khan
(Ex Chief Research Officer)
House No. 68, Street No.51,
F-11/3, Islamabad

b) External Examiner 2: Signature:____________

Dr. Shamim Akhter
Professor and Chairperson
Department of Zoology, Wildlife
and Fisheries, PMAS Arid
Agriculture University,
Rawalpindi

Supervisor Name: **Dr. Muhammad Ali Nawaz** Signature:____________

Name of HOD: **Prof. Dr. Amina Zuberi** Signature:____________

Date: 12.01.2024

CHAIRPERSON
Department of Zoology
Quaid-i-Azam University
Islamabad.

DEPARTMENT OF ZOOLOGY
QUAID-I-AZAM UNIVERSITY
ISLAMABAD
DATE 12-01-2024

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ACKNOWLEDGEMENTS

All praises and thanks to **Allah** Almighty, the only creator of the universe, the most merciful and entire source of wisdom who blessed us with knowledge. All my efforts are fruitful only because of His rewards. I owe my deepest respect to **Prophet Muhammad (S.A.W)**, the most perfect among all human beings ever born on earth, who is a forever source of guidance and knowledge for humanity.

I feel honored to be part of the Carnivore Conservation Lab (CCL) under the supervision of Dr. Muhammad Ali Nawaz. He is not only a teacher, mentor, or supervisor for me but also my biggest support throughout my Ph.D. work. I completed and submitted this thesis only because of him, and if he were not there, I would have lost hope.

Dr. Amina Zuberi and Dr. Sarwat Jahan, Department of Zoology, Quaid-i-Azam University, always supported and encouraged me, keeping me motivated. Dr. Ranjini Murali, Snow Leopard Trust, USA, taught me the concept of Ecosystem Services. Her support and guidance, from concept to journal manuscript reviews, have been exceptional. Dr. Shakeel Hayat, Institute of Management Sciences, Peshawar, helped improve the publication manuscript marvelously.

I feel privileged to have had the opportunity to meet and work under the supervision of Dr. Toni Lyn Morelli, University of Massachusetts, Amherst, USA, for a few months. She welcomed me into her lab and provided valuable input in shaping snow leopard distribution modeling. She made my stay comfortable and memorable. She has been the main person in providing critical feedback to improve the manuscripts.

Muhammad Arshad, Himalayan Wildlife Foundation, Islamabad, helped in data collection and analysis and provided Gurez Valley communities with detailed insights on ecosystem services. Shakeel Ahmad, PhD Scholar, CCL, Quaid-i-Azam University, helped me the most with data arrangement, formatting, and the great moral support to complete this work. Tahir Mehmood, Shakeel Malik, Barkatullah Khan, Muhammad Amir, Sana Ullah, and Muhammad Abuzar Razi helped me with data collection and data entry for the Chitral and Gurez Valley surveys. I thank Doost Ali Nawaz at Snow Leopard Foundation

(SLF) Pakistan and Muhammad Asif at WWF-Pakistan for GIS support whenever required on an emergency basis. Thanks to Muhammad Jahangir, Ejaz ur Rehman, and Fathul Bari for help in getting information on the Chitral Valley in the Hindu Kush range in Pakistan in detail.

Special thanks to Nargis Shaheen for giving me time and helping me overcome this difficult time. I am very grateful to Naeem Masih, Zoology Department, who helped me submit my thesis and always helped remotely. He always made all the arrangements, which relieved me so much.

I am grateful to the Higher Education Commission (HEC), Pakistan, and the authorities who allowed me to visit the University of Massachusetts, USA, to improve my knowledge and skills through the International Research Support Initiative Program (IRSIP). I am also thankful to the Snow Leopard Trust (SLT) for the generous financial support for my entire research work, which made it all possible. Thanks to SLF Pakistan, which provided some of their old data for my study.

My mother, Sultan bhai, mother-in-law, husband, Saeeda bhabhi, siblings, and daughters were my support and greatly sacrificed during this process. They had waited for this moment for years, which would be my payback gift to make them happy and proud.

Uzma Saeed
Islamabad, Pakistan (2024).

LIST OF ACRONYMS

$	US Dollar
%	Percent
°C	Degree Celsius
AIC	Akaike's information criterion
AJK	Azad Jammu and Kashmir
AUC	Area under the curve
BBC	British Broadcasting Corporation
Bio1	Annual Mean Temperature
Bio12	Annual Precipitation
Bio14	Precipitation of the Driest Month
Bio15	Precipitation Seasonality
Bio18	Precipitation of Warmest Quarter
Bio19	Precipitation of Coldest Quarter
Bio2	Mean Diurnal Range
Bio3	Isothermality
Bio4	Temperature Seasonality
Bio7	Temperature Annual Range
Bio8	Mean Temperature of Wettest Quarter
Bio9	Mean Temperature of Driest Quarter
C2ES	Center for Climate and Energy Solutions
CCAFS	Climate Change, Agriculture and Food Security
CGCM3	Coupled Global Climate Model
CICES	Common International Classification on Ecosystem Services
CNN	Cable News Network
E	East
ENMs	Ecological Niche Models
ES	Ecosystem Services
et al	And Others
etc	Et Cetra
FAO	Food and Agriculture Organization
GB	Gilgit Baltistan
GCMs	Global Circulation Models

GIS	Geographic Information System
GLMs	Generalized Linear Models
GLOF	Glacial Lack Outburst Flood
H0	Null Hypothesis
Ha	Alternate Hypothesis
HEC	Higher Education Commission, Pakistan
HH	Household
HKH	Hindu Kush Himalaya
HWF	Himalayan Wildlife Foundation
ICIMOD	International Centre for Integrated Mountain Development
IFRI	International Forestry Resources and Institutions
IPCC	Intergovernmental Panel on Climate Change
IRs	Indian Rupees
IRSIP	International Research Support Initiative Program
ISRI	Environmental Systems Research Institute
kM^2	Square Kilometers
KP	Khyber Pakhtunkhwah
m	Meters
M1	Area Including China
M2	Area Excluding China
Masl	Meters above sea level
MaxEnt	Maximum Entropy
MDNP	Musk Deer National Park
MEA	Millennium Ecosystem Assessment
MESS	Multivariate environmental similarity surface
mm	Millimetres
MoCC	Ministry of Climate Change
MOP	Mobility Oriented Parity
N	North
n	Number
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NTFPs	Non-Timber Forest Products
PCA	Principle Component Analysis

PCs	Principle Components
PMD	Pakistan Meteorological Department
POP	Human Population Density
PRA	Participatory Rural Approach
RCP	Representative Concentration Pathway
REDD	Reducing emissions from deforestation and forest degradation
SDMs	Species Distribution Models
SEDAC	Socioeconomic Data and Applications Centre
SLF	Snow Leopard Foundation
SLT	Snow Leopard Trust
SSPs	Shared Socioeconomic Pathways
TEEB	The Economics of Ecosystem & Biodiversity
TEV	Total Economic Valuation Framework
UNDP	United Nations Development Programme
US	United States
USD	United States Dollar
vs	Versus
WWF	World Wide / Wildlife Fund for Nature
yr	Year

ABSTRACT

The earth's ecosystems are being affected by global climate change, with northern latitudes and terrestrial regions warming more than oceans. Pakistan ranks 8th among nations highly susceptible to water scarcity, desertification, rapid melting of glaciers, severe weather conditions, and the spread of afflictions. The Himalayas are expected to experience an increase in average temperature and rainfall, which will affect the growth of plants and shift their distribution up the mountains. This shift of trees will reduce the habitat of the snow leopard, a vulnerable species, by 30%. The snow leopard has been the focus of research since the 1970s, but only a small portion of its habitat has been studied for its ecology and conflicts with humans. Previous research on conservation has overlooked the human dimension, particularly in regions where local populations depend on livestock herding. This disregard for the human aspect is quite apparent. To devise a successful plan for preserving snow leopards and their habitats that serve multiple purposes in Pakistan and the wider Himalayan region, more research is required to fill the knowledge gaps regarding the protection of both the livelihoods of local communities and the snow leopards.

To achieve the above-mentioned research gaps, four study objectives were established: (i) evaluating the climate change impacts on snow leopard habitat, under current and climate change scenarios (ii) monetary valuation of ecosystem services in snow leopard habitat in Pakistan; (iii) understanding perceptions of climate change and exploring the perspectives of mountain communities concerning adaptation strategies, and (iv) recommending conservation measures to preserve the habitat and maintain the livelihoods of local communities while ensuring the survival of the snow leopard under changing climatic conditions.

The work focused primarily on the population of snow leopards in Pakistan; however, it also incorporated a wider area of the greater Himalayan region to understand better the potential shifts in habitat caused by climate change. Data for the predictive modelling of snow leopard habitat were obtained through advanced techniques such as camera trapping and molecular genetics and analyzed using cutting-edge methods, including the Kuenm approach. The ecosystem services data were collected in June 2017 and November 2018 and analyzed using the PRA method, the Total Economic Valuation framework, and the Common International Classification of Ecosystem Services approach. Data for the climate change perceptions, impacts, and adaptation strategies of the indigenous communities of Chitral Valley were collected in November 2018 using the PRA approach and analyzed using content analysis, counting, and frequency distributions. Temperature (1973 - 2022) and rainfall data (1993 - 2022) for the Chitral Valley were obtained from the Department of Meteorology, Government of Pakistan, and were examined graphically.

The predictive modelling was run in two geographical areas: Pakistan, India, and Nepal, and another that included these countries along with China (which had no snow leopard occurrence data). This aimed to understand the potential shifts in snow leopard habitat suitability and distribution under different emission scenarios. Results indicate that by 2070, the snow leopard habitat in the greater Himalayan region may shrink by 16.9% to 23% under Representative Concentration Pathway 4.5 and 8.5 individually, with the extremely suitable habitat declining from 37% to 31.2% between present and future conditions. The annual mean temperature (bio1) remains the key determinant of the snow leopard's habitat suitability. The habitat may also shrink by 10% to 13% by 2070 in the area, including China. Our study shows that Panthera uncia habitat is greatly susceptible to climate change, and the loss of 17 - 23% of these habitats could have devastating consequences for the species. To counter these effects, it's essential to concentrate on safeguarding climate sanctuaries and constructing pathways for species conservation. Moreover, addressing ongoing threats such as illegal hunting and conflicts between humans and wildlife is necessary.

Through the ecosystem services valuation assessment, the high dependence of the local communities on the natural resources in the Western Himalayan and Hindukush ranges of Pakistan was identified. The studies found that the ecosystem services were worth 6730 ± 520 USD per household per year in the Gurez Valley and 7272 ± 481.6 USD per household per year in the Chitral Valley, respectively. These values were 3.1 and 3.7 times greater than a household's typical earnings in the subject valleys, emphasizing the significance of these services to the well-being of local communities. The ecosystem service with the utmost value was livestock forage, worth 4105 ± 306 USD per household per year in the Gurez Valley and 2219 ± 83 USD per household per year in the Chitral Valley.

The mountain communities were keenly aware of the impacts associated with climate change, such as shifts in temperature, precipitation, snowfall, glacier melt, flooding, and drought events, as well as pest attacks. These public perceptions are supported by meteorological records, which indicate a rise in temperature and a reduction in precipitation, with an average increase of 0.32ºC per decade between 1973 and 2022. These changes have adversely affected crop yields, livestock rearing, water resources, pastureland productivity, and human health. Locals have noted that human-wildlife conflict has significantly impacted biodiversity in the Chitral Valley. To adapt to these changes, communities have implemented various measures, including water management, cultivating different crop varieties, infrastructure development, institutional support, migration, livelihood diversification, and using clean energy alternatives. These results offer critical data for creating successful conservation plans in response to the problems posed by climate change and sustaining mountain communities' livelihoods.

The mountain regions in Pakistan are hugely susceptible to the effects of climatic change, including human activities, making it a pressing priority to implement climate adaptation and mitigation measures. Involving local communities and incorporating traditional wisdom into conservation plans can be vital in ensuring sustainable management. A market-driven system like payment of ecosystem services and certification schemes, including biodiversity offset programs, can encourage better management practices and aid in preserving the cultural, economic, and ecological prosperity of mountain communities in Pakistan. Moreover, the government has the potential to assist in making livelihood resources easily reachable, enabling access to markets, disseminating knowledge and information, and enhancing the capacity of local communities to adjust to and change in response to climate disturbances and environmental threats.

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

CHAPTER 1

General Introduction

1 GENERAL INTRODUCTION

1.1 CLIMATE CHANGE AND VULNERABILITY OF MOUNTAIN ECOSYSTEMS

Climate change caused by high greenhouse gas emissions is a primary global concern. Human activities are the primary cause of global warming, with a 1.07°C increase in temperature from 2010 to 2019, according to Arias et al., (2021). The global average surface temperature anomaly in 2020 was 0.98°C, with a sustained increase from 1850 to 2015 and a slight decrease from 1998 to 2013, as Rahmstorf et al., (2017) reported. Extreme hot temperatures have increased three-fold in Europe, and severe cold has decreased by 2-3 days from 1950 to 2018, as noted by Lorenz et al., (2019). Asia has also experienced a significant increase in the intensity and frequency of hot extremes and a reduction in cold extremes. North America had a temperature in 2020 that was 0.90°C above the 1910-2000 average, according to NOAA (2021).

According to Dai (2021), from 1950 to 2018, there was an increase in precipitation in North America, Eurasia, South America, and Australia but a decrease in eastern Australia, Africa, the Middle East, and parts of Asia, South America, and Canada. The trends of heavy precipitation events varied greatly and were region and season specific. Over the last half of the 20^{th} century, the average annual maximum daily precipitation, daily mean precipitation intensities, and the likelihood of daily precipitation exceeding 50 mm have all increased over land areas, resulting in a global average precipitation rate increase of 2.54 mm per decade (Du et al., 2019; Seneviratne et al., 2019).

The effects of climate change are evident across all levels of ecosystems, from individual species to entire ecosystems. At the individual level, changes can be seen in physical attributes, behaviour patterns, the timing of life events, and geographical distributions. At the ecosystem level, shifts in productivity, species interactions, and overall characteristics are observed. These changes hurt the benefits that ecosystems provide to humans and, thus, human well-being (Weiskopf et al., 2020).

1.2 WILDFIRES ON A GLOBAL SCALE

The rise in global temperatures has led to more frequent forest fires, with only 3% being naturally ignited (Hirschberger, 2016). Most forest fires result from human activities (FAO, 2007). Forest fires are a significant factor driving forest degradation, leading to decreased productivity, loss of biodiversity, reduced carbon stocks, disrupted nutrient cycling, and a decline in ecosystem services (Amiro et al., 2000; Amiro et al., 2001; Pérez-Cabello et al., 2012). About 85% of the world's fire-affected surface area is found in tropical savannahs, covering 19% of the Earth's total land (Global Forest Watch, 2021).

In April 2020, there was a 13% increase in global fire alerts compared to 2019, a record-breaking year for forest fires (WWF, 2020). Each year, forest fires impact over 350 million hectares of land (Amiro et al., 2001; Merino et al., 2004). Recent significant fires in countries such as Australia (Nolan et al., 2020), Brazil (BBC, 2019), the United States, Greece (CNN, 2020; Smith et al., 2019), and Indonesia have not only harmed ecosystems but also added to climate change by releasing carbon emissions (Mannan et al., 2017). In the Himalayan region, many forest fires are caused by human activities, unlike in Australia or California, where natural causes play a significant role (Helvarg, 2019; Tran et al., 2020).

In the United States, the top fifteen wildfires between 2000 and 2017 caused nearly $1 billion in damages. In 2019, wildfires resulted in an estimated $4.5 billion loss in California and Alaska (NOAA, 2021). During 2020, five out of the six largest fires in California and Oregon experienced historically extensive wildfire expansion and destruction, leading to poor air quality for millions of people (C2ES, 2021).

The Hindu Kush Himalayan (HKH) region, often called the Third Pole or the Water Tower, is vulnerable to climate change, experiencing a rise in annual temperatures (IGES and ICIMOD 2013; Wester et al., 2019; Zomer et al., 2014). Climate change has increased the number of hot and dry days, escalating the risk of forest fires. Recently, forest fires have become a significant ecological concern due to shifting climate patterns and related factors. These fires devastate biodiversity and endangered species' habitats and release greenhouse gases (FAO, 2007; Volkova et al., 2019). In the Western Himalayas, forest fires are common during the summer season due to the accumulation of fuel on the forest floor and low soil moisture content. In northeastern India, forest fires are primarily linked to shifting cultivation. India experienced 520,861 active forest fires from 2003 to 2017, primarily in the eastern Himalayan states' dense evergreen and deciduous forests.

Having mentioned all these facts about forest fires on a global and regional scale, it is stated that the effects of climate change are a concern for the conservation of the endangered snow leopard in Pakistan's HKH region. Although the objective of this thesis was not to study the impacts of forest fires on the habitat of snow leopards in Pakistan, some recommendations are provided in Chapter 6 for the managers, practitioners, and policymakers to avoid forest fire incidences in future.

Species' responses to climate change effects are evident in the changing distribution ranges, moving poleward and towards higher elevations. This trend has been observed in a variety of taxonomic groups, including plants, birds, butterflies, mammals, amphibians, and insects, and the leading edge of range expansions at a high elevation/high latitude and trailing edge contractions at a low elevation/low latitude have also been documented. (Franco et al., 2006; Parmesan, 2006; Thomas et al., 2006; Hickling et al., 2005; Perry et al., 2005; Karban & Strauss, 2004; Parmesan & Yohe, 2003; Root et al., 2003; Hill et al., 2002; Walther et al., 2002; Warren et al., 2001). Climate change-driven changes in species distribution are limited by their physiological constraints on adapting to temperature or precipitation variations (Walther et al., 2002). As a result, widespread changes in species distribution can be expected as species move to areas with more suitable climates.

The effects of climate change are taking a toll on alpine ecosystems and causing changes in timing, geography, and physical characteristics of individual species, as well as alterations in productivity, species interactions, and overall properties at the ecosystem level (Theurillat & Guisan, 2001). The impact of climate change on the mountain cryosphere is far-reaching. It affects local, regional, and global resources despite their crucial role in providing vital livelihoods, food security, well-being, and cultural identity (Masson-Delmotte et al., 2021). High mountain regions, defined by the IPCC as landscapes with high elevation, steep topography, cold temperatures, and remoteness (Hock et al., 2019), are especially vulnerable to the effects of climate change. The low temperatures in these areas are susceptible to radiative forcing and will result in disproportionate warming with any increase in atmospheric humidity due to rising temperatures (Chen et al., 2014). Furthermore, as the vertical temperature gradient decreases (Held & Soden, 2006) and the cooling effect of aerosols becomes weaker, warming will be intensified at higher elevations. Due to warming, the decline in snow cover exacerbates the problem by increasing the absorption of solar radiation (snow-albedo feedback), leading to higher surface air temperatures and further snowmelt (Scherrer et al., 2011).

About 10% of the world's population resides in high mountain regions that are especially vulnerable to the impacts of climate change (Jones & O'Neill, 2016). These communities, particularly those in developing nations, struggle to deal with the consequences of climate change due to limited resources and a lack of options for alternative livelihoods (McDowell et al., 2012). Traditionally, mountain communities have used different elevations for agriculture and pastoral activities. However, the changes in the cryosphere, such as snow and glaciers, are impacting their access to resources and exposing them to hazards like avalanches, landslides, and rain-on-snow floods (Hock et al., 2019). As a result, there has been an increase in wage labour migration as those affected by climate change seek employment opportunities in urban or lowland areas (Parveen et al., 2015). These mountain communities, often in remote and hard-to-reach locations, can benefit from tourism to diversify their income, create jobs, support other local industries, and counter population decline (Keller, 2018).

1.3 SNOW LEOPARD – A VULNERABLE SPECIES

The Snow leopard inhabits a vast range from the southern Himalayas to Siberia in the north, including mountain ranges such as the outer Himalayas, Karakoram, Hindu Kush, Pamir, Kunlun, Tien Shan, Sayan, and Altai, as well as isolated mountains in the Gobi region, across 12 countries (McCarthy et al., 2016). The snow leopard lives in mountainous areas with altitudes between 3,000 and 5,000 meters above sea level and experiences low temperatures and dry conditions, resulting in a scarcity of prey. The primary food source is wild caprids, such as the Blue Sheep and Siberian Ibex, with Argali and Markhor consumed in some regions (Mallon et al., 2016; Suryawanshi et al., 2013).

The population of snow leopards is uncertain, with estimates ranging from 4,080 to 7,500 (Snow Leopard Network, 2014).

Snow leopards are apex predators in their habitats and feed on mountain sheep and goats. In their absence, the ecological balance would be thrown off, causing an increase in herbivore populations and consequent changes to the vegetation. This would also impact other wildlife inhabiting the same areas (McCarthy et al., 2017). Additionally, the same landscape provides crucial resources for the people who live there, such as medicine and wood for shelter, heat, and fuel. Furthermore, the headwaters of 20 major river basins in snow leopard habitats provide water for about 22 countries, with over 2 billion people residing in these basins (Sindorf et al., 2014). Hence, with the conservation of the snow leopard only, the entire natural environment and the people who depend on it.

Snow leopard research was initiated in the 1970s, but only a tiny portion of the animal's habitat has been studied. Most research has focused on the species' ecology and the conflicts between snow leopards and humans, with most studies in Nepal, India, and China (Sharma & Singh, 2020). The human aspect of conservation, particularly in regions where people rely on raising livestock, has not received adequate attention. There is also a lack of understanding about the long-term impacts of climate change in countries like Pakistan. This study highlights the need for more research to create effective plans for conserving snow leopards and their habitats in the greater Himalayan region.

1.4 VALUATION OF ECOSYSTEM SERVICES

Assessments of ecosystem services provide helpful information for decision-making (IPBES, 2016; Crossman et al., 2013). Over the past 20 years, several reviews have combined the findings of ecosystem services assessments, outlining the worldwide trends in ecosystem services economic valuation (De Groot et al., 2012; De Groot et al., 2010; Costanza et al., 1997). Some of these reviews have concentrated on ecosystem services assessments at a continental scale, such as in Asia (Shoyama et al., 2017) and Europe (Maes et al., 2012).

In the mountain ecosystems of the western Himalayas and Hindukush ranges in Pakistan, ecosystem services are vital for supporting local livelihoods and economies. Most residents in the mountainous, arid regions of the Western Himalayas are agro-pastoralists who live in villages and sustain themselves through subsistence agriculture and pastoralism. This traditional way of life gives them access to nearby natural areas for fuelwood, forage, and fodder (Awan et al., 2020). However, the growing population in these mountain regions could negatively impact the sustainability of ecosystem services (Sharma et al., 2019). The absence of specific policies and regulations for managing ecosystem services is also a significant hindrance (FAO, 2015; MoCC, 2017; MoCC, 2021; Climate Change Center, 2017). Additionally, local communities, particularly those with limited income options, rely heavily on ecosystem services for survival.

Ecosystem services valuation is thus crucial for correcting the mismanagement of the environment and measuring its impact on national income by treating it as a valuable resource rather than a free input. Furthermore, economic valuation is fundamental in determining the harm caused by human activities that have led to ecosystem degradation. In the Hindu Kush Himalayan region, there is a research gap for ecosystem services, with only a few studies conducted in Pakistan, reflecting a lack of investment in this area (Kandel et al., 2021; Martín-Lopez et al., 2019). The monetary valuation of ecosystem services in snow leopard habitats, analyzed in this doctoral work, is a unique and novel contribution to understanding the human impact on natural resources and ecosystem services.

1.5 SPECIES DISTRIBUTION MODELLING

Assessing the impact of climate change on species can be effectively done through Species Distribution Models (SDMs) (Thuiller et al., 2008). These models are used to forecast species' geographical range with the goal of conservation (Elith & Leathwick, 2009; Phillips et al., 2006; Thuiller et al., 2009). However, the challenge lies in determining the best model among the various algorithms available (Elith et al., 2011; Renner & Warton, 2013), especially regarding future climate scenarios (Thuiller, 2004).

Apart from Species Distribution Models (SDMs), Ecological Niche Models (ENMs) have gained traction as a valuable tool in distributional ecology (Araújo et al., 2019). They have been extensively studied across various fields, such as ecology (Anderson, 2017; Zurell, 2017; Osorio-Olvera et al., 2020), evolutionary biology (Saupe et al., 2018), and conservation biology (Freeman et al., 2018). Several R packages have been tailored for ENMs, including Niche Toolbox, Niche, and Kuenm (Warren et al., 2008; Cobos et al., 2019a). Notably, Kuenm stands out as the pioneering R package incorporating comprehensive model calibration and evaluation methods, as developed by Cobos et al., (2019b).

The Kuenm approach offers a comprehensive way to assess the impact of climate change on species using Species Distribution Models (SDMs). It involves three key stages in Ecological Niche Modeling: calibrating the model, creating, and evaluating the final model, and analyzing the risk of extrapolation. The MOP (mobility-oriented parity) metric in Kuenm evaluates the risk of overinterpreting the model results when transferring it to new areas. It compares the environmental conditions between the calibration locations and the multiple areas where the models are being used. Additionally, the Grinell R Package helps determine the area that is accessible to a species.

The habitat use of snow leopards has been studied using various Species Distribution Modeling approaches in different countries (Atzeni et al., 2020; Chi et al., 2019; Poyarkov et al., 2019; Watts et al., 2019; Cheti et al., 2020; Hameed et al., 2020; Holt et al., 2018). However, a regional study using the robust KUENM approach was necessary to achieve and compare results with similar studies further to understand snow leopards' future and present distribution modelling and make conservation implications.

1.6 AIM AND OBJECTIVES

This doctoral thesis aims to assess snow leopards' habitat in relation to climate change and evaluate the financial worth of ecosystem services affected by human activities. The snow leopard, a vulnerable species found across 12 countries, is of particular interest in Pakistan, where it can be found in districts that include GB, Chitral, Swat, Dir, Kohistan of KP, and Muzaffarabad and Neelum of AJK. However, despite its significance, there is a limited scientific understanding of the species, calling for further research to formulate effective conservation strategies.

The study aimed to bridge the critical knowledge gap surrounding the species' distribution in the present and future in the greater Himalayan region (Pakistan, India, and Nepal), as well as to perform the first-ever monetary assessment for ecosystem services in the Gurez Valley and the Hindukush range's Chitral Valley. The research is based on empirical data obtained through modern techniques such as camera trapping and molecular genetics, analyzed through advanced methods and the PRA approach, and financially evaluated through the CICES framework. The specific objectives with the respective hypotheses are presented below:

1. Objective

Assess the impacts of climate change on snow leopard habitat under current and climate change scenarios in the greater Himalayas (Pakistan, India, and Nepal).

Hypothesis

We hypothesize that as global temperatures continue to rise due to climate change, there will be a reduction in the snow leopard habitat range in the greater Himalayas. Furthermore, we anticipate that higher elevations will experience a more pronounced habitat loss than lower elevations, as these areas are more sensitive to temperature changes.

2. Objective

Assess the economic value of the ecosystem services in Pakistan's snow leopard habitat.

Hypothesis

The ecosystem services provided by snow leopard habitat in Pakistan have substantial economic value that can be quantified and monetized.

3. Objective

Assess public perceptions of climate change in mountain communities.

Hypothesis

The public concern and awareness about climate change in mountain communities will correlate with the extent and immediacy of observed climate change impacts, with communities facing more significant changes showing greater concern.

4. Objective

Propose conservation actions for the snow leopard habitat to safeguard the livelihood of local communities and snow leopard survival under climate change.

1.7 STUDY AREA

The study area comprised Pakistan, India, and Nepal's highest, northernmost greater Himalayan regions. Figure 1.1 shows Gurez and Chitral Valleys for the valuation of ecosystem services and the Greater Himalayan region for the Climate Change Modelling of Snow leopards. The greater Himalayan range has an average elevation of more than 20,000 feet (6,100m, Britannica, 2018). Pakistan's northern areas (72-75^{o} E and 35-37^{o} N) are characterized by rugged and glaciated peaks, hills, and gullies (Bischof et al., 2014). They are in the watershed regions of the Hindu Kush, Himalayan, and Karakoram Mountain ranges.

The Gurez Valley (34°41' 34°58' N and 74°32' 74°53' E; 2000-6000 masl; 528.15 km^2) is situated in the Himalayan orogenic belt in northern Kashmir and southern Gilgit-Baltistan (43° to 36°45' N and 74° to 75° E) priority landscape in Pakistan. This area is characterized by harsh environmental conditions and restricted agricultural suitability; hence, pastoralism is the most common livelihood strategy. The vegetation areas comprise coniferous woodland, scrub, and the alpine desert. The average rainfall is about 200 mm below 3000 m elevation and around 2000mm below 6000 m elevation. At lower altitudes, the temperature can range from 45°C to -4°C, while at higher elevations, the temperature can be as low as -20°C during the winter.

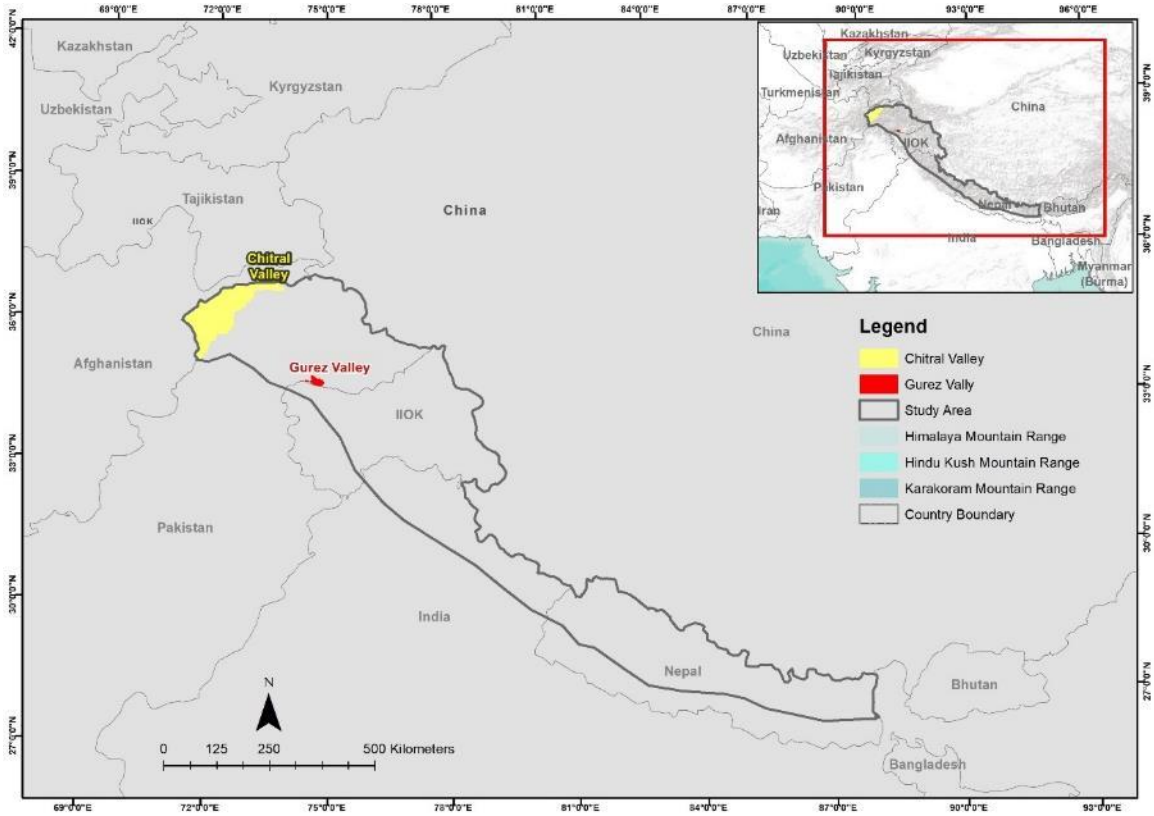


Figure 1.1: Study Area Map For The Entire Ph.D. Research Work

Chitral Valley is in the Khyber Pakhtunkhwa province and is situated between 36°15′ and 37°8′ N latitude and 72°22′ and 74°6′ E longitude. With an elevation ranging from 1070 to 7700 meters above sea level (Nüsser & Dickoré, 2002), the district covers a total area of 14,850 km2 (Khan et al., 2013). Being situated in the centre of two zoogeographical zones and part of the Palearctic faunal region with a slight oriental influence, Chitral provides favorable conditions for large biodiversity. The climate in Chitral is of the continental type, with temperatures differing from warm at lower altitudes to moderate in the middle and cool at higher elevations (Dossier, 2022).

1.8 THESIS STRUCTURE

This doctoral thesis comprises six chapters arranged in four independent papers (chapters 2-5). Chapter 1 describes the study background and provides a general introduction. Chapters 2-5 provide detailed studies on the thesis objectives and the materials and methods used to attain these objectives. Finally, chapter 6 provides an overall conclusion, future implications, and recommendations.

Chapter 1 gives a general introduction, study area description, background research, and study research question, study needs, and available information. The study's overall goal and specific thesis objectives are also provided.

Chapter 2 includes the climate change vulnerability of snow leopards in the greater Himalayan region (Pakistan, India, and Nepal). Snow leopard presence records were adopted from Hameed et al., 2020; Watts et al., 2019; and Aryal et al., 2016. It describes various environmental factors influencing snow leopard distribution, including human population, study background, current and future (2070) habitat suitability, and the habitat loss and gain by 2070 under the two emission scenarios.

Chapter 3 includes the valuation of ecosystem services in Gurez Valley, Pakistan. It describes indigenous communities' high dependence on ecosystem services in monetary terms and the climate change perceptions on the ecosystem services, using the PRA methods and classifying the provisioning ecosystem services through a 'common international classification on ecosystem services' approach and the 'total economic valuation framework'. The results presented in this chapter have been published (Saeed et al., 2022).

Chapter 4 provides information on the valuation of ecosystem services in Chitral Valley, Pakistan. It describes indigenous communities' higher dependence on ecosystem services than the Gurez Valley communities. Evaluation of services and interpretation followed the same procedure described in Chapter 3 above.

Chapter 5 describes the vulnerability of mountain communities in Chitral due to the changing climate and their indigenous adaptation strategies. Evidence was collected from the public and then correlated with the meteorological data that climate. A questionnaire was adopted from Climate Crowd WWF—US, and the data were analyzed through content analysis using statistical techniques such as counting and frequency distributions. In addition, the meteorological data were examined graphically.

<u>Chapter 6</u> includes the overall conclusion, future implications, and study recommendations.

1.9 RESEARCH PUBLCATION REFERENCE OF CHAPTER 3 OF THIS THESIS

Saeed, U., Arshad, M., Hayat, S., Morelli, T. L., & Nawaz, M. A. (2022). Analysis of provisioning ecosystem services and perceptions of climate change for indigenous communities in the Western Himalayan Gurez Valley, Pakistan. *Ecosystem Services*, 56,101453. https://doi.org/10.1016/j.ecoser.2022.101453

1.10 REFERENCES

Amiro, B. D., Chen, J. M. and Liu, J. (2000). Net Primary Productivity Following Forest Fire for Canadian Ecoregions. *Canadian Journal of Forest Research*, 30(6): 939–947. https://doi.org/10.1139/x00-025

Amiro, B.D., Todd, J.B., Wotton, B.M., Logan, K.A., Flannigan, M.D., Stocks, B.J., Masn J.A., Martell, D.L. and Hirsch, K.G. (2001). Direct Carbon Emissions from Canadian Forest Fires, 1959-1999', *Canadian Journal of Forest Research*, 31(3): 512–525. https://doi.org/10.1139/x00-197

Anderson, R.P. (2017). When and how should biotic interactions be considered in models of species niches and distributions? *Journal of Biogeography*, 44, 8–17. https://doi.org/10.1111/jbi.12825

Araújo, M.B., Anderson, R.P., Barbosa, A.M., et al. (2019). Standards for distribution models in biodiversity assessments. *Science Advances*, 5, eaat4858. https://doi.org/10.1126/sciadv.aat4858

Arias, P., Bellouin, N., Coppola, E., Jones, R., Krinner, G., Marotzke, J., Naik, V., Palmer, M., Plattner, G.K., Rogelj, J. and Rojas, M. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Technical Summary.

Atzeni, L.; Cushman, S.A.; Bai, D.; Wang, J.; Chen, P.; Shi, K.; Riordan, P. (2020). Meta-replication, sampling bias, and multi-scale model selection: A case study on snow leopard (*Panthera uncia*) in western China. *Ecol. Evol.* 10, 7686–7712. https://doi.org/10.1002/ece3.6492

Awan, M. N., Kabir, M., Ahmad, S., & Huettmann, F. (2020). The Future of biodiversity in the changing watersheds of Kashmir Himalaya, Pakistan: Conservation challenges and opportunities. *Hindu Kush-Himalaya Watersheds Downhill: Landscape Ecology and Conservation Perspectives*, 113. https://doi.org/10.1007/978-3-030-36275-1_7

BBC, (2019). The Amazon in Brazil is on fire-how bad is it? Accessed online February 2020 https://www.bbc.com/news/worldlatin-america-49433767.

Bischof, R., Ali, H., Kabir, M., Hameed, S., & Nawaz, M. A. (2014). Being the underdog: An elusive small carnivore uses space with prey and time without enemies. *Journal of Zoology*, *293*(1), 40–48. https://doi.org/10.1111/jzo.12100

Britannica, T. Editors of Encyclopedia. Great Himalayas. Encyclopedia Britannica. Accessed online 2nd February, 2018 https://www.britannica.com/place/Great-Himalayas

C2ES. (2021). Wildfires and Climate Change, Centre for Climate and Energy Solutions. Accessed online 14th October 2023. https://www.c2es.org/content/wildfires-andclimate-change/

Chen T, De Jeu RAM, Liu YY, Van der Werf GR, Dolman AJ (2014). Using satellite-based soil moisture to quantify the water driven variability in NDVI: a case study over mainland Australia. *Remote Sens Environ* 140:330–338. https://doi.org/10.1016/j.rse.2013.08.022

Chetri, M., Odden, M., Devineau, O., McCarthy, T., Wegge, P. (2020). Multiple factors influence local perceptions of snow leopards and Himalayan wolves in the central Himalayas, Nepal. *PeerJ*, 8, e10108. https://doi.org/10.7717/peerj.10108

Chi, X., Jiang, F., Gao, H., Qin, W., Wu, T., Zhang, J., Cai, Z., Zhang, T. (2019). Habitat suitability analysis of snow leopard (*Panthera uncia*) and bharal (*Pseudois nayaur*) in the Sanjiangyuan National Park. *Acta Theriol. Sin*. 39, 397–409. http://www.mammal.cn/CN/10.16829/j.slxb.150300

Climate Change Center, (2017). AJ&K Climate Change Policy. Planning & Development Department, Azad Government of the State of Jammu & Kashmir. Accessed online 2nd March 2024 https://pndajk.gov.pk/uploadfiles/downloads/CC%20AJK%20Policy%202017.pdf

CNN, (2020) California wildfires have burned an area almost the size of Connecticut. Accessed online September 2020. https://edition.cnn.com/2020/09/14/us/california-wildfires-monday/index.html

Cobos, M. E., Peterson, A. T., Barve, N., & Osorio-Olvera, L. (2019). kuenm: an R package for detailed development of ecological niche models using MaxEnt. *PeerJ*, 7, e6281 https://doi.org/10.7717/peerj.6281

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., ... & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *nature*, *387*(6630), 253-260. https://doi.org/10.1038/387253a0

Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., ... & Maes, J. (2013). A blueprint for mapping and modelling ecosystem services. *Ecosystem services*, *4*, 4-14. https://doi.org/10.1016/j.ecoser.2013.02.001

Dai, A. (2021). Hydroclimatic trends during 1950–2018 over global land. *Climate Dynamics*, 56(11-12), 4027-4049. https://doi.org/10.1007/s00382-021-05684-1

De Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological complexity*, *7*(3), 260-272. https://doi.org/10.1016/j.ecocom.2009.10.006

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., ... & Van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem services*, *1*(1), 50-61. https://doi.org/10.1016/j.ecoser.2012.07.005

Du, H., Alexander, L. V., Donat, M. G., Lippmann, T., Srivastava, A., Salinger, J., ... & Wu, Z. (2019). Precipitation from persistent extremes is increasing in most regions and globally. *Geophysical Research Letters*, 46(11), 6041-6049. https://doi.org/10.1029/2019GL081898

Elith, J., & Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual review of ecology, evolution, and systematics*, 40, 677-697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., & Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*, 17(1), 43-57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

FAO, (2007) Fire management-global assessment 2006. A thematic study prepared in the framework of the global forest resources assessment 2005. FAO, Rome. Accessed online 2nd March 2024 https://www.fao.org/3/a0969e/a0969e00.htm

FAO, (2015). In R. Romeo, A. Vita, R. Testolin, T. Hofer, (Ed.), Mapping the vulnerability of mountain peoples to food insecurity. Rome. http://www.fao.org/3/a-i5175e.pdf

Annual Progress Report, Pakistan Snow Leopard and Ecosystem Protection Program (PSLEP). Report Submitted to the Global Environment Facility (GEF) funded United Nations Development Program (UNDP) project on Transboundary Cooperation for Snow Leopard and Ecosystem Conservation. Accessed online 2nd March 2024 https://info.undp.org/docs/pdc/Documents/PAK/PSLEP%20Annual%20Progress%20Report.pdf

Franco, A. M. A., Hill, J. K., Kitschke, C., Collingham, Y. C., Roy, D. B., Fox, R., Huntley, B., & Thomas, C. D. (2006). Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Global Change Biology*, 12(8), 1545-1553. https://doi.org/10.1111/j.1365-2486.2006.01180.x

Freeman, B., Roehrdanz, P. R., & Peterson, A. T. (2018). Modeling endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa. *Biodiversity and Conservation*, 28(3), 671–685. https://doi:10.1007/s10531-018-01684-6

Global Forest Watch, (2021). Global Forest Watch Land Cover Dashboard. Accessed online 14th October, 2021 https:// www.globalforestwatch.org/dashboards/global/

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

Held, I. M., & Soden, B. J. (2006). Robust responses of the hydrological cycle to global warming. *Journal of climate*, *19*(21), 5686-5699. https://doi.org/10.1175/JCLI3990.1

Helvarg, D. (2019). How will California Prevent More Mega-wildfire Disasters?, National Geopraphic. Accessed online 14th October, 2023. https://www.nationalgeographic.com/science/article/how-will-california-preventmore-mega-wildfire-disasters

Hickling, R., Roy, D. B., Hill, J. K., & Thomas, C. D. (2005). A northward shift of range margins in British Odonata. *Global Change Biology*, 11(3), 502-506. https://doi.org/10.1111/j.1365-2486.2005.00904.x

Hill J. K., Thomas C. D., Fox R., Telfer M. G., Willis S. G., Asher J. and Huntley B. (2002). Responses of butterflies to twentieth century climate warming: implications for future ranges. *Proc. R. Soc. Lond. B.* 269 2163–2171 http://doi.org/10.1098/rspb.2002.2134

Hirschberger, P. (2016). Forests ablaze: causes and effects of global forest fires. *WWF: Berlin, Germany*. Accessed online 2nd March 2024 https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF-Study-Forests-Ablaze.pdf

Hock, R., G. Rasul, C. Adler, B. Cáceres, S. Gruber, Y. Hirabayashi, M. Jackson, A. Kääb, S. Kang, S. Kutuzov, Al. Milner, U. Molau, S. Morin, B. Orlove, and H. Steltzer, 2019: High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 131-202. https://doi.org/10.1017/9781009157964.004.

Holt, C.D.S.; Nevin, O.T.; Smith, D.; Convery, I. (2018). Environmental niche overlap between snow leopard and four prey species in Kazakhstan. *Ecol. Inform*. 48, 97–103. https://doi.org/10.1016/j.ecoinf.2018.09.005

IGES, I. (2013). Technical report: climate change adaptation needs of people of the Hindu Kush Himalayas. *IGES, Hayama, Japan*. Accessed online 2nd March 2024 https://www.iges.or.jp/en/topics/climate/adaptation?gad_source=1&gclid=CjwKCAiAuYuvBhApEiwAzq_YiQj5TKwMbUk6tvfcXe6ADT2WeR2XHYHK7ZqylaXBk4TSilsf1etCHhoCkkoQAvD_BwE

IPBES, (2016). The methodological assessment report on scenarios and models of biodiversity and ecosystem services. Zenodo. https://doi.org/10.5281/zenodo.3235429

Jones, B., & O'Neill, B. C. (2016). Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways. *Environmental Research Letters*, *11*(8), 084003. https://doi10.1088/1748-9326/11/8/084003

Kandel, P., Chettri, N., Chaudhary, S., Sharma, P., & Uddin, K. (2021). Ecosystem services research trends in the water tower of Asia: A bibliometric analysis from the Hindu Kush Himalaya. *Ecological Indicators*, *121*, 107152. https://doi.org/10.1016/j.ecolind.2020.107152

Karban, R., Strauss, S.Y. (2004). Physiological tolerance, climate change, and a northward range shift in the spittlebug, *Philaenus spumarius*. Ecological Entomology, 29, 251-254. https://doi.org/10.1111/j.1365-2311.2004.00576.x

Keller, E. (2018). Noisy business politics: lobbying strategies and business influence after the financial crisis. *Journal of European Public Policy*, *25*(3), 287-306. https://doi.org/10.1080/13501763.2016.1249013

Khan, N., Shaukat, S. S., Ahmed, M., & Siddiqui, M. F. (2013). Vegetation-environment relationships in the forests of Chitral district Hindukush range of Pakistan. *Journal of Forestry Research*, 24(2), 205–216. https://doi.org/10.1016/j.ecolecon.2009.04.018.

Lorenz, R., Stalhandske, Z., & Fischer, E. M. (2019). Detection of a climate change signal in extreme heat, heat stress, and cold in Europe from observations. *Geophysical Research Letters*, *46*(14), 8363-8374. https://doi.org/10.1029/2019GL082062

Machado-Stredel, F., Cobos, M. E., & Peterson, A. T. (2021). A simulation-based method for selecting calibration areas for ecological niche models and species distribution models. *Frontiers of Biogeography*, 13(4). https://doi.org/10.21425/F5FBG48814

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., ... & Bidoglio, G. (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem services*, *1*(1), 31-39. https://doi.org/10.1016/j.ecoser.2012.06.004

Mallon, D., Harris, R. B., & Wegge, P. (2016). Snow leopard prey and diet. In *Snow leopards* (pp. 43-55). Academic Press. https://doi.org/10.1016/B978-0-12-802213-9.00004-3

Mannan A, Feng Z, Ahmad A, Beckline M, Saeed S, Liu J, Shah S, Amir M, Ammara U, Ullah T. (2017). CO2 emission trends and risk zone mapping of forest fires in subtropical and moist temperate forests of Pakistan. *Appl Ecol Environ Res* 17(2):2983–3002. http://dx.doi.org/10.15666/aeer/1702_29833002

Martín-López B, Leister I, Lorenzo Cruz P, Palomo I, Grêt-Regamey A, Harrison PA, et al. (2019). Nature's contributions to people in mountains: A review. *PLoS ONE* 14(6): e0217847. https://doi.org/10.1371/journal.pone.0217847.

Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou. (2021). IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, http://doi:10.1017/9781009157896.001.

McCarthy, T., Mallon, D., Jackson, R., Zahler, P. & McCarthy, K. (2017). Panthera uncia. The IUCN Red List of Threatened Species (2017).e.T22732A50664030. http://dx.doi.org/10.2305/IUCN.UK.2017-2.RLTS.T22732A50664030.en

McCarthy, T., Mallon, D., Sanderson, E. W., Zahler, P., & Fisher, K. (2016). What is a snow leopard? Biogeography and status overview. In *Snow leopards* (pp. 23-42). Academic Press. https://doi.org/10.1016/B978-0-12-802213-9.00003-1

McDowell, J.Z. and J.J. Hess, (2012). Accessing adaptation: multiple stressors on livelihoods in the Bolivian highlands under a changing climate. *Glob. Environ. Change*, 22(2), 342–352, https://doi:10.1016/j.gloenvcha.2011.11.002

Merino, A., Pérez-Batallón, P. and Macías, F. (2004). Responses of Soil Organic Matter and Greenhouse Gas Fluxes to Soil Management and Land Use Changes in a Humid Temperate Region of Southern Europe. *Soil Biology and Biochemistry*, 36(6): 917–925. https://doi.org/10.1016/j.soilbio.2004.02.006

MoCC, (2017). *National forest policy 2015*. Ministry of Climate Change, Government of Pakistan, Islamabad, Pakistan. Accessed online 2nd March 2024 https://pbit.punjab.gov.pk/system/files/National%20Forest%20Policy%202016.pdf

MoCC, (2021). *National climate change policy* (updated version). Ministry of Climate Change, Government of Pakistan, Islamabad, Pakistan. Accessed online 2nd March 2024 https://www.nrsp.org.pk/gcf/docs/National-Climate-Change-Policy-of-Pakistan.pdf

Murali R, Lkhagvajav P, Saeed U, Kizi VA, Zhumbai-Uulu K, Nawaz MA, Bhatnagar YV, Sharma K, Mishra C. (2017a). Valuation of ecosystem services in snow leopard landscapes of Asia. Snow Leopard Trust, Nature Conservation Foundation, Snow Leopard Conservation Foundation, Snow Leopard. Accessed online 2nd March 2024 https://globalsnowleopard.org/wp-content/uploads/2018/12/Valuation-of-ecosystem-services-in-snow-leopard-landscapes.pdf

NOAA. (2021). Billion-Dollar Weather and Climate Disasters: Events, National Centres for Environmental Information. http://doi:10.25921/stkw7w73

Nolan RH, Boer MM, Collins L, Resco de Dios V, Clarke H, Jenkins M, Bradstock RA (2020). Causes and consequences of eastern Australia's 2019–20 season of mega-fires. *Glob Change Biol* 26(3):1039–1041. https://doi.org/10.1111/gcb.14987

Nomination Dossier, (2022). Chitral Bashkar Garmchashma Biosphere Reserve (CBGBR), Wildlife Department, Khyber Pakhtunkhwa, Pakistan.

Nüsser, M., & Dickoré, W. B. (2002). A tangle in the triangle: Vegetation map of the eastern Hindukush (Chitral, northern Pakistan). Erdkunde. https://www.jstor.org/stable/23218603.

Osorio-Olvera, L., Yañez-Arenas, C., Martínez-Meyer, E. & Peterson, A.T. (2020) Relationships between population densities and niche-centroid distances in North American birds. *Ecology Letters*, 23, 555–564. https://doi.org/10.1111/ele.13453

Parmesan, C. & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421, 37-42. https://doi.org/10.1038/nature01286

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst*. 37, 637-69. https://10.1146/annurev.ecolsys.37.091305.110100

Parveen, S., Winiger, M., Schmidt, S., & Nüsser, M. (2015). IRRIGATION IN UPPER HUNZA: EVOLUTION OF SOCIO-HYDROLOGICAL INTERACTIONS IN THE KARAKORAM, NORTHERN PAKISTAN. Erdkunde, 69(1), 69–85. http://www.jstor.org/stable/24365265

Pérez-Cabello, F., Cerd, A., De La Riva, J., Echeverr, M.T., Garc a- Mart, A., Ibarra, P., Lasanta, T., Montorio, R., Palacios, V. (2012). Micro-scale Post-fire Surface Cover Changes Monitored using High Spatial Resolution Photography in a Semiarid Environment: A Useful Tool in the Study of Post-fire Soil Erosion Processes. *Journal of Arid Environments*, 76: 88–96. https://doi.org/10.1016/j.jaridenv.2011.08.007

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D. (2005). Climate change and distribution shifts in marine fishes. *Science*, 308, 1912-1915. https://doi.org/10.1126/science.1111322

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190(3-4), 231-259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Poyarkov, A., Rozhnov, V. (2019). Potential habitat of snow leopard (*Panthera uncia*, *Felinae*) in south Siberia and adjacent territories based on the maximum entropy distribution model. Зоологический Журнал, 98, 332–342. http://dx.doi.org/10.1134/S0044513419030061

Rahmstorf, S., Foster, G., & Cahill, N. (2017). Global temperature evolution: recent trends and some pitfalls. *Environmental Research Letters*, *12*(5), 054001. https://doi.10.1088/1748-9326/aa6825

Renner, I. W., & Warton, D. I. (2013). Equivalence of MaxEnt and Poisson point process models for species distribution modeling in ecology. *Biometrics*, 69(1), 274-281. https://doi.org/10.1111/j.1541-0420.2012.01824.x

Root, T.L., Price J.T., Hall K.R. et al., (2003). Fingerprints of global warming on wild animals and plants. *Nature*, 421, 57-59. http://dx.doi.org/10.1038/nature01333

Sannigrahi, S., Pilla, F., Basu, B., Basu, A.S., Sarkar, K., Chakraborti, S., Joshi, P.K., Zhang, Q., Wang, Y., Bhatt, S. and Bhatt, A. (2020). Examining the Effects of Forest Fire on Terrestrial Carbon Emission and Ecosystem Production in India using Remote Sensing Approaches. *Science of the Total Environment*, 725: 138331. https://doi.org/10.1016/j.scitotenv.2020.138331

Saupe, E.E., Barve, N., Owens, H.L., Cooper, J.C., Hosner, P.A. & Peterson, A.T. (2018). Reconstructing ecological niche evolution when niches are incompletely characterized. *Systematic Biology*, 67, 428–438. https://doi.org/10.1093/sysbio/syx084

Scherrer, D., S. Schmid and C. Körner, (2011). Elevational species shifts in a warmer climate are overestimated when based on weather station data. *Int. J. Biometeorol*., 55(4), 645–654, https://doi:10.1007/s00484-010-0364-7.

Seneviratne, S. I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., ... & Zhou, B. (2021). 11 Chapter 11: Weather and climate extreme events in a changing climate. In *Climate Change 2021: The Physical Science Basis*; Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate, Change; Masson-Delmotte, V., Zhai, P., et al., Eds.; Cambridge University Press: Cambridge, UK, 1513–1766. Accessed online 2nd March 2024 https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter11.pdf

Sharma, E. et al. (2019). Introduction to the Hindu Kush Himalaya Assessment. In: Wester, P., Mishra, A., Mukherji, A., Shrestha, A. (eds) The Hindu Kush Himalaya Assessment. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_1

Sharma, R. K., & Singh, R. (2020). Over 100 years of snow leopard research: A spatially explicit review of the state of knowledge in the snow leopard range. *WWF, Gland, Switzerland*. Accessed online 2nd March 2024 https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/4octxor1ep_Report_Over_100_Years_of_Snow_Leopard_Research_May_12__2021.pdf

Shoyama, K., Kamiyama, C., Morimoto, J., Ooba, M., & Okuro, T. (2017). A review of modeling approaches for ecosystem services assessment in the Asian region. *Ecosystem Services*, *26*, 316-328. https://doi:10.1016/j.ecoser.2017.03.013

Sindorf, N., Forrest, J., and B. Arakwiye. (2014). Guardians of the Headwaters: Snow Leopards, Water Provision, and Climate Vulnerability. Washington D.C.: World Wildlife Fund. Accessed online 2nd March 2024 https://thirdpolegeolab.org/files/resources/guardians-mapbook-volume-2_final_42.pdf

Smith, A., Schismenos, S., Stevens, G., Hutton, L., Chalaris, M., & Emmanouloudis, D. (2019). Understanding large-scale fire events: megafires in Attica, Greece and California, USA. In Youth Science Policy Interface Publication - 2nd Special Edition: Disaster Risk Reduction: Moving Forward, Thinking Ahead (pp. 29-34). https://www.preventionweb.net/files/68036_68036drrunmgcy2019final.pdf

Snow leopard Network, (2014). Snow leopard survival strategy. *Seattle, Washington, USA*, 1-145. Accessed online 2nd March 2024 https://snowleopardconservancy.org/wpcontent/uploads/2014/10/Snow_Leopard_Survival_Strategy_2014.1-reduced-size.pdf

Suryawanshi, K. R., Bhatnagar, Y. V., Redpath, S., & Mishra, C. (2013). People, predators and perceptions: patterns of livestock depredation by snow leopards and wolves. *Journal of Applied Ecology*, *50*(3), 550-560. https://doi.org/10.1111/1365-2664.12061

Theurillat, J. P., & Guisan, A. (2001). Potential impact of climate change on vegetation in the European Alps: a review. *Climatic change*, *50*(1-2), 77-109. http://dx.doi.org/10.1023/A:1010632015572

Thomas, C.D., Franco, A.M.A. & Hill, J.K. (2006). Range retractions and extinction in the face of climate warming. *TREE,* 21, 415-416. https://doi.org/10.1016/j.tree.2006.05.012

Thuiller, W. (2004). Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology*, 10(12), 2020-2027. https://doi.org/10.1111/j.1365-2486.2004.00859.x

Thuiller, W., Lafourcade, B., Engler, R., & Araújo, M. B. (2009). BIOMOD–a platform for ensemble forecasting of species distributions. *Ecography*, 32(3), 369-373. https://doi.org/10.1111/j.1600-0587.2008.05742.x

Thuiller, W.; Albert, C.; Araújo, M.B.; Berry, P.M.; Cabeza, M.; Guisan, A.; Hickler, T.; Midgley, G.F.; Paterson, J.; Schurr, F.M.; et al. (2008). Predicting global change impacts on plant species' distributions: Future challenges. Perspect. *Plant Ecol. Evol. Syst*. 9, 137–152. https://doi.org/10.1016/j.ppees.2007.09.004

Tran, B. N., Tanase, M.A., Bennett, L.T. and Aponte, C. (2020). High-severity Wildfires in Temperate Australian Forests have Increased in Extent and Aggregation in Recent Decades. *PloS One*, 15(11): e0242484. https://doi.org/10.1371/journal.pone.0242484

Volkova L, Roxburgh SH, Surawski NC, Meyer CM, Weston CJ. (2019). Improving reporting of national greenhouse gas emissions from forest fires for emission reduction benefits: an example from Australia. *Environ Sci Policy* 94:49–62. http://dx.doi.org/10.1016/j.envsci.2018.12.023

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.-M., Hoegh-Gulgberg, O. & Bairlein, F. (2002) Ecological responses to recent climate change. *Nature*, 416, 389-395. http://dx.doi.org/10.1038/416389a

Warren, D.L., Glor, R.E. & Turelli, M. (2008). Environmental niche equivalency versus conservation: quantitative approaches to niche evolution. *Evolution*, 62, 2868-2883. https://doi:10.1111/j.1558-5646.2008.00482.x.

Warren, M.S., Hill, J.K., et al., & Thomas, C.D. (2001). Rapid responses of British butterflies to opposing forces of climate change and habitat change. *Nature* 414:65-69 https://doi.org/10.1038/35102054

Watts, S.M.; McCarthy, T.M.; Namgail, T. (2019). Modelling potential habitat for snow leopards (*Panthera uncia*) in Ladakh, India. *PLoS ONE*, 14, e0211509. https://doi.org/10.1371/journal.pone.0211509

Weiskopf, S. R., Rubenstein, M. A., Crozier, L. G., Gaichas, S., Griffis, R., Halofsky, J. E., Hyde, K.J.W., Morelli, T.L., Morisette, J.T., Muñoz, R.C., Pershing, A.J., Peterson, D.L., Poudel R., Staudinger, M.D., Sutton-Grier, A.E., Thompson, L., Vose, J., Weltzin, J.F., Whyte, K.P. (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Science of the Total Environment*, 733, 137782. https://doi.org/10.1016/j.scitotenv.2020.137782

Wester A, Mishra A, Mukherji AB, Shrestha (eds) (2019). The Hindu Kush Himalaya assessment— mountains, climate change, sustainability, and people. Springer Nature Switzerland AG, Cham. https://doi.org/10.1007/978-3-319-92288-1

WWF, (2020). Fires, Forest, and the Future: A Crisis Raging out of Control? World Wide Fund For Nature Conservation. Accessed online 2nd March 2024 https://wwfint.awsassets.panda.org/downloads/wwf_forestfiresreport2020_final.pdf

Zomer RJ, Trabucco A, Metzger MJ, Wang M, Oli KP, Xu J (2014). Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India, Nepal. Clim Change 125(3–4):445. http://dx.doi.org/10.1007/s10584-014-1176-2

Zurell, D. (2017) Integrating demography, dispersal and models. *Journal of Avian Biology*, 48, 1505–1516. https://doi.org/10.1111/jav.01225

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

CHAPTER 2

Greater Himalayan Climate Emergency – Is Conservation Working for Snow Leopards?

2 GREATER HIMALAYAN CLIMATE EMERGENCY – IS CONSERVATION WORKING FOR SNOW LEOPARDS?

ABSTRACT

Assessing species' vulnerability to climate change is crucial for devising effective adaptation strategies. The greater Himalayan region, encompassing Pakistan, India, and Nepal, faces accelerated warming, posing a significant threat to its ecosystems and native species, including the endangered snow leopard—a key indicator of ecosystem health. This study, modeling climate scenarios under RCP 4.5 and 8.5, focuses on two regions: **M1** (Area Including China) and **M2** (Area Excluding China). Objectives include understanding species distribution under different climate scenarios and projecting future habitats. Based on 364 detections, results suggest that 16.9% and 23% of habitats in **M2** may disappear by 2070 under RCP 4.5 and 8.5, respectively. Mean annual temperature is the primary determinant of suitable habitat, with no significant impact on human population density. Highly suitable habitat is projected to decrease from 37% to 32.6% and 31.2% under RCP 4.5 and 8.5, respectively. In **M1**, a 10% and 13% reduction in habitats is anticipated by 2070 under RCP 4.5 and 8.5. Temperature seasonality (Bio4) is crucial in **M1**, with highly suitable habitat increasing by 10%11.8%, while unchanged habitat decreases by 75.8%-73.4% by 2070 (RCP 4.5 and 8.5). Habitat loss in **M2** and increased human activities in **M1** present significant conservation challenges for the region's snow leopard and other species. These findings offer insights for conservation planning, recommending protected areas expansion, particularly in climate refugia regions of Pakistan, India, and Nepal, and increasing staffing to combat poaching. It also supports promoting transboundary conservation to connect snow leopard populations across these countries. Strengthening monitoring and research efforts to understand the impact of climate change on snow leopards and their habitat and guiding adaptive management strategies are needed. Additionally, efforts to raise public awareness to encourage action in reducing the impacts of climate change on snow leopards and their habitat are needed.

Keywords: Climate Change, Snow Leopard, Greater Himalayan Region, Species Distribution Modelling, Habitat Suitability, Kuenm.

2.1 INTRODUCTION

Climate change presents a significant and escalating threat to global biodiversity, disrupting biological events and species distributions (Bhatta et al., 2020; Weiskopf et al., 2020; Singer, 2017). Even the enigmatic snow leopard, a high-altitude mountain dweller, faces substantial peril from climate change (Juan, 2017). The 21st century has seen an alarming 1°C rise in global surface temperatures from the 19th century (IPCC, 2021). This warming is more pronounced in certain regions, such as the Tibetan Plateau, where temperatures have surged by up to 3°C over two decades, triggering ecological transformations and glacier recession, which affects freshwater resources (Pritchard, 2017).

Snow leopards, vital apex predators in alpine ecosystems, inhabit vast territories spanning 12 countries in Central and South Asia, including the Himalayas, Hindukush, Karakoram, Altai, Sayan, Tien Shan, Kunlun, and Pamir Mountain ranges (Nyhus et al., 2016; Snow Leopard Working Secretariat, 2013; Fox & Chundawat, 2016; Thompson, 2013), covering an estimated area of 1.8 to 3.26 million km^2. Their global population is estimated at 7,446 to 7,996 individuals, relying on a 2.8 million km^2 habitat within the Asian highlands across these 12 nations (Khanal et al., 2018). However, rapid regional changes driven by economic expansion have increased human activities (Khanal et al., 2018). In response to limited pasture lands, local communities have shifted from nomadic grazing to more sedentary practices, causing habitat fragmentation (Li et al., 2016). Climate change will likely exacerbate these human-induced threats (Forrest et al., 2012; Khanal et al., 2018).

Species distribution modelling (SDM) is a critical tool in ecology and conservation biology, as it helps predict species distribution based on environmental variables. A range of techniques, from statistical methods like MaxEnt (Phillips et al., 2006) and generalized linear models (GLMs; Elith & Leathwick, 2009) to machine learning approaches like Random Forest (Cutler et al., 2007), Support Vector Machines (Elith et al., 2011), Boosted Regression Trees (Elith et al., 2008), and Deep Learning techniques (Peterson & Soberón, 2012) and Bayesian modelling (Guillera et al., 2015), have been utilized depending on the specific characteristics of data and research questions. To investigate the climate change vulnerability of snow leopards, the Maximum Entropy algorithm (MaxEnt model) has been primarily employed so far (Li et al., 2021; Li et al., 2016) to evaluate potential changes in suitable snow leopard habitat in Qinghai Province, China, and in the entire snow leopard range within the current, near, and far future, including the last glacial maximum, mid-Holocene scenarios respectively. Both studies expected a decrease in the suitable snow leopard habitat in the Qinghai Province, China, and a loss and fragmentation in the Himalayas and Hengduan Mountains, respectively.

More recently, ecological niche models (ENMs) have become a widely used tool in distributional ecology (Araújo et al., 2019) and have been the focus of several studies in fields such as ecology (Anderson, 2017; Zurell, 2017; Osorio-Olvera et al., 2020), evolutionary biology (Saupe et al., 2018), and conservation biology (Freeman et al., 2018). Several R packages have been developed for ENMs, including Niche Toolbox, Niche, and Kuenm (Warren et al., 2008; Cobos et al., 2019). Kuenm is the first R package to include intensive calibration and evaluation methods for model development (Cobos et al., 2019). Therefore, this work also aimed to employ the Kuenm approach to investigate the climate change vulnerability of snow leopards in the greater Himalayan region.

We sought to determine snow leopard dispersal differences and envisage its future habitats in the greater Himalayan region under changing climate in the current and future time periods under RCP 4.5 and RCP 8.5 scenarios in two areas. Area **M1** comprised India, Pakistan, and Nepal, based on the area accessible by dispersal and the area sampled and represented well (over relevant periods, Barve et al., 2011). Area **M2** also included China, although there were no detection points for China. We hypothesized:

2.1.1 Hypothesis

Based on our species-accessible areas **M1** and **M2** in the greater Himalayan region, we hypothesize that there will be significant differences in snow leopard suitable habitat under changing climate conditions in the current and future time periods, particularly under the RCP 4.5 and RCP 8.5 scenarios.

2.2 METHODOLOGY

2.2.1 Study Area

The greater Himalayan region parts of Pakistan, India, and Nepal comprised the study area (Figure 2.1). This region has an average elevation of more than 20,000 feet (6,100m, Britannica, 2018).

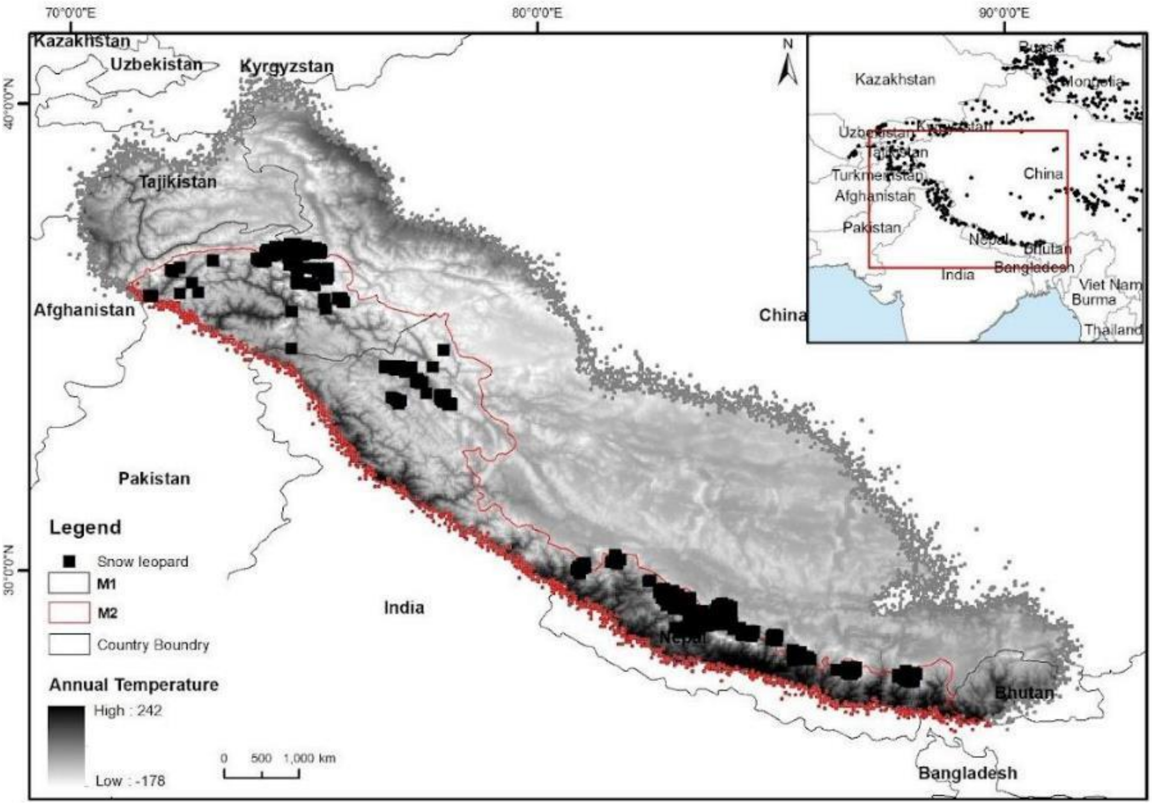


Figure 2.1: Accessible Areas M1 and M2 Showing the Snow Leopard Presence Locations

2.2.2 Snow Leopard Survey Data

The total number of records for snow leopard modelling in the entire study area was 842 (Figure 2.1). The presence data for snow leopards were collected from Pakistan, as mentioned by (Hameed *et al.*, 2020). These data were compiled through camera trap surveys (n=71), genetic records (n=111), occupancy sampling (n=176), and sign surveys (n=37) between 2006 and 2019, thus assembling a total of (n=395) snow leopard presence locations for Pakistan. The presence data of snow leopards in India and Nepal were collected from the published literature (Watts et al., 2019; Aryal et al., 2016). The snow leopard presence data (n = 83) from India included 46 points from camera traps and 37 points from direct observations in the Ladakh area.

Detections in Nepal were gathered through the collection of scats, pugmarks, and camera traps between 2007 and 2014 in various locations throughout the country. (Ale, 2007; Ale & Brown, 2009, Aryal et al., 2014 a,b,c).

The presence locations were then thinned by retaining only one presence point per 1-km^2 grid cell and eliminating duplicates. This resulted in 364 presence points for the species distribution modeling.

2.2.3 M Area

To estimate the species accessible area **M** (**Appendix 2.1**) over relevant time periods (Barve et al., 2011), which should be used as the model calibration areas, we used grinell R Package (Machado-Stredel et al., 2021), ellipsoid algorithm, considering 2.5 resolution, "normal" dispersal kernal, kernal spread "5", max dispersers "2", replicates "13" and dispersal events "30" (Fernando, 2021;). Our **M** area did not extend much to the south and west, which reflected niche-based limitations. This further indicated that it is the effect of no surviving dispersers to go farther out than the base of the Himalayas. So, most of the simulation's spread was northward into China. Therefore, based on these results, the choice of the calibration area was supposed to be a combination of **M,** i.e., the area accessible by dispersal, and the area that had been sampled and represented well. As there was no sampling from China, two **M** hypotheses were formulated simultaneously: **(i) M1** as the stimulated area excluding China; and **(ii) M2** as the stimulated area including China (**Figure 2.1**)

The original data on the presence of the species were thinned out by applying a 10-kilometre distance filter with the help of the SDM toolbox, to decrease spatial autocorrelation. This resulted in 200 records for snow leopards in two areas, **M1** (including China) and **M2** (excluding China), for modeling purposes (as shown in **Figure 2.1**). The presence records were then divided into three equal parts for training the model, testing it, and finally evaluating the final model (Cobos et al., 2019 and Senula et al., 2019).

2.2.4 Environmental and Human Population Layers

For this analysis, climate data were obtained from two sources. The current (1970-2000) bioclimatic conditions were obtained from the "WorldClim" database, which summarized 19 bioclimatic data layers at a 2.5′ spatial resolution (Hijmans et al., 2005, available at http://www.worldclim.org). For the assessment of future distributional potential, data was sourced from the "Climate Change, Agriculture and Food Security (CCAFS)" portal (http://www.ccafs-climate.org/), using two emission scenarios (RCP 4.5 and RCP 8.5 for 2070) based on 5 globally recognized and highly reliable global circulation models (GCMs), ISS-E2-R, MIROC-MIROC 5, MOHC-HadGEM2-CC, MPI-ESM-LR, NCAR-CCSM 4, with a spatial resolution of 2.5' (Bosso et al., 2017; Khan et al., 2018). The future climate projections were based on various Representative Concentration Pathways (RCPs), which consider socio-economic conditions, greenhouse gas emissions, and air pollutant emissions to provide climate change projections (Albuquerque et al., 2018).

The human population density layers for current (2010) and future (2070) conditions were adopted from SEDAC (Socioeconomic Data and Applications Center, https://sedac.ciesin.columbia.edu/). The global spatially explicit population projections are important for understanding potential future interactions between human society and climate change. A series of global spatial population projections were created at a 1/8-degree resolution, following the Shared Socioeconomic Pathways (SSPs) (Jones & O’Neill, 2016; O’Neill et al., 2015).

2.2.5 Snow Leopard Habitat Suitability Distribution Model

The R package Kuenm, which handles three key phases of ecological niche modeling (ENM), was used as the modeling algorithm in this study (Phillips et al., 2006). The strict extrapolation risk analysis and assessment, facilitated by the MOP (mobility-oriented parity) and MESS metrics, helps to prevent over-interpretation of the model results. Kuenm offers three options for extrapolation during transfers (free extrapolation,

extrapolation and clamping, and no extrapolation; Owens et al., 2013), and multiple options can be utilized in a single run. The MOP compares environmental conditions between the calibration areas (**M**) and the areas or scenarios to which the models are transferred. The output maps display the level of similarity between the conditions in the calibration and the model transfer areas, with values of zero indicating strict extrapolation.

Kuenm's approach, under the "free extrapolation" setting, depicts responses in areas with a different environment from the calibration area that follow the patterns found in the calibration environment data. If the "extrapolation and clamping" setting is used, the response in areas with distinct environments from the calibration region will be limited to the values found at the edge of the calibration region. Finally, when using the "no extrapolation" setting, the response will be set to zero if the environments in the transfer areas are more extreme than those where the models were calibrated.

The MOP metric can be used to calculate extrapolation risks in transfer areas. It calculates the difference in environment between the transfer region and the nearest part of the calibration region (**M** or accessible area). It is a better option for estimating extrapolation risks in ecological niche modeling than the MESS metric in MaxEnt, which evaluates the difference from the center of the **M** region. MOP is more appropriate for extrapolation in niche model transfers due to the uneven nature of most environmental spaces.

2.2.6 Data Processing

Four climatic variables (Bio8, Bio9, Bio18, and Bio19) were not used due to the presence of spatial artifacts (Escobar et al., 2014; Ashraf et al., 2017; Ribeiro et al., 2017). The remaining 15 bioclimatic variables and human population data were limited to the **M1** and **M2** areas for model calibration.

A principal component analysis (PCA) examined the current conditions. The PCA transforms a group of highly correlated variables into a set of independent, orthogonal axes (Janzekovic & Novak, 2012). The first three PCs were used to define the **M** areas. To choose climate variables, the first six PCs of current climate conditions were chosen and projected to the future using the "kuenm_rpca" function in R (Cobos et al., 2019a) as they collectively accounted for 99% of the overall variation. In addition, I identified a limited set of 7 bioclimate variables, after using Pearson's correlation coefficient in the calibration area to remote any highly correlated variables ($r^2 \geq 0.75$ Appendix 2.2 and 2.3): Bio1, Bio2, Bio3, Bio4, Bio7, Bio12, and Bio14. We calibrated and evaluated six distinct models of both **M1** and **M2**, using the 6 climate PCs, 7 single climate variables, and these climate data in combination with the human population density. Details on the variables and their combinations in each of the 6 sets are provided in Appendix 2.3. We employed the kuenm R package (Cobos et al., 2019a) to evaluate the six sets by selecting the best candidate solutions. This was done based on three criteria: the solutions were statistically significant, had a low error in terms of omission rate (less than 0.05), and had low values of the Akaike information criterion (AIC; within two units of the minimum value; Warren & Seifert, 2011; Brewer et al., 2016). The selected variables were then used to model distributions given future climate (Yates et al., 2018; Wenger & Olden, 2012).

The extrapolation risk was evaluated using the MOP metric with the Kuenm package. The final statistics were calculated using the kuenm Mod_stat function. The output maps were converted to continuous maps based on an omission error rate of 5% or 10% (Pearson et al., 2007). The results of the ENM were considered indices of suitability, and the threshold values were indices of relative suitability to prevent over-interpretation. The future-transfer maps were thresholded similarly to the current-day models, and the areas were calculated for comparison.

2.3 RESULTS

2.3.1 Model Selection and Accuracy

To create a model of snow leopard habitat distribution in **M1** and **M2** regions, a comprehensive exploration of 3162 potential models was conducted (Appendix 2.4 and Appendix 2.5). The most optimal model (M_2_F_pt_Set2) for the **M1** area was determined by combining nine environmental variables, including Bio1, Bio2, Bio3, Bio4, Bio7, Bio12, Bio14, Bio15, and human population density (Appendix 2.6), with a regularization parameter of 2. This model showed a low omission rate of 0.004 and had a mean AUC ratio of 1.36, which was significant (Table 2.1).

Table 2.1: Parameters Used to Measure Model Performance

Area	Best Models	Mean AUC Ratio	Omission Rate at 5%	AICc	Delta AICc
M1 (Including China)	M_2_F_pt_Set2	1.360147	0.004	2217.369	0
M2 (Excluding China)	M_3_F_lqt_Set1	1.333138	0.016949	2131.065	0
	M_3_F_lqt_Set2	1.31182	0.016949	2131.076	0.01068
	M_3_F_qpt_Set2	1.282088	0.013898	2131.594	0.528578

For **M2** area, three models were chosen as best where set 1 included a combination of variables Bio1 - Bio4, Bio7, Bio12, Bio14, and Bio15, (regularization parameter of 0.4 – 0.5). These models were statistically significant based on mean AUC ratio (Table 2.1). Set 2 included a combination of variables Bio1 - Bio4, Bio7, Bio12, Bio14, Bio15, and human population density (Appendix 2.6).

2.3.2 Climatic Variables Contribution

Table 2.2 outlines the percentage contributions and permutation importance of environmental variables and human population density for predicting snow leopard habitat in **M1** and **M2** areas. In **M2**, the most influential variables were Annual Mean Temperature (Bio1), Temperature Seasonality (Bio4), and Isothermality (Bio3). In **M1**, the key predictors were Temperature Seasonality (Bio4), Precipitation of the Driest Month (Bio14), and human population density (POP). The primary predictor variable differed between **M1** and **M2**, with Bio1 being crucial in **M2** and Bio4 in **M1**. Additionally, the least important environmental variables varied between **M1** and **M2**, with Temperature Annual Range (Bio7) being the least important in **M2** and Precipitation Seasonality (Bio15) in **M1**.

Table 2.2: Percentage Contribution and Permutation Importance of Environmental Variables

Variables for M1 (Including China)	**Variable Acronym**	**Percent Contribution (%)**	**Permutation Importance (%)**
Temperature Seasonality	Bio4	23.4	45.2
Precipitation of Driest Month	Bio14	20.9	5.9
Human Population Density	POP	18.7	5.1
Annual Precipitation	Bio12	14.5	23.1
Annual Mean Temperature	Bio1	10.9	4.6
Temperature Annual Range	Bio7	4.1	0.4
Mean Diurnal Range	Bio2	2.7	0.6
Isothermality	Bio3	2.6	12.7
Precipitation Seasonality	Bio15	2.2	2.3
Variables for M2 (Excluding China)			
Annual Mean Temperature	Bio1	36.6	32.8
Isothermality	Bio3	20	21.9
Precipitation of Driest Month	Bio14	17.7	24
Precipitation Seasonality	Bio15	9.4	5
Annual Precipitation	Bio12	4.4	4.3
Mean Diurnal Range	Bio2	4.3	3.6
Temperature Seasonality	Bio4	3.5	5.8
Human Population Density	POP	3.3	2.2
Temperature Annual Range	Bio7	0.7	0.4

2.3.3 Human Population Density

Human population density showed less contribution in **M2** because of very low human population conditions in the Karakoram Hindu Kush and Pamir landscapes owing to their higher elevation and altitude, where no human population density is predicted by 2100. On the contrary, in **M1**, human population density showed a significant contribution because of the less rugged and larger area and higher human population and settlements, thus impacting the snow leopard habitat in the south-eastern Himalayas (Table 2.2).

2.3.4 Snow Leopard's Current Habitat Suitability

According to the distribution model, snow leopards' habitat is currently spread across the major mountain ranges, including the Himalayas, Karakorum, Hindu Kush, and Pamir. Further, it indicates that this species can maintain populations in the arid climatic area of the Karakoram range, falling in Pakistan, India, and Nepal in the eastern Himalayas (Figure 2.2).

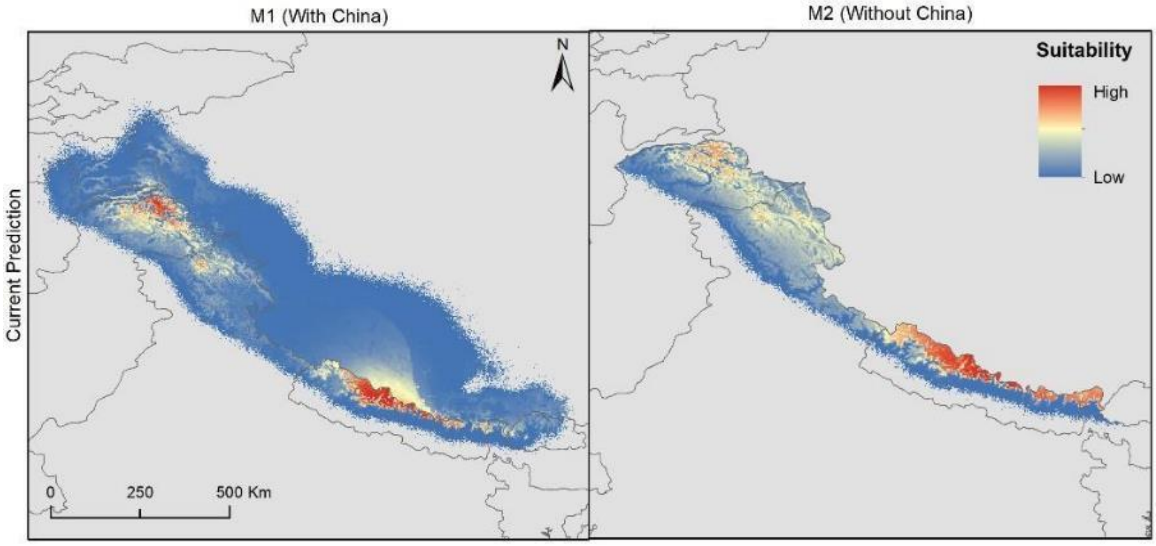


Figure 2.2: Habitat Suitability for Snow Leopard Between 1970-2000 Climatic Conditions in M1 and M2 Areas

Our results showed 121,299 km^2, i.e., 37% of the total **M2** area, suitable for snow leopards under 1970-2000 climatic conditions (Tables 2.3 & Appendix 2.7). The highly suitable areas in **M2** include northeast Gilgit (indicated by Hameed et al., 2020), north-eastern Karnali, northern and central Dhaualagri and Bagmati, and northern Gandaki. The moderately suitable areas included northern Gandaki, Seti, north-western Karnali, Mechidarjiling, and the border between Sikkim and China.

Our results showed 95,552 km^2 i.e., 9.24% of the total **M1** area, suitable for snow leopards under present climatic conditions (Tables 2.3 & Appendix 2.7). The highly suitable areas in **M1** include northeast Gilgit (indicated by Hameed et al., 2020 and Ali, et al., 2021) in the Karakoram range in Pakistan, northwest Kargil, and northeast Ladakh (at borderline) in the Indian Himalayan range, whereas east Karnali, northern Dhaualagri, northeast Gandaki, northern Bagmati, northeast Dahakpur, northwest and northeast Sagarmatha, northwest and northeast Koshi, and Mechidarjiling in the eastern Himalayan range (Figure 2.2).

2.3.5 Snow Leopard Habitat Under Future Climatic Conditions

Our results showed **M1,** which excluded China, with increased and higher suitability in future climatic conditions, but the model showed high extrapolation risk and prediction, which highlights the importance of area selection. On the contrary, the high suitability area reduces in the case of **M2**, referring to the impact of changing climate, hence resulting in habitat shrinkage. About 106,212 km^2 habitat i.e.,10% of **M1** area under 4.5 greenhouse gas emission scenario**,** is highly suitable for snow leopards for 2070 climatic conditions. Approximately 122,787 km^2 i.e., 11.8% of the total **M1** area under RCP 8.5, is highly suitable as well. The highly suitable areas in **M1** under RCP 4.5 include Northern Gilgit (Hameed et al., 2020 as well) with adjacent moderately suitable habitats. In addition, the northwest Kargil and Doda areas have highly suitable habitats. In Nepal, highly suitable areas include, East Karnali, North Dhaualagri, Northern Gandaki, and a small Northern portion of Bagmati. The moderately suitable areas include the provinces of Zhongba, Saga and Gyong in China. The highly suitable areas in **M1** under RCP 8.5 include almost the same areas as those of RCP 4.5 but with relatively more moderately suitable adjacent habitat areas.

Around 106,212 km^2 (32.6%) of habitat in the **M2** area is highly suitable under the 4.5 greenhouse gas emissions scenario, whereas 100,563 km^2 (31.2%) of the total **M2** area under RCP 8.5 is highly suitable (Tables 2.3 & Appendix 2.7). Highly suitable areas in **M2** are almost like **M1** but thinner in size, under 4.5 and 8.5 greenhouse gas emission scenarios in 2070. The uppermost, North-eastern part of the Greater Himalayan range is seen with a wider, moderately suitable habitat (Figure 2.3). More highly suitable habitat is seen towards the Northeastern edge of Nepal under RCP 4.5 in M2, compared to the northwestern Nepalese area. Less highly suitable habitat is observed under the RCP 8.5 compared to the 4.5 greenhouse gas emissions scenario (Figure 2.3).

Table 2.3: Percentage Area Calculations for the 1970-2000 Climatic Conditions and 2070 Scenarios for the Potential Distributional Area of Snow Leopard

Area	Classification	Current (%)	2070 (%)	
			RCP 4.5	RCP 8.5
M1 (Including China)	Unsuitable	76.83249	73.79663	71.06418
	Moderately suitable	13.91765	15.92156	17.04951
	Highly suitable	9.249863	10.28182	11.88631
M2 (Excluding China)	Unsuitable	27.00087	43.17773	44.67195
	Moderately suitable	35.95609	24.15164	24.06979
	Highly suitable	37.04305	32.67062	31.25826

Range expansion is seen in black in the **M1** and **M2** future habitat suitability maps (Figure 2.3). These are the areas where the model has predicted habitat suitability in the future, but these are not suitable habitats under the 1970-2000 climatic conditions. This is so because some of these predict the suitable habitat for snow leopards towards the south-eastern edge of the Himalayas. These areas are larger in **M1** and **M2** under the 8.5 greenhouse gas emissions scenario compared to the 4.5 greenhouse gas emissions scenario.

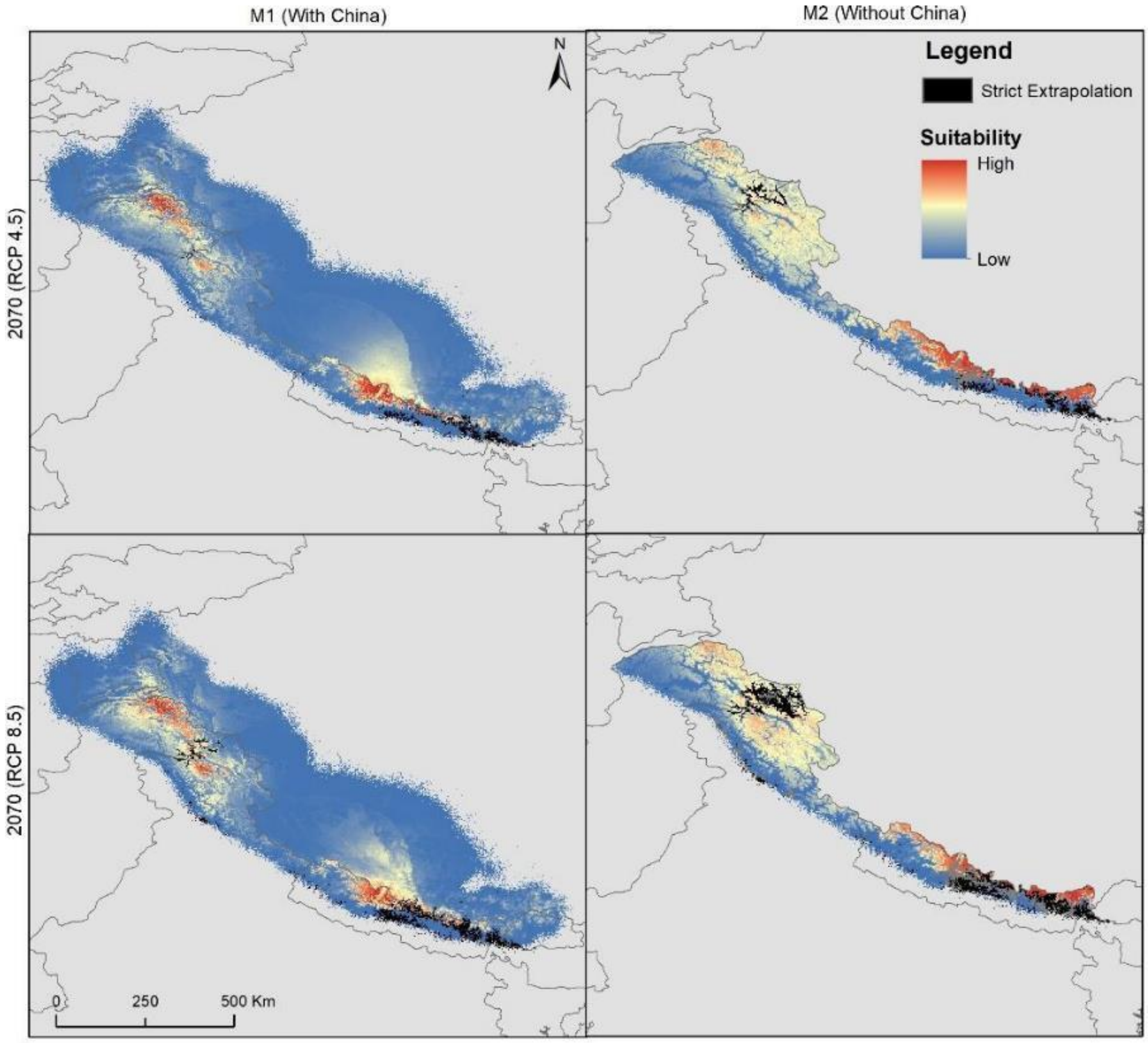


Figure 2.3: Potential Distribution of Snow Leopard for Future Climatic Conditions in M1 and M2 Areas

2.3.6 Snow Leopard Habitat Gain and Loss in M1

The findings reveal varying trends in snow leopard habitat changes under different greenhouse gas emission scenarios (RCP 4.5 and RCP 8.5). In M1, under RCP 4.5, there is a habitat gain of 14.1%, with more gain than loss (10%). Under RCP 8.5, habitat gain and loss are nearly equal at 13.4% and 13.1%, respectively. Specific geographic shifts are observed, with habitat gain in the north-western Himalayas in Pakistan and central Chitral, and habitat loss in areas such as southwest Gilgit and parts of Indian-occupied Kashmir. In Indian-occupied Srinagar, Ladakh, Lahul Spiti, Kinnaur, and Uttarkashi, habitat gain is noted, while loss occurs in the northeast of Ladakh and central Kinnaur (Figure. 2.4).

Nepal experiences no habitat gain and habitat loss in southwest Karnali. In China, habitat gain is observed in various regions, including Zhongba, Coqen, Ngamring, Saga, and Gyirong, with notable shifts under different emission scenarios. In M1's western Himalayan area, habitat loss is more pronounced under RCP 8.5, particularly around Kargil. Notably, there is a shift in habitat gain from the northern end of M1 to the south-eastern edges of Ladakh, Lahul Spiti, and Kinnaur. In China, under RCP 8.5, habitat gain decreases in Zhongba province, accompanied by more habitat loss in southern areas (Figure 2.4).

2.3.7 Snow Leopard Habitat Gain and Loss in M2

Greater habitat loss is observed in **M2** under RCP 4.5 and 8.5 scenarios, accounting for 16.9% and 23%, respectively, compared to habitat gain at 6.4% and 7%, respectively.

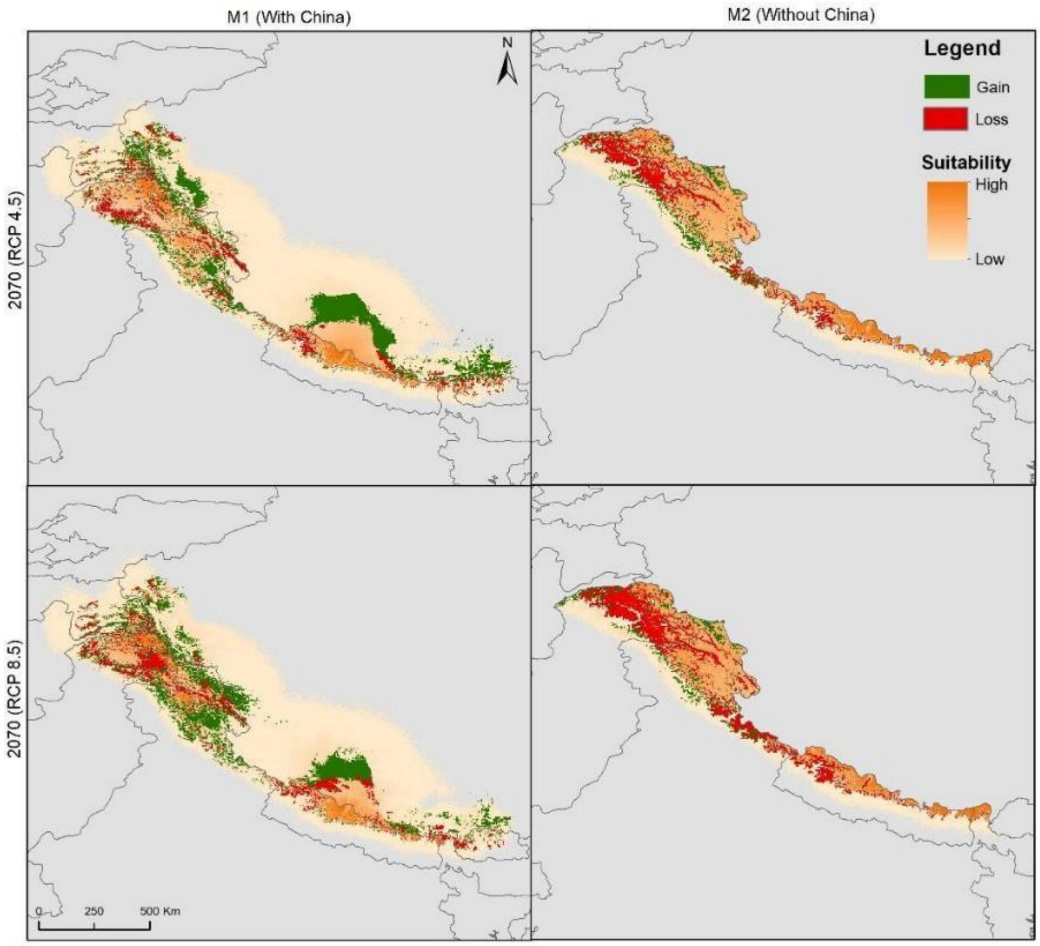


Figure 2.4: Habitat Gain and Loss with Suitability Index of Snow Leopard for Future Climatic Conditions under RCP 4.5 & RCP 8.5 in M1 and M2 Areas

These percentages surpass those in **M1**, underscoring the pronounced impact of climate change on snow leopard habitats in the greater Himalayan region (refer to Table 2.4 and Figure 2.4). In **M2**, Pakistan experiences habitat loss in northern Chitral, southwestern Gilgit, and Chilas under RCP 4.5. In India, habitat loss is noted in the southwest of Indian-occupied Kashmir, particularly in parts of southwestern Ladakh, southern Kinnaur, northeastern Uttarkashi, Prayag, and northern Pithoragarh. Nepal witness's habitat loss predominantly in southwestern Karnali. Under the 8.5 greenhouse gas emission scenario in Pakistan, substantial habitat loss occurs in the central and southwestern parts of Gilgit Baltistan region. In India, habitat loss is observed in select areas of Ladakh, southern Lahul, Spiti, Kinnaur, eastern Prayag, northern Chamoli, Pithoragarh, and Mahakal. In Nepal, habitat loss is concentrated in southwestern Karnali and some portions of Haualagin.

Table 2.4: Habitat Gain and Loss Calculated for M1 and M2 as Percentage Areas under RCP 4.5 and 8.5 for 2070

Area	Classification	2070 (%)	
		RCP 4.5	RCP 8.5
M1 (Including China)	Habitat gain	14.155	13.451
	Habitat loss	10.036	13.118
	No change	75.807	73.429
M2 (Excluding China)	Habitat gain	6.4359	7.0571
	Habitat loss	16.911	23.318
	No change	76.663	69.624

2.4 DISCUSSION

2.4.1 Model Accuracy – M Simulation

Although the **M** areas derived from simulations are essentially assumptions, they approximate the regions a species could have historically explored. The primary objective of this study was to devise a simulation-based methodology for estimating the accessible area of a species grounded in biologically realistic assumptions. This approach allows for incorporating pertinent climate changes in the estimation process, delineating the fundamental ecological niche of a species. The identified area, combined with the known locations where the species is presently found, serves as an initial reference point (Peterson & Soberón, 2012).

The careful selection of model calibration areas significantly influences the accuracy of modeling results. Therefore, meticulous consideration and selection of these areas are imperative for effective model calibration. The suitability layer of the ellipsoid indicates a predominant dispersal pattern towards the north, primarily due to the unsuitability of the south for establishing new populations. The limited extension of the **M** area to the south and west reflects niche-based constraints, illustrating the absence of surviving dispersers venturing beyond the base of the Himalayas. Consequently, the simulation records predominantly demonstrate a northward spread into China.

2.4.2 Current Habitat Suitability of Snow Leopards in Greater Himalayas

Our model's predictions align with the conclusions drawn by Li et al. (2016), affirming that snow leopard habitats predominantly exist in the Himalayas and other high-altitude mountain ranges across Asia. Consistency is observed with the findings of Hameed et al. (2020) and Ali et al. (2021), specifically regarding Pakistan, where both studies highlight the habitat suitability of the Pamir-Karakoram Mountain range. For instance, north-eastern Gilgit is identified as a stronghold for snow leopards due to the presence of their prey species, including blue sheep and ibex.

Furthermore, our results substantiate the insights presented by Watts et al. (2019), who identified 12% of the Indian Ladakh area (approximately 90,000 km^2) as highly suitable and an additional 18% as moderately suitable for snow leopards. Consistent findings are also noted by Aryal et al. (2013, 2014a), underscoring that the eastern Himalayan region of Nepal constitutes 10% of the total global habitat for snow leopards, providing highly favorable conditions for the species.

Additionally, our results resonate with the observations made by Forrest et al. (2012), emphasizing the transformative impact of current climate change on the ecosystems, wildlife, plants, and local livelihoods in the Trans-Himalayan region. This underscores the pressing need for cross-border collaboration in snow leopard conservation, as highlighted by Li et al. (2021), especially for protecting some of the world's highest mountain ranges, including the Himalayas.

2.4.3 Future Habitat Suitability of Snow Leopards in Greater Himalayas

We observed a notable decrease in **M2**, amounting to 32.6% in the 4.5 emission scenario and 31.2% in the 8.5 emission scenario. This projection of a decline from the current available habitat (37%) suitable for snow leopardsl by the year 2070 aligns with Aryal et al.'s (2016) observations of diminishing blue sheep and snow leopard habitats in future scenarios in Nepal.

Our results are consistent with the forecasts of Farrington & Li (2016) and Forrest et al. (2012), anticipating the East Himalaya Mountain ranges in China as one of the most susceptible areas, with an approximate 30% decline in the cat's Himalayan habitat. Moreover, Li et al. (2016) predicted a substantial reduction in snow leopard habitat, particularly in Nepal and Bhutan within the Himalayas.

In summary, our findings underscore the impact of climate change on snow leopard habitat in the greater Himalayan region, suggesting a potential contraction. The significance of area selection is highlighted, as the **M1** area indicates increased suitability for future climatic conditions, characterized by high extrapolation risk and prediction, despite the absence of snow leopard presence points in China. In contrast, the **M2** area reveals a reduction in the highly suitable habitat for snow leopards.

2.4.4 Anthropogenic Factors

The mountainous regions of Central Asia have undergone well-documented changes in human development and environmental consequences (Nogues-Bravo et al., 2007; Riordan et al., 2015). Snow leopard habitats, characterized by challenging terrain, predominantly house pastoralist communities with low population density, as illustrated in **M1**. Our study indicates a significant impact of human population density on snow leopard habitat in **M1**, in contrast to **M2**, reflecting the influence of specific area selection.

Li et al. (2016) noted extensive infrastructure development in the entire snow leopard range region in China during the 1980s, impacting snow leopard habitats through activities like mining and tourism. The proliferation of the cattle population, leading to overgrazing, poses challenges for both snow leopards and their MaxEnt prey species.

Like other large carnivores, the snow leopard is vulnerable to human impacts (Namgail et al., 2007) and necessitates expansive habitat areas for survival (Johansson et al., 2016). Despite its ecological significance and role as an indicator of ecosystem health (Snow et al., 2013; Murali et al., 2017), the snow leopard's population is believed to be declining across its range due to various human-induced pressures, including human-wildlife conflict (Suryawanshi et al., 2013; Maheshwari & Sathyakumar, 2020), poaching (Nowell et al., 2016), and declining prey availability (Mishra et al., 2004). Khan et al. (2021) reported growth of built-up areas (163%) and agricultural land (153%) in snow leopard habitat in Pakistan due to the expanding human population, while forested areas (28%) and regions with snow cover (52%) have decreased from 2000 to 2020.2.4.5.

2.4.5 Environmental Factors

In the **M2** region of the study, the crucial predictor variables were Annual Mean Temperature (Bio1, contributing 36.6%) and Isothermality (Bio3, contributing 20%). The Himalayas and Tibetan Plateau experience higher average temperatures than the global average, impacting these regions significantly (Forrest et al., 2012; Li et al., 2016; Tiwari & Jha, 2018). Previous research, including Aryal et al. (2016) and Watts et al. (2019), has highlighted the major influence of Annual Mean Temperature on habitat models, with the latter noting a negative correlation to elevation. Isothermality (Bio3) suggests that species distribution may be influenced by temperature fluctuations throughout the month in relation to the year.

In **M1**, the most significant predictor variables were "Temperature Seasonality" (Bio4, contributing 23.4%) and "Precipitation of the Driest Month" (Bio14, contributing 20.9%). Bio4 measures temperature changes throughout the year, while Bio14 indicates total precipitation during the driest month, crucial for determining the impact of extreme precipitation on a species' potential range.

The study reveals a substantial contribution of annual precipitation (Bio12, 14.5%) in **M1** compared to **M2** (4.4%). Tiwari and Jha (2018) noted a 20% decline in precipitation in the Western Himalayas since the last century. Anticipated future decreases in annual precipitation, already evident in recent studies, may pose challenges for snow leopards, which are typically found at elevations of 3,500 to 5,500 meters between timber and snow lines. This highlights the critical role of precipitation in sustaining life in this region.

2.5 CONCLUSION

In this study, we projected the potential distribution of snow leopards across their range in the greater Himalayan region under current and future time periods. The primary environmental variables influencing snow leopard habitat were identified as Bio1 and Bio12. The analysis indicates a reduction in suitable habitats for snow leopards by 2070, particularly under extreme future temperature scenarios. The current modeling framework demonstrates the presence of suitable habitat in both present and future climates across various greenhouse gas scenarios. Our research underscores the vulnerability of the snow leopard's existing habitat to climate change, projecting a significant loss in their present suitable habitat within the Himalayan range due to rapid climate change.

To reduce the impacts of climate change and human disturbances in the greater Himalayan region, this study contributes to developing and implementing conservation plans for snow leopards. Urgent reviews of management strategies in respective countries are necessary to enhance their effectiveness in snow leopard conservation. The study's findings can be utilized to assess or adjust the boundaries of current snow leopard ranges to align with future habitat requirements. Protecting and restoring the delicate alpine steppe habitat will benefit snow leopards and other related species.

Recommendations include expanding the coverage of protected areas by the governments of snow leopard range countries. This expansion should specifically target climate refugia identified in this study, encompassing areas in Pakistan (northern Gilgit), India (northwest Kargil and Doda), and Nepal (eastern Karnali, northern Dhaulagiri, northern Gandaki, and northern Bagmati). Adequate staffing in these areas is crucial to control the poaching of snow leopards. Transboundary conservation efforts should promote connectivity among snow leopard populations within the greater Himalayan countries, namely Pakistan, India, and Nepal. Strengthening monitoring and research endeavors is recommended to gain a better understanding of the impacts of climate change on snow leopard populations and their habitat, informing adaptive management strategies.

2.6 REFERENCES

Albuquerque, F., Benito, B., Rodriguez, M.A.M., Gray, C. (2018). Potential changes in the distribution of Carnegiea gigantea under future scenarios. PeerJ 6, e5623. https://doi.org/10.7717/peerj.5623

Ale, S. B. (2007). *Ecology of the snow leopard and the Himalayan tahr in Sagarmatha (Mt. Everest) National Park, Nepal*. University of Illinois at Chicago. Accessed online 2nd March 2024 http://www.carnivoreconservation.org/files/thesis/ale_2007_phd.pdf

Ale, S. B., & Brown, J. S. (2009). Prey behavior leads to predator: a case study of the Himalayan tahr and the snow leopard in Sagarmatha (Mt. Everest) National Park, Nepal. *Israel Journal of Ecology & Evolution*, *55*(4), 315-327. http://dx.doi.org/10.1560/IJEE.55.4.315

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

Ali H, Din JU, Bosso L, Hameed S, Kabir M, Younas M, et al. (2021). Expanding or shrinking? range shifts in wild ungulates under climate change in Pamir-Karakoram mountains, Pakistan. *PLoS ONE* 16(12): e0260031.https://doi.org/10.1371/journal.pone.0260031

Anderson, R.P. (2017) When and how should biotic interactions be considered in models of species niches and distributions? *Journal of Biogeography*, 44, 8–17. https://doi.org/10.1111/jbi.12825

Araújo MB, Peterson AT. (2012). Uses and misuses of bioclimatic envelope modeling. *Ecology* 93(7):1527–1539 DOI 10.1890/11-1930.1. https://doi.org/10.1890/11-1930.1

Araújo, M.B., Anderson, R.P., Barbosa, A.M., et al. (2019). Standards for distribution models in biodiversity assessments. *Science Advances*, 5, eaat4858. https://doi.org/10.1126/sciadv.aat4858

Aryal A, Shrestha UB, Ji W, Ale SB, Shrestha S, Ingty T, et al. (2016). Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalaya. *Ecol Evol*., 6: 4065– 4075. https://doi.org/10.1002/ece3.2196PMID:27516864

Aryal, A., Brunton, D., & Raubenheimer, D. (2013). Habitat assessment for the translocation of blue sheep to maintain a viable snow leopard population in the Mt Everest Region, Nepal. *Zoology and Ecology*, *23*(1), 66-82. http://dx.doi.org/10.1080/21658005.2013.765634

Aryal, A., Brunton, D., Ji, W., Barraclough, R.K., Raubenheimer, D. (2014a). Human–carnivore conflict: ecological and economical sustainability of predation on livestock by snow leopard and other carnivores in the Himalaya. *Sustain. Sci*. 9, 321–329.https://doi.org/10.1007/s11625-014-0246-8.

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

Aryal, A., Brunton, D., Ji, W., Raubenheimer, D. (2014c). Blue sheep in the Annapurna Conservation Area, Nepal: habitat use, population biomass and their contribution to the carrying capacity of snow leopards. *Integr. Zool.* 9, 34–45.https://doi.org/10.1111/1749-4877.12004.

Aryal, A., Shrestha, U.B., Ji, W., Ale, S.B., Shrestha, S., Ingty, T., Maraseni, T., Cockfield, G., Raubenheimer, D. (2016). Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalaya. *Ecol. Evol.* 6, 4065–4075. https://doi.org/10.1002/ece3.2196.

Ashraf, U., Peterson, A. T., Chaudhry, M. N., Ashraf, I., Saqib, Z., Rashid Ahmad, S., & Ali, H. (2017). Ecological niche model comparison under different climate scenarios: a case study of Olea spp. in Asia. *Ecosphere*, *8*(5), e01825. https://doi.org/10.1002/ecs2.1825

Barve, N., V. Barve, A. Jimenez-Valverde, A. Lira Noriega, S. P. Maher, A. T. Peterson, J. Soberpn, and F. Villalobos. (2011). The crucial role of the accessible area in ecological niche modeling and species distribution modeling. *Ecological Modelling* 22211:1810–1819. http://dx.doi.org/10.1016/j.ecolmodel.2011.02.011

Beaumont, L.J., Pitman, A., Poulsen, M., Hughes, L., (2007). Where will species go? Incorporating new advances in climate modelling into projections of species distributions. Glob. Chang. Biol. 13, 1368e1385. Beaumont, L.J., Hughes, L., Pitman, A., 2008. Why is the choice of future climate scenarios for species distribution modelling important? *Ecology Letters* 11, 1135e1146. http://dx.doi.org/10.1111/j.1365-2486.2007.01357.x

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters* 15(4):365-377. https://doi.org/10.1111/j.1461-0248.2011.01736.x

Bhatnagar, Y.V., Mathur, V.B., Sathyakumar, S., Ghoshal, A., Sharma, R.K., Bijoor, A., Raghunath, R., Timbadia, R., Lal, P. (2016). South Asia: India. in: McCarthy, T., Mallon, D., Nyhus, P.. (Eds.), *Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes*. pp. 457-469.

Bhatta, L. D., Udas, E., Khan, B., Ajmal, A., Amir, R., & Ranabhat, S. (2020). Local knowledge based perceptions on climate change and its impacts in the Rakaposhi valley of Gilgit-Baltistan, Pakistan. *International Journal of Climate Change Strategies and Management*. https://doi.org/10.1108/IJCCSM-05-2019-0024

Bosso L, Luchi N, Maresi G, Cristinzio G, Smeraldo S, Russo D. (2017). Predicting current and future disease outbreaks of *Diplodia sapinea* shoot blight in Italy: species distribution models as a tool for forest management planning. *For Ecol Manage.* 400: 655–664.https://doi.org/10.1016/j.foreco.2017.06.044

Brewer, M. J., A. Butler, & S. L. Cooksley. (2016). The relative performance of AIC, AICC and BIC in the presence of unobserved heterogeneity. *Methods in Ecology and Evolution* 7:679–692. https://doi.org/10.1111/2041-210X.12541

Britannica, T. Editors of Encyclopedia. Great Himalayas. Encyclopedia Britannica. Accessed online 2nd February 2018. https://www.britannica.com/place/Great-Himalayas

Brown, J. L. (2014). SDMtoolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. *Methods in Ecology and Evolution* 57:694–700. https://doi.org/10.1111/2041-210X.12200

Cobos, M.E., Peterson, A.T., Barve, N. & Osorio-Olvera, L. (2019b) kuenm: an R package for detailed development of ecological niche models using MaxEnt. *PeerJ*, 7, e6281. https://doi.org/10.7717/peerj.6281

Cobos, M.E., Peterson, A.T., Osorio-Olvera, L. & Jiménez-García, D. (2019a) An exhaustive analysis of heuristic methods for variable selection in ecological niche modeling and species distribution modeling. *Ecological Informatics*, 53, 100983. https://doi.org/10.1016/j.ecoinf.2019.100983

Cutler, D. R., Edwards Jr, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., & Lawler, J. J. (2007). Random forests for classification in ecology. Ecology, 88(11), 2783-2792. https://doi.org/10.1890/07-0539.1

Elith, J., & Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics*, 40, 677-697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Elith, J., Leathwick, J. R., & Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology*, 77(4), 802-813. https://doi.org/10.1111/j.1365-2656.2008.01390.x

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., & Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*, 17(1), 43-57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

Escobar, L.E., Lira-Noriega, A., Medina-Vogel, G. & Peterson, A.T. (2014). Potential for spread of the white-nose fungus (*Pseudogymnoascus destructans*) in the Americas: use of MaxEnt and Niche to assure strict model transference. *Geospatial Health,* 9, 221–229. https://doi.org/10.4081/gh.2014.19

Farrington, J. D., & Li, J. (2016). Chapter 8 - Climate Change Impacts on Snow Leopard Range, Editor(s): Thomas McCarthy, David Mallon, Snow Leopards, Academic Pres., 85-95, ISBN 9780128022139 https://doi.org/10.1016/B978-0-12-802213-9.00008-0.

Forrest, J.L.; Wikramanayake, E.; Shrestha, R.; Areendran, G.; Gyeltshen, K.; Maheshwari, A.; Mazumdar, S.; Naidoo, R.; Thapa, G.J.; Thapa, K. (2012) Conservation and climate change: Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. *Biol. Conserv*., 150, 129–135. https://doi.org/10.1016/j.biocon.2012.03.001

Fox, J. L., & Chundawat, R. S. (2016). What is a snow leopard? Behavior and Ecology. *In Snow Leopards. Biodiversity of the World: Conservation from Genes to Landscapes.* (pp. 13-21). Academic Press. https://doi.org/10.1016/B978-0-323-85775-8.00051-0

Freeman, B., Roehrdanz, P.R. & Peterson, A.T. (2018) Modeling endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa. *Biodiversity and Conservation*, 28, 671–685. https://doi.org/10.1007/s10531-018-01684-6

Guillera-Arroita, G., Lahoz-Monfort, J. J., Elith, J., Gordon, A., Kujala, H., Lentini, P. E., ... & Wintle, B. A. (2015). Is my species distribution model fit for purpose? Matching data and models to applications. *Global Ecology and Biogeography*, 24(3), 276-292. https://doi.org/10.1111/geb.12268

Hameed, S., Din, J. U., Ali, H., Kabir, M., Younas, M., Ur Rehman, E., & Nawaz, M. A. (2020). Identifying priority landscapes for conservation of snow leopards in Pakistan. *Plos one*, *15*(11), https://doi.org/10.1371/journal.pone0228832

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high-resolution interpolated climate surfaces for global land areas. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *25*(15), 1965-1978.https://doi.org/10.1002/joc.1276.

Hunter, D., McCarthy, K., McCarthy, T., (2016). Techniques and Technologies for the Study of a Cryptic Felid., in: McCarthy, T., Mallon, D., Nyhus, P. (Eds.), *Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes*. Academic Press, pp. 345–353.

IPCC, (2021). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. http://doi:10.1017/9781009157896.001.

Janžekovič, F., & Novak, T. (2012). PCA–a powerful method for analyze ecological niches. Principal component analysis–multidisciplinary applications, 127-142. https://doi:10.5772/38538

Johnson, E. E., L. E. Escobar, and C. Zambrana Torrelio. (2019). An ecological framework for modeling the geography of disease transmission. *Trends in Ecology and Evolution* 34:655–668. https://doi.org/10.1016/j.tree.2019.03.004

Jones, B., & O'Neill, B. C. (2016). Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways. *Environmental Research Letters*, 11(8), 084003. http://doi:10.1088/1748-9326/11/8/084003

Jones, B., O'Neill, B. C., McDaniel, L., McGinnis, S., Mearns, L. O., & Tebaldi, C. (2015). Future population exposure to US heat extremes. *Nature Climate Change*, 5(7), 652-655. http://dx.doi.org/10.1038/nclimate2631

Kalashnikova, Y.A.; Karnaukhov, A.S.; Dubinin, M.Y.; Poyarkov, A.D.; Rozhnov, V.V. (2019). Potential habitat of Snow leopard (*Panthera uncia*, felinae) in south Siberia and adjacent territories based on the Maximum Entropy Distribution Model. *Zool. Zhurnal*. 98, 332–342. http://dx.doi.org/10.1134/S0044513419030061

Khan N, Shahid S, Ahmed K, Ismail T, Nawaz N, Son M. (2018). Performance assessment of general circulation model in simulating daily precipitation and temperature using multiple gridded datasets. Water (Switzerland). 10: 1793.https://doi.org/10.3390/w10121793

Khanal, G., Poudyal, L. P., Devkota, B.P., Ranabhat, R., Wegge. P. (2018). Status and conservation of snow leopard Panthera uncia in Api Nampa Conservation Area, Nepal. 2018 Oryx 08: 1-8. http://dx.doi.org/10.1017/S0030605318000145

Krishnan, R., Shrestha, A. B., Ren, G., Rajbhandari, R., Saeed, S., Sanjay, J., ... & Ren, Y. (2019). Unravelling climate change in the Hindu Kush Himalaya: rapid warming in the mountains and increasing extremes. In *The Hindu Kush Himalaya Assessment* (pp. 57-97). Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_3

Laghari, J.R., (2013). Melting glaciers bring energy uncertainty The Himalayan thaw will affect hydroelectric power. Nature – London - 502 (7473), 617e619. http://dx.doi.org/10.1038/502617a

Levinsky, I., Skov, F., Svenning, J.C., Rahbek, C., (2007). Potential impacts of climate change on the distributions and diversity patterns of European mammals. *Biodivers. Conserv*. 16, 3803e3816. http://dx.doi.org/10.1007/s10531-007-9181-7

Li, J. , Liu, F. , Xue, Y. D. , Zhang, Y. , & Li, D. Q. (2017). Assessing vulnerability of giant panda to climate change in the Qinling Mountains of China. *Ecology and Evolution*, 7(11), 4003–4015. https://doi.org/10.1002/ece3.2981

Li, J., McCarthy, T. M., Wang, H., Weckworth, B. V., Schaller, G. B., Mishra, C., ... & Beissinger, S. R. (2016). Climate refugia of snow leopards in High Asia. *Biological Conservation*, *203*, 188-196. https://doi.org/10.1016/j.biocon.2016.09.026

Li, J., Xiao, L., and Lu, Z (2016). Challenges of snow leopard conservation in China. *Science China. Life Sciences*, *59*(6), 637. https://doi:10.1007/s11427-016-5067-9

Li, J., Xue, Y., Hacker, C. E., Zhang, Y., Li, Y., Cong, W., ... & Zhang, Y. (2021). Projected impacts of climate change on snow leopard habitat in Qinghai Province, China. *Ecology and Evolution*, 11(23), 17202-17218. https://doi.org/10.1002/ece3.8358

Li, J., Yin, H., Wang, D., Jiagong, Z., Lu, Z., (2013). Human-snow leopard conflicts in the Sanjiangyuan Region of the Tibetan Plateau. *Biol. Conserv*. 166, 118–123. http://dx.doi.org/10.1016/j.biocon.2013.06.024

Machado-Stredel, F., Cobos, M. E., & Peterson, A. T. (2021). A simulation-based method for selecting calibration areas for ecological niche models and species distribution models. *Frontiers of Biogeography*, 13(4). https://doi.org/10.21425/F5FBG48814

Machado-Stredel, F., Cobos, M. E., & Peterson, A. T. (2021). A simulation-based method for selecting calibration areas for ecological niche models and species distribution models. *Frontiers of Biogeography*, *13*(4). https://doi.org/10.21425/F5FBG48814

McCarthy, T., Mallon, D., Sanderson, E., Zahler, P., Fisher, K., (2016). What is a snow leopard? In: McCarthy, T., Mallon, D. (Eds.), *Snow Leopards of the World*. Elsevier, Academic Press, pp. 23–42. http://dx.doi.org/10.1016/B978-0-12-802213-9.00003-1

McCarthy, T.M., Chapron, G., 2003. Snow Leopard Survival Strategy. ISLT and SLN, Seattle, USA. Accessed online 2nd March 2024 http://www.catsg.org/fileadmin/filesharing/3.Conservation_Center/3.4._Strategies___Action_Plans/Snow_leopard/McCarthy_et_al_2003_Snow_leopard_survival_strategy.pdf

Network, S.L. Snow Leopard Survival Strategy, Revised Version (2014).1; International Snow Leopard Trust and Snow Leopard Network: Seattle, WA, USA, 2014; pp. 1–145. Accessed online 2nd March 2024 https://globalsnowleopard.org/wp-content/uploads/2018/12/Snow_Leopard_Survival_Strategy_2014.1.pdf

Nyhus, P.J.; McCarthy, T.; Mallon, D. (2016). *Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes*; Academic Press: Cambridge, MA, USA

Osorio-Olvera, L., Yañez-Arenas, C., Martínez-Meyer, Osorio-Olvera, L., Yañez-Arenas, C., Martínez-Meyer, E. & Peterson, A.T. (2020). Relationships between population densities and niche-centroid distances in North American birds. *Ecology Letters*, 23, 555–564. https://doi.org/10.1111/ele.13453

Owens, H.L., Campbell, L.P., Dornak, L.L., et al. (2013) Constraints on interpretation of ecological niche models by limited environmental ranges on calibration areas. *Ecological Modelling*, 263, 10–18.https://doi.org/10.1016/j.ecolmodel.2013.04.011

PEARSON, R.G.; RAXWORTHY, C.J.;NAKAMURA, M.; TOWNSEND PETERSON, A. Peterson, A. T., & Soberón, J. (2012). Species distribution modeling and ecological niche modeling: Getting the concepts right. *Natureza & Conservação*, 10(2), 102-107. http://dx.doi.org/10.4322/natcon.2012.019

Peterson, A. T., M. Papes, and M. Eaton. (2007). Transferability and model evaluation in ecological niche modeling: a comparison of GARP and MaxEnt. *Ecography* 30:550–560. https://doi.org/10.1111/j.0906-7590.2007.05102.x

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190(3-4), 231-259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Prichard, S. J., Stevens-Rumann, C. S., & Hesburg, P. F. (2017). Tamm Review: Shifting global fire regimes: Lessons from reburns and research needs. *Forest Ecology and Management*, *396*, 217-233. https://doi.org/10.1016/j.foreco.2017.03.035

Ribeiro, V., A. T. Peterson, F. P. Werneck, and R. B. Machado. (2017). Ecological and historical views of the diversification of *Geositta miners* (Aves: *Furnariidae: Sclerurinae*). *Journal of Ornithology* 158:15–23. http://dx.doi.org/10.1007/s10336-016-1398-3

Saupe, E.E., Barve, N., Owens, H.L., Cooper, J.C., Hosner, P.A. & Peterson, A.T. (2018). Reconstructing ecological niche evolution when niches are incompletely characterized. *Systematic Biology*, 67, 428–438. https://doi.org/10.1093/sysbio/syx084

Senula, S. F., J. T. Scavetta, J. A. Banta, U. G. Mueller, J. N. Seal, and K. Kellner. (2019). Potential distribution of six North American Higher-Attine Fungus Farming Ant (*Hymenoptera: Formicidae*) species. *Journal of Insect Science* 19:24. https://doi.org/10.1093%2Fjisesa%2Fiez118

Singer, M. C. (2017). Shifts in time and space interact as climate warms. Proceedings of the National Academy of Sciences of the United States of America 114:12848–12850. https://doi.org/10.1073/pnas.1718334114

Snow Leopard Working Secretariat, (2013). Global Snow Leopard and Ecosystem Protection Program. (Bishkek, Kyrgyz Republic). Accessed online 2nd March 2024 https://snowleopard.org/wp-content/uploads/2013/11/Global-Snow-Leopard-and-Ecosystem-Protection-Program-GSLEP-October-2013.pdf

Thompson, W., (2013). Sampling rare or elusive species: concepts, designs, and techniques for estimating population parameters.

Treves A, Karanth KU (2003). Human-Carnivore Conflict and Perspectives on Carnivore Management Worldwide. *Conserv Biol* 17: 1491–1499. Available: http://doi.wiley.com/10.1111/j.1523-1739.2003.00059.x.

Warren, D.L., Glor, R.E. & Turelli, M. (2008) Environmental niche equivalency versus conservation: quantitative approaches to niche evolution. *Evolution*, 62, 2868-2883. https://DOI:10.1111/j.1558-5646.2008.00482.x.

Warren, D.L., Seifert, S.N., (2011). Ecological niche modeling in MaxEnt: the importance of model complexity and the performance of model selection criteria. *Ecol. Appl.* 21, 335–342.https://doi.org/10.1890/10-1171.1

Watts, S.M., McCarthy, T.M., Namgail, T., (2019). Modelling potential habitat for snow leopards (Panthera uncia) in Ladakh, India. *PLoS One*. https://doi.org/10.1371/journal.pone.0211509

Weiskopf, S. R., Rubenstein, M. A., Crozier, L. G., Gaichas, S., Griffis, R., Halofsky, J. E., Hyde, K.J.W., Morelli, T.L., Morisette, J.T., Muñoz, R.C., Pershing, A.J., Peterson, D.L., Poudel R., Staudinger, M.D., Sutton-Grier, A.E., Thompson, L., Vose, J., Weltzin, J.F., Whyte, K.P. (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Science of the Total Environment*, 733, 137782. https://doi.org/10.1016/j.scitotenv.2020.137782

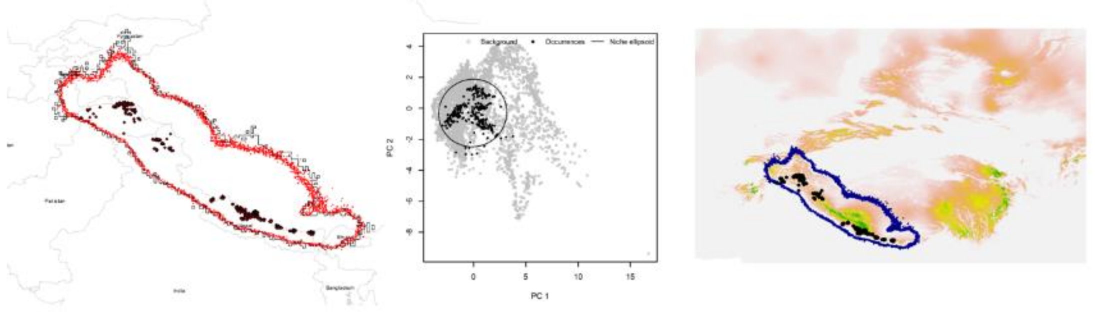
Wenger, S. J., and J. D. Olden. (2012). Assessing transferability of ecological models: an underappreciated aspect of statistical validation. *Methods in Ecology and Evolution* 3:260–267. https://doi.org/10.1111/j.2041-210X.2011.00170.x

Wolf, M., & Ale, S. O. M. (2009). Signs at the top: habitat features influencing snow leopard *Uncia uncia* activity in Sagarmatha National Park, Nepal. *Journal of Mammalogy*, *90*(3), 604-611. https://doi.org/10.1644/08-MAMM-A-002R1.1

Yates, K. L., Bouchet, P. J., Caley, M. J., Mengersen, K., Randin, C. F., Parnell, S., ... & Sequeira, A. M. (2018). Outstanding challenges in the transferability of ecological models. *Trends in ecology & evolution*, *33*(10), 790-802. https://doi.org/10.1016/j.tree.2018.08.001

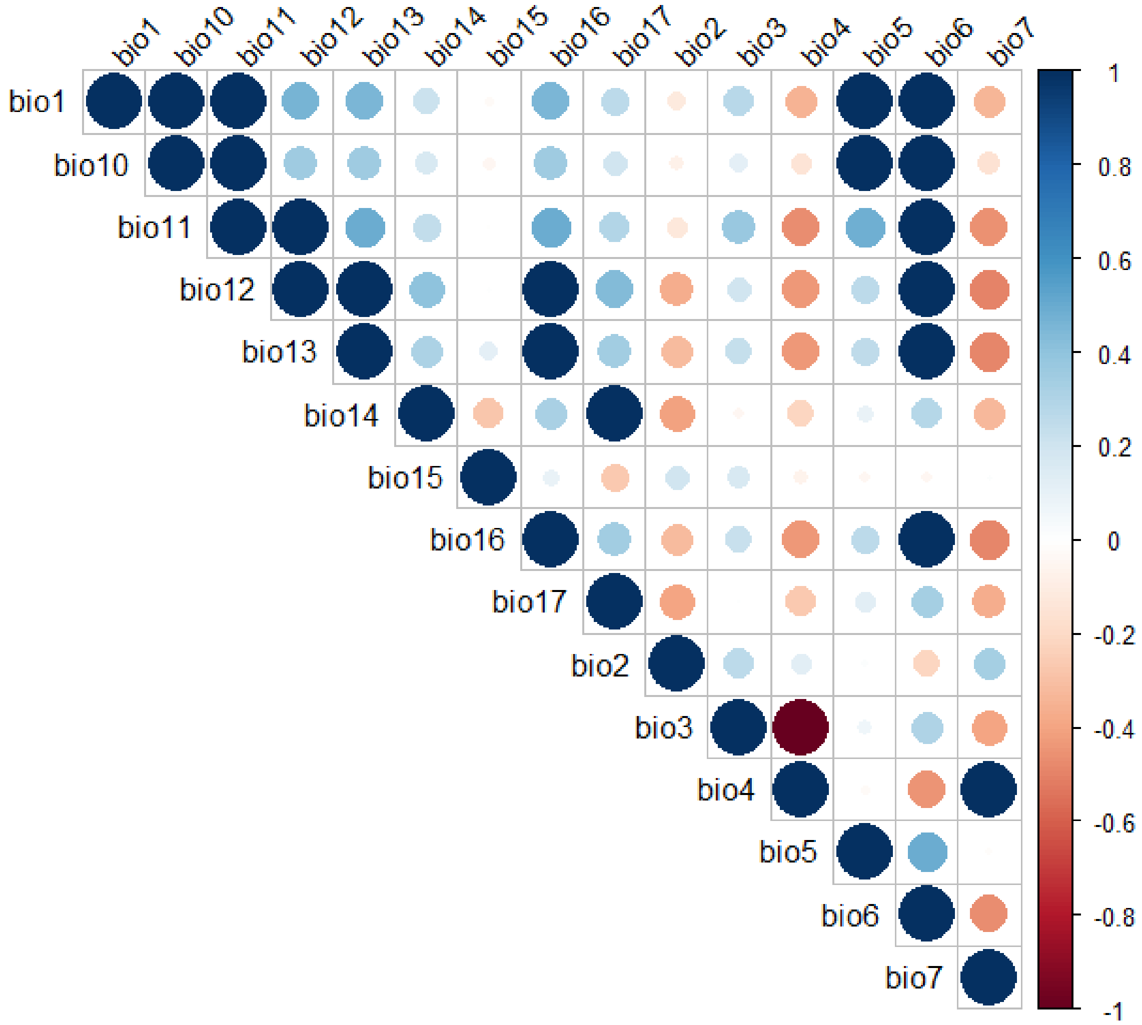
Zurell, D. (2017) Integrating demography, dispersal and models. *Journal of Avian Biology*, 48, 1505–1516. https://doi.org/10.1111/jav.01225

APPENDIX 2.1: ACCESSIBLE AREA (M) OF SNOW LEOPARD IN GREATER HIMALAYAN REGION

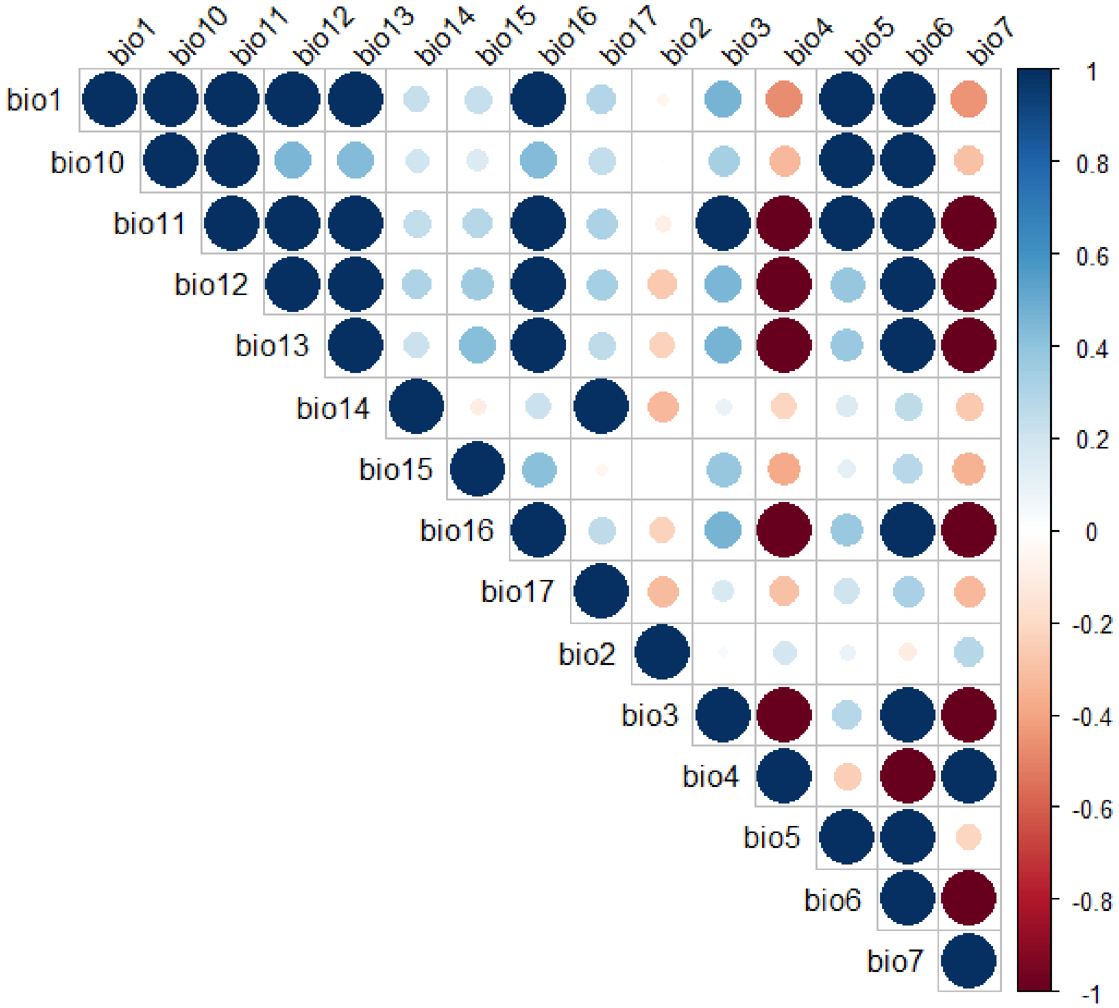


Red=2.5'resolution dispersal_kernel = "normal", kernel_spread = 5, max_dispersers = 2, replicates = 13, dispersal_events = 30

APPENDIX 2.2: CORRELATION MATRIX FOR THE M1 AREA



APPENDIX 2.3: CORRELATION MATRIX FOR THE M2 AREA



APPENDIX 2.4: DETAIL OF M1 MODELS

Criteria	Number of Models
All candidate models	3162
Statistically significant models	2743
Models meeting omission rate criteria	943
Models meeting AICc criteria	4
Statistically significant models meeting omission rate criteria	917
Statistically significant models meeting AICc criteria	4
Statistically significant models meeting omission rate and AICc criteria	1

APPENDIX 2.5: DETAIL OF M2 MODELS

Criteria	Number of Models
All candidate models	2108
Statistically significant models	2098
Models meeting omission rate criteria	723
Models meeting AICc criteria	3
Statistically significant models meeting omission rate criteria	713
Statistically significant models meeting AICc criteria	3
Statistically significant models meeting omission rate and AICc criteria	3

APPENDIX 2.6: DETAIL OF THE VARIABLES IN EACH OF THE 6 SETS USED FOR MODELS CALIBRATION

Models	Variables & Combinations
Set 1	Bio1, Bio2, Bio3, Bio4, Bio7, Bio12, Bio14, Bio15
Set 2	Bio1, Bio2, Bio3, Bio4, Bio7, Bio12, Bio14, Bio15, POP
Set 3	PC1, PC2, PC3, PC4, PC5
Set 4	PC1, PC2, PC3, PC4, PC5, PC6
Set 5	PC1, PC2, PC3, PC4, PC5, POP
Set 6	PC1, PC2, PC3, PC4, PC5, PC6, POP

APPENDIX 2.7: SNOW LEOPARD SUITABLE HABITAT AREA (KM^2) PREDICTIONS

Area	Classification	Current (km^2)	2070 (km^2)	
			RCP 4.5	RCP 8.5
M1 (Including China)	Unsuitable	793,690	762,329 (-3.9%)	734,102 (-7.5%)
	Moderately suitable	143,771	164,471 (14%)	176,123 (22.5%)
	Highly suitable	95,552	106,212 (11%)	122,787 (28%)
	Sum	1,033,013	1,033,012 (-0.0)	1,033,012 (-0.0)
M2 (Excluding China)	Unsuitable	88,416	140,371 (58.7%)	143,718 (62.5%)
	Moderately suitable	117,740	78,517 (-33%)	77,437 (-34%)
	Highly suitable	121,299	106,212 (-12%)	100,563 (-17%)
	Sum	327,455	325,100 (-0.7)	321,718 (-1.7%)

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

CHAPTER 3

Analysis of Provisioning Ecosystem Services and Perceptions of Climate Change for Indigenous Communities in the Western Himalayan Gurez Valley, Pakistan

3 ANALYSIS OF PROVISIONING ECOSYSTEM SERVICES AND PERCEPTIONS OF CLIMATE CHANGE FOR INDIGENOUS COMMUNITIES IN THE WESTERN HIMALAYAN GUREZ VALLEY, PAKISTAN

ABSTRACT

The inhabitants of mountainous regions are at significant risk due to climate change. It is crucial to comprehend how ecosystem services (ES) support these communities presently and how climate change will impact these services to formulate suitable adaptation strategies. The Gurez Valley in the Western Himalayas of Pakistan offers a unique chance to investigate these issues since this underexplored area is increasingly vulnerable to global climate change and the overuse of resources. The objective of this research was to (a) recognize and evaluate the provisioning ES in the region, (b) determine the reliance of native communities on ES by assessment, and (c) assess the perceptions of these communities regarding the effect of climate change on the ES in the Gurez Valley. Semi-structured interviews and focus group discussions were employed to classify the provisioning ES, using the CICES table (Common International Classification on Ecosystem Services) and the 'Total Economic Valuation (TEV)' Framework. The outcomes revealed that the native communities heavily depend on the ES, valued at 6,730 ± 520 USD/HH/yr and perceive climate change as a substantial threat to water, crop, and livestock rearing ES in the Valley. The total economic value of the provisioning ES is 3.1 times higher than the average income of a household. For some households, medicinal plant collection is a significant source of income, worth 766 ± 134.8 USD/HH/yr. The sustainable use of ES and adaptation and climate change mitigation are culturally, economically, and ecologically significant for the Western Himalayans.

Keywords: Climate change, economic valuation, provisioning ecosystem services, focus group, interview, Gurez Valley, Western Himalayas.

3.1 INTRODUCTION

Mountains cover 22% of the global land surface but harbour more than 85% of the world's amphibian, bird, and mammal species (Rahbek et al., 2019). They are among the most endangered habitats ecosystems on earth, being exposed and prone to the effects of climate change (FAO, 2015a). Research has shown increased warming rates in the world's mountains (Wester et al., 2019). This climate exposure is affecting biodiversity, endemic species, and human populations. Of the approximately 13% of the global population that lives in montane ecosystems, about 90% live in the Global South, of which half live in the Asia-Pacific and one-third in China (Huddleston et al., 2003; Macchi, 2010; FAO, 2015b).

According to Xu et al. (2019), the Hindu Kush Himalayan (HKH) region is an epicentre of varied life forms, harbouring over 35,000 plant species and more than 200 animal species, including the endangered snow leopard. Additionally, this region is a water source for approximately 1.9 billion individuals. The changing climate strains mountain people there, many of whom are poor and are now exposed to additional survival threats and potential inequities (Gentle & Maraseni, 2012). Ecosystem services (ES) are the benefits humans obtain from ecosystems (Millennium Ecosystem Assessment, 2005) and include provisioning (e.g., goods that can be consumed, such as timber and minerals) and non-provisioning ES (e.g., goods or processes that are not directly consumed or can be enjoyed in situ such as carbon sequestration, soil formation, recreation, and spiritual enrichment; Maitane et al., 2018).

Mountain ES provide significant economic value, including water, crops, animal products, timber and non-timber forest products, and tourism (Egan & Price, 2016). For example, the Himalaya, Karakoram, and Hindu Kush Mountain ranges are home to about 25,000 plant species, of which around 10,000 are of medicinal value (Pei, 1992). In the Western Himalayas of Pakistan, it is estimated that, out of the total 675 wild edible plant species, 171 species are used to cure diseases (Arora & Nayar, 1984). In the Trans-Himalayas in the Spiti Valley, local communities highly depend upon ES, such as animal dung and wild plants, as fertilizer and fodder for their livestock (Murali et al., 2017b). High dependence on fodder and grass in the Pyuthan District, Nepal (Arun, 2004) has also been documented.

Climate change is threatening the ES of this region. In recent decades, the HKH has seen substantial warming, approximately equivalent to the world average (Krishnan et al., 2019), resulting in glacial retreat, impacts on biodiversity and plant phenology, and losses of ES, including decreases in water availability and agricultural productivity (Pritchard, 2017; Bhatta et al., 2020). Even if global warming is limited to 1.5°C, warming in the HKH region would most likely be at least 0.3°C higher and 0.7°C higher in the north-west Himalaya and Karakoram due to their high altitude and latitude (IPCC, 2021). In addition to climate change, the secluded valleys of the Western Himalayas in Pakistan have been under increasing pressure in recent decades because of population growth, resulting in the increased harvesting of non-timber products (Awan et al., 2021).

Pastoral and agro-pastoral communities live across the range in Asia's high mountains and rely on the ES for their ways of life and subsistence (Murali et al., 2017a). For example, previous studies found that the economic benefits derived from the ES in the high-elevation Qurumbar National Park, Pakistan, contributed to 5955 USD/HH/yr (Din et al., 2020), in Tost 150,100 ± 13,290 USD/HH/yr, in Spiti Valley, India 3622 ± 149 USD per household per year (Murali et al., 2017b), in Changtang 79303 ± 9204 USD/HH/yr, and in Sarychat 25,544 ± 5236 USD/HH/yr (Murali et al., 2020).

In this paper, we aimed to (a) identify and value provisioning ES in the region, (b) delineate indigenous communities' reliance on ES, and (c) estimate whether climate change is already impacting the values of ES in the Gurez Valley in the Western Himalayas. This study is the first attempt to quantify indigenous communities' dependence on provisioning ES in the Gurez Valley and compare the values with studies conducted by Murali et al., 2017a in similar landscapes (Spiti Valley in the Indian Trans-Himalayas, Tost Nature Reserve in Mongolia, Changtang region in Ladakh, and Sarychat region in Kyrgyzstan). The comparison reveals the significant impact of climate change on the provisioning values of ES.

3.2 MATERIALS AND METHODS

3.2.1 Conceptual Steps

To explore the above study objectives, we first conducted interviews at the household level through questionnaires after selecting six communities with a sample size of 10% from each community (Figure 3.1). The questionnaire was developed based on the IFRI field manual, forming the basis of the focus group discussion questions followed by the detailed household interview questions. One focus group discussion was conducted in each community to compile the list of ES. To value the ES described in these discussions, we relied on the 'Common International Classification on Ecosystem Services' (CICES) and the 'Total Economic Valuation' (TEV) framework, suggested by 'The Economics of Ecosystems & Biodiversity' (TEEB). ES valuation was done through the 'market price-based approach' and the 'replacement cost method' (Wyatt, 2009). The total economic value was calculated by adding each ES's means and standard errors. The ES that are perceived by local community members to be impacted by climate change in the Gurez Valley. We compared these valuations across local and regional contexts.

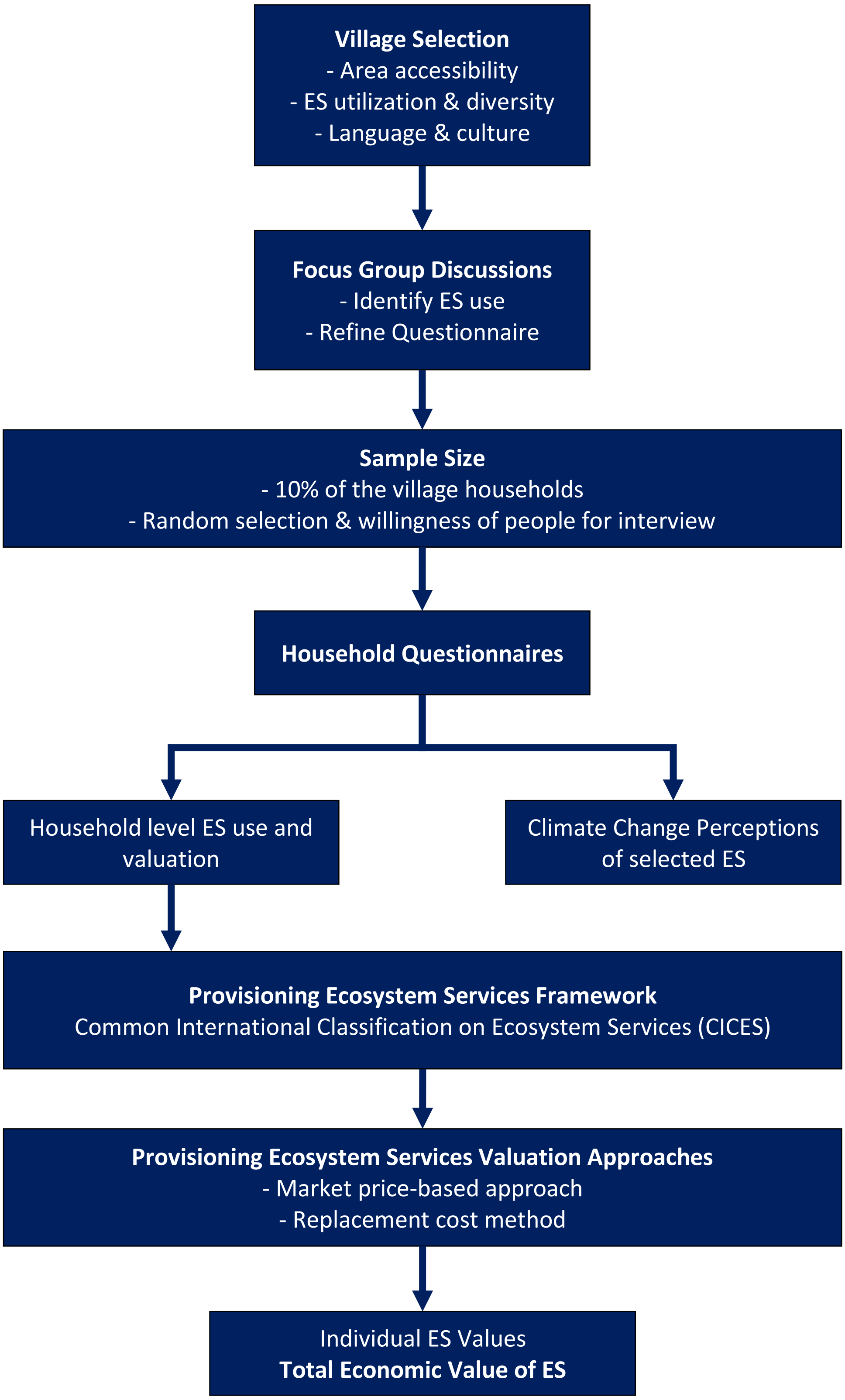


Figure 3.1: Conceptual Steps Adopted to Value ES and Taking Perceptions of Climate Change in Gurez Valley

3.2.2 Study Area

Pakistan’s northern areas (35-37°N and 72-75° E) are characterized by glaciated crests, shallow valleys, gullies, hills, and rugged peaks (Bischof et al., 2014). They fall in the water catchment areas of the mountains of Karakoram, the Himalayas, and the Hindu Kush. The Gurez Valley (34°41' 34°58' N and 74°32' 74°53'E; 2000-6000 masl; 528.15km^2) is situated in the Himalayan orogenic belt in northern Kashmir and southern Gilgit-Baltistan and falls under the Global Snow Leopard Ecosystem Program's (43° to 36°45' N and 74° to 75° E) priority landscape in Pakistan (Figure 3.2). This area is characterized by harsh environmental conditions and restricted agricultural suitability; hence, pastoralism is the most common livelihood strategy. The vegetation areas comprise coniferous woodland, scrub, and the alpine desert. The average rainfall is about 200mm below 3000 m elevation and around 2000mm below 6000 m elevation. The temperature varies from 45°C to -4°C in lower elevations, whereas in higher elevations, it is -20°C.

The Gurez Valley was declared a National Park on 24 September 2007, with a total area of 528 km^2 (Qureshi et al., 2013). Unregulated grazing, not on an annual rotational basis, and the removal of dry fuel wood collection and not on an area assessment basis have been reported as primary management issues in the Valley (Ahmed & Mahmood, 1998). The Valley consists of 18 villages with a population of 25,388 individuals (Snow Leopard Foundation - Pakistan, unpublished data, 2019), mainly dependent on subsistence farming and livestock for livelihood as other low-productivity ecosystems (FAO, 2010). Due to the harsh ground conditions, most of the households in these villages are confined for easy access to farms, grazing areas, and forest resources in and adjacent areas of MDNP in Gurez Valley. Most people in the Valley are resident agro-pastoralists. Plate 3.1 shows Gurez Valley in Western Himalayan, Pakistan, in 2017.

Plate 3.1: A Photo of Gurez Valley in Western Himalayan Pakistan taken in June 2017

The crops include maize, wheat, barley, millet, fruit, nuts, and potatoes. Sheep, goats, donkeys, cattle, and horses are kept as livestock. Water is brought to agricultural fields by irrigation canals (at times 20 km long). Other sources of revenue are gathering medicinal plants, fungi, wood harvesting, and, sometimes, hunting wild animals from the woods at lower altitudes.

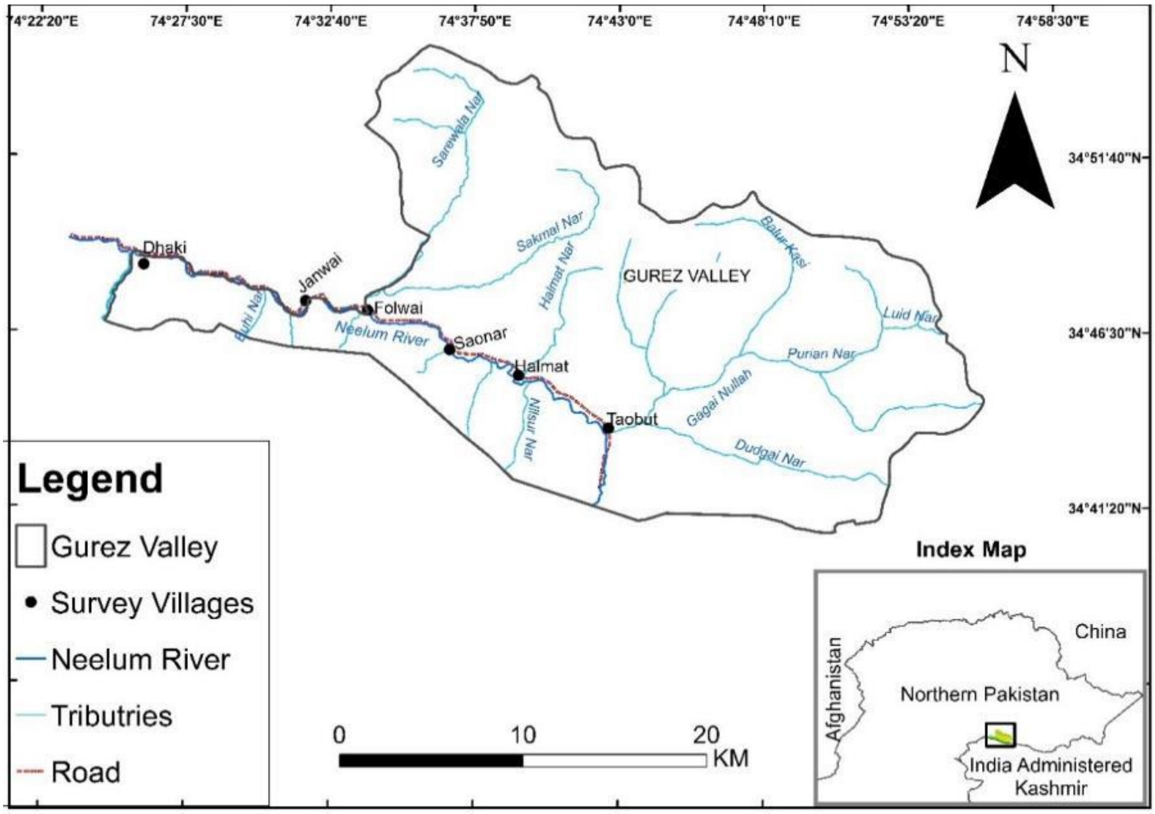


Figure 3.2: Map of Gurez Valley, Showing 6 Survey Villages

3.2.3 Data Collection

Community Description and Selection

A total of six communities were selected on account of accessibility in the Valley and people's willingness to participate in interviews (Figure 3.2). Prior conversations with our local representative team members were held to guarantee an accurate depiction of ES use, such as crops cultivated, animals reared, and the type and amount of natural resource harvestings, such as medicinal plants, forage, and fuelwood. Data were collected at the household level for a 10% sample size of each community to provide a complete picture of ES usage and perceptions of climate change in the Gurez Valley. All fieldwork was carried out in June 2017.

Generally, the inhabitants of these communities conduct subsistence agriculture by cultivating maize, beans, and potatoes in locally known fields such as Makki, Alo, and Lobia. For example, only one crop is grown biannually, while the agriculture fields remain snow-covered for the rest of the year. In addition, the inhabitants collect grass, fuelwood, and medicinal plants from the communal and forest land near their villages. The crops are grown mainly for household use, but some individuals sell surplus production for income. The agricultural fields surround the settlements and the border of the forest. In addition, the community uses a lot of the nearby forest land as pasture for their animals.

To obtain primary data for the subject study, 172 interviews were conducted, including six focus group discussions. The number of interviews in each selected community included households from Dhakki (n = 18), Janwai (n = 13), Followi (n = 59), Saonar (n = 18), Halmat (n = 45), and Taobut (n = 19). In the sampled communities, the male-to-female ratio was 49 to 51%. The average household size was 7.91 people. The interviewees were adults above the age of 18 years and included both men and women at the household level. The survey and participatory rural appraisal were used to gather information about the social structure, livestock, agriculture, and use of wood for fuel and building purposes. We also reported the views of community people on climate change and its consequences for ES, including impacts on crop cultivation, livestock production, and water availability.

Focus Group Discussion Procedure

The focus group discussion procedure was adopted to determine the ES harnessed by local people at the household level in the Gurez Valley. One discussion was conducted in each of the six communities. Following an explanation of the study's topic and objective, participants were asked to mention the ES in the Gurez Valley. The questions and responses were conducted verbally, with facilitators using local vernacular to the extent feasible to ensure that participants understood what was being said. Each focus group discussion lasted no more than two hours and was moderated by a member of the study team, who were all local and fluent in the local language. The group facilitator ensured that all participants contributed to the discussion to support the group's perspective (Van Oort et al., 2015). The discussions were noted in the questionnaire and the team members' notebooks for later analysis. We started by talking to various key informants to understand better how ES is used. We inquired about the number and quantity of agricultural products, subsistence crops harvested, livestock owned (age and gender categorization), water utilized, fodder, fuelwood, wild animal and plant products, and manure collected from the pastures (Appendix 3.1). The focus group discussions were centred on compiling the list of ES for each of the 06 communities. Plate 3.2 shows Local Communities' Interviews Held in the Western Himalayan Gurez Valley in Pakistan in 2017.

Plate 3.2: A Photo of Local Communities' Interviews Held in the Western Himalayan Gurez Valley in Pakistan in June 2017

Questionnaire

A questionnaire, forming the basis for focus group discussion, was developed following the guidelines provided by the modified version of the "International Forestry Resources and Institutions" (IFRI) field manual to obtain information at the household level (Wertime et al., 2011). The IFRI questionnaire has been extensively used to understand the human use of shared pool resources in forest systems (Epstein, 2017). The specific questions asked to each household related to the ES obtained through the crop's cultivation in 6 communities are shown in Table 3.1.

We also collected information on the perceived impacts of climate change on provisioning ES by asking them if climate change had been impacting the ES, such as crop cultivation, livestock rearing, and water availability. Table 3.1 provides interview questions about how people think climate change will affect them.

3.2.4 ES Identification and Economic Valuation

The interview responses were recorded and compared against each provisioning ES typology for the economic valuation. These were assigned codes and allocated to the groups of provisioning ES built upon the CICES (Common International Classification of Ecosystem Services) table (Haines-Young & Potschin, 2010).

Table 3.1: Details on the Focus Group Discussion and Specific Interview Questions

Focus Group Discussion Questions	
(i)	What are the benefits provided by nature in the valley
(ii)	What crops are grown in the village, which are sold, and how much is one kg of a particular crop sold for?
(iii)	Are any wild plants or animal products collected for agriculture to either fertilize or level the land?
(iv)	How is the water brought from the pastures for agriculture and shared in the village?
(v)	What is used for fertilizer, and how much fertilizer is needed for one acre of land in a year?
(vi)	How are the different livestock herded in the village? When are they taken to the pastures? How are they fed during the winter months?
(vii)	Is the forage collected and names of the plants that are collected?
(viii)	What is livestock used for, and what are the prices per kg and liter of meat, fodder, livestock feed, and milk, respectively?
(ix)	What are the rates for selling the livestock with respective age/sex?
(x)	Are any wild plants or animal products collected and sold from pasture? (xi) What is the price of firewood if bought from the market?
General Interview Questions	
(i)	What are the crops that they grow?
(ii)	How much land do they own?
(iii)	How much land do they cultivate?
(iv)	How much of crops did they harvest and sell last year?
(v)	Do they hire labour in farm?
(vi)	If so, how many and for how many days in a year, and at what rate?
(vii)	Do they buy any fertilizers or pesticides?
(viii)	If so, how much do they spend on these?
(ix)	How much local fertilizer do you use?
(x)	How do they plough land?

(xi)	What is the rate/hour if they use a tractor, and how many hours do they use it for?
Specific questions – ES obtained through livestock rearing	
(i)	What are the livestock that they own?
(ii)	what is the age/sex composition?
(iii)	What is the livestock used for?
(iv)	How much milk do they get per day?
(v)	How much meat did they sell last year?
(vi)	Do they use livestock to plough land?
(vii)	If so, which one, and for how long?
(viii)	Do they buy any animal feed or fodder for your livestock?
(ix)	If so, how much do they spend on it?
Specific questions – ES obtained through pasture use	
(i)	How much wild plants, wood, and dung do they collect?
(ii)	How much time do they spend collecting these services?
(iii)	How much water does their household consume in a day?
(iv)	Where do they get water from?
(v)	Do they pay for water?
(vi)	If so, how much do they pay per month?
(vii)	Do they collect any medicinal plants from the pastures?
(viii)	What do they use it for?
(ix)	How much do they collect in a year?
Questions on climate change perceptions	
(i)	Have you experienced any changes in climate in the last five years?
(ii)	If you have noticed changes in climate, how have they impacted your crops?
(iii)	If you have noticed changes in climate, how have they impacted your Livestock?
(iv)	If you have noticed changes in climate, how have they impacted your access to/sources of water availability?

The 'Total Economic Valuation Framework' (TEV) suggested by The Economics of Ecosystems & Biodiversity (TEEB) was used for calculating the economic value of provisioning ES (Kumar and Martinez Alier., 2011). The TEV framework is a well-organized method to delineate all the benefits that an ecosystem provides. The TEV framework is a well-known tool for economic valuations of ES because it represents value in economic or other market-based units that can be compared across ES types (Pomfret, 2014; Table 3.2). Using this framework, the provisioning ES is evaluated by employing direct and indirect use values humans use. We used market price-based and replacement cost methods to determine ES values. This framework has been used by earlier studies as well, those that were conducted by Murali et al. (2017a), Murali et al. (2017b), and Murali et al. (2020) in similar mountainous and arid environments. Furthermore, we also wanted to verify if the earlier studies' findings validated our study's results.

ES Valuation Based on Market Price

The market price-based method is used to assess the value of provisioning ES. Since provisioning ES is often sold, market prices are considered to provide reliable information on value (Pomfret, 2014). Therefore, this strategy was adopted for the ES with a market price in the Gurez Valley. Table 3.2 details the economic valuation method (Kumar & Yashiro, 2014) for each ES considered in this study.

ES Valuation Using the Replacement Cost Method

The cost of replacing ES with artificial technologies is estimated using the replacement cost approach. This strategy was utilized in Gurez Valley to replace ES, which lacked a market price and might be replaced by similar materials available for purchase. The prices chosen were those found on the local market. Table 3.2 details the economic valuation method (Kumar & Yashiro, 2014) for each ES considered in this study.

The economic values of the ES were calculated using the replacement cost method for the following CICES classes: (i) "surface water for drinking" (e.g., for household purposes), (ii) "materials from plants, algae, and animals for agricultural use" (e.g., fodder for livestock), (iii) "surface water for non-drinking purposes" (e.g., for livestock consumption), and (v) "animal-based energy" (e.g., physical labour by ox to plough land, and donkey and horse to transport materials). The local values used to calculate each ES in the Gurez Valley, and the formulae used to get the economic value of an ES under this approach are provided in Appendix 3.2 and 3.3.

Table 3.2: Methods used and Units of Measurement for Estimating the Economic Value of Provisioning ES in Gurez Valley

Sr. #	CICES ES Class	Provisioning ES	Economic Valuation Method	Unit Price
1	Cultivated crops	Beans & Potatoes	Market price-based approach	Kg/HH/yr
2	Reared animals and their outputs	Milk	Market price-based approach	L/HH/yr
		Meat	Market price-based approach	Animals/HH/yr
3	Surface water for drinking	Water for drinking	Replacement cost method	L/HH/yr
4	Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	Market price-based approach	Kg/HH/yr
5	Materials from plants, algae, and animals for agricultural use	Fodder for livestock	Replacement cost method	Kg/HH/yr
6	Surface water for non-drinking purposes	Water for livestock consumption	Replacement cost method	L/HH/yr
7	Plant-based resources	Fuelwood	Market price-based approach	Kg/HH/yr
8	Animal-based energy	Ox to plough land, donkey & horse to transport materials	Market price-based approach	Animals/HH/yr

The economic values of the ES were analyzed as per the market price-based method under CICES classes for the following categories: (i) "cultivated crops" (e.g., beans and potatoes), (ii) "livestock and their outputs" (e.g., milk and meat), (iii) "fibres and other materials from plants, algae, and animals for direct use or processing" (e.g., medicinal plants) and (iv) "plant-based resources" (e.g., fuelwood). Detail on the local market prices used to value these ES, and on the formulae used to get the economic value of each ES is given in Appendix 3.2 and 3.3.

The economic value of crops was analyzed by determining the total amount of crops gathered yearly and multiplying it by the market value. The value of all the external inputs, such as chemical fertilizers and the labour employed, tractor and ox physical labour costs were subtracted from the harvested crops value to get the ES value of the crop yield. The economic value of milk was estimated by multiplying the market value per liter by the number of liters per household daily consumption multiplied by the total number of days per year. The economic value of meat was estimated by multiplying the market price of an animal per household by the number of animals sold annually. Medicinal plant value was calculated using the annual collection of medicinal plants per household, multiplied by the local market prices. Finally, the economic value of the fuelwood was estimated by multiplying the annual per-household consumption of the fuelwood with its local price.

The value of water for daily household consumption was calculated by multiplying the known water volume by the number of people in the house and the price of water. The local price of water was the labour charges used to bring water from the natural streams to the households. Stream water is the primary water source for Gurez communities and is free of charge. The value of water for livestock consumption was determined by multiplying the annual collection of water for the livestock with the local water price (Ward, 2007). The economic value of the fodder for livestock was estimated primarily for the different livestock species individually. The amounts of fodder consumed were multiplied by the local price of fodder annually and then added up to get the value of fodder for livestock in the Valley. Animal-based energy was estimated for donkeys and horses transporting materials from the pastures to the settlement areas. The annual household cost was determined by multiplying the days by the local animal labour rates. The cost of ox physical labour to plough land was not considered under this category to avoid double counting because the ox physical labour to plough land was considered as external input under the crop ES economic valuation.

3.2.5 Total Economic Value

The overall economic benefit was determined by assigning each household the economic value for each provisioning ES by adding the means and standard errors for each service (Lindberg, 2000). First, the respondents calculated household earning values for all their various sources of income (Cavendish, 2002), such as employment, agricultural produce, livestock products sold, and medicinal plants, and then added them to determine the Gurez Valley's average income.

3.2.6 Climate Change Perceptions

The qualitative information gathered through the interviews on the perceived impacts of climate change on ES, such as water, crop cultivation, and livestock rearing, were analyzed as the percentage responses for the entire sample.

3.3 RESULTS

3.3.1 Provisioning ES

The provisioning ES (Table 3.3) identified by the indigenous communities represented 8 of the 16 CICES classes (Haines-Young & Potschin, 2010). The most frequently used ES were 'cultivated crops' (used by 100% of the respondents), 'surface water for drinking' (used by 100% of the respondents), 'materials from plants, algae, and animals for agricultural use,' i.e., 'fodder for livestock' (used by 100% of the respondents), 'surface water for non-drinking, i.e., water for livestock consumption (used by 100% of the respondents), and 'plant-based resources', i.e., fuelwood (used by 100% of the respondents) in the Gurez Valley.

The other services used were 'reared animals and their outputs', e.g., milk and meat (97.7%), 'fibres and other materials from plants, algae and animals for direct use or processing', such as medicinal plants (33.7%), and 'animal-based energy', such as ox labour to plough land and donkey and horse labour to transport materials (17.4%). Plate 3.3 shows livestock rearing as an ES in the Gurez Valley, whereas Plate 3.4 shows surface water for drinking and non-drinking purposes as an ES in Gurez Valley. Table 3.4 lists the identified provisioning ES used by Gurez Valley communities, indicating the percentage of respondents using these services. The Dhaki community used the most ES (82%) on average, followed by the Folowai and Taobat communities (78% each), the Saonar community (76%), the Halmat community (74%), and the Janawai community (69%). Figure 3.3 details each ES percentage used by the selected communities in the Gurez Valley.

Table 3.3: List of Provisioning ES from Gurez Valley (Services are Coded Based on the CICES Classification System)

CICES Section	CICES Division	CICES Group	CICES Class	Class Type	Provisioning ES Identified	% Responses
Provisioning Services	Nutrition	Biomass	Cultivated crops	Crops by amount, type	Maize, potato, beans, green pea, spinach, karam, turumba, shunny (valuation done for beans and potatoes only)	100
			Reared animals and their outputs	Animals, products by amount, type	Horse, cow, goat, sheep, and donkey. Cow used for milk and meat, goat and sheep used for meat, horses and donkeys used for transport. (Valuation done for milk and meat only)	97.7
		Water	Surface water for drinking	By amount, type	Water for household purpose	100
	Materials	Biomass	Fibers and other materials from plants, algae and animals for direct use or processing	Materials by amount type, use, media, (land, soil, freshwater, marine)	Medicinal plants	33.7
			Materials from plants, algae and animals for		Fodder for livestock	100

CICES Section	CICES Division	CICES Group	CICES Class	Class Type	Provisioning ES Identified	% Responses
			agricultural use			
		Water	Surface water for non-drinking purposes	By amount, type and use	Water for livestock consumption	100
	Energy	Biomass based energy resource	Plant-based resources	By amount, type, source	Fuelwood	100
		Mechanical energy	Animal-based energy		Ox to plough land, donkey & horse to transport materials	17.4

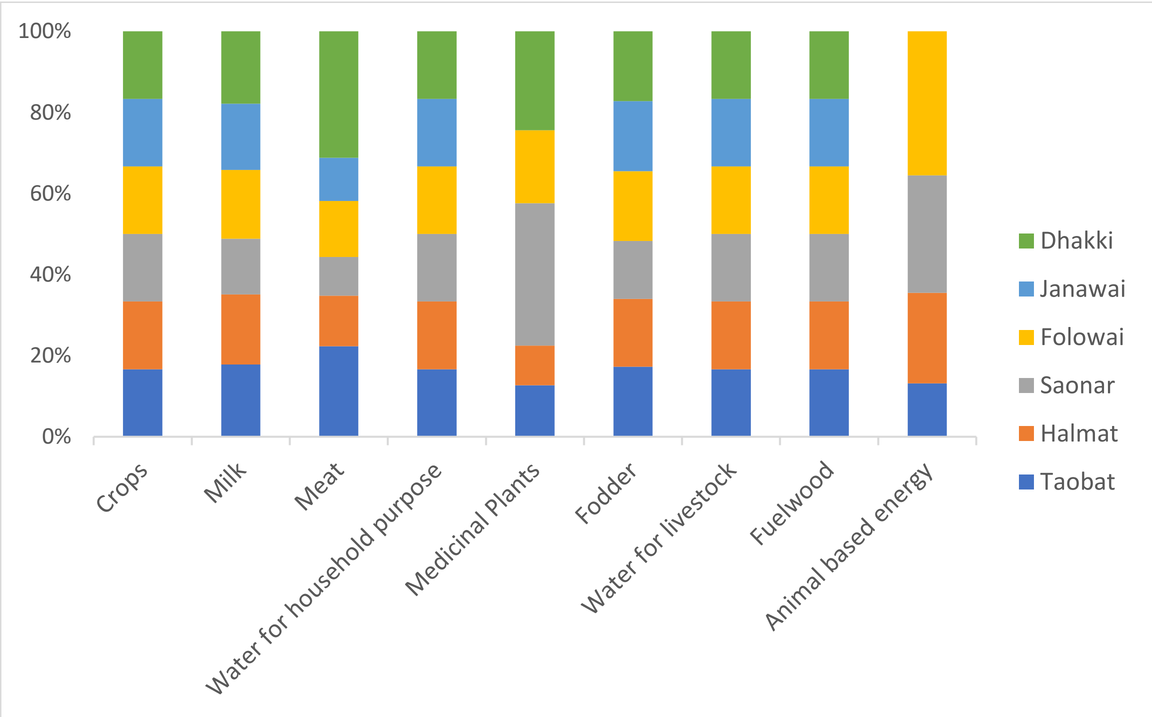


Figure 3.3: ES Percentage Use by Selected Villages in Gurez Valley

Plate 3.3: Livestock Rearing is an ES in Pakistan's Western Himalayan Gurez Valley

Plate 3.4: The Surface Water for Drinking and Non-drinking Purposes is an ES in the Western Himalayan Gurez Valley, Pakistan

3.3.2 Economic Values

The most economically valued ES was ‘fodder for livestock’ 4105 ± 306 USD/HH/yr, contributing around 61% of the total economic importance of ES supply. This was followed by ‘horse & donkey physical labour to transport materials’ 1166 ± 111 USD/HH/yr, ‘fuelwood’ 1044 ± 26.7 USD/HH/yr, ‘medicinal plants’ 766 ± 134.8 USD/HH/yr, and milk and meat all together 707 ± 44.6 USD/HH/yr (where milk = 609 ± 34.6 USD/HH/yr and meat = 98 ± 10 USD/HH/yr). The economic value of ‘crops’ was 65.8 ± 6.5 USD/HH/yr, water for non-drinking uses was 18.5 ± 0.5 USD/HH/yr, and water for drinking purposes was 11.4 USD/HH/yr. Water was the least economically valued service (Table 3.4).

In the Gurez Valley, people's livelihood depended on local provisioning ES such as "cultivated crops, " "reared animals and their outputs, " and "medicinal plants, " whereas the other sources included employment. Plate 3.5 shows the crops grown in Gurez Valley as an ES. The gross economic value of identified provisioning services amounted to 6730 ± 520 USD/HH/yr (Table 3.4). However, the economic values did not capture the dependency on local ES alone. The approximate economic support of the provisioning ES of 6,730 ± 520 USD/HH/yr was 3.1 times the annual household income in the Gurez Valley. Therefore, the 22.8% share of the total economic value of ES directly contributed to the household income worth 1538 USD/HH/yr (the economic support sought from the ES such as cultivated crops, livestock rearing and their outputs, and the medicinal plants). In contrast, the remaining 77.1% share contributed to the costs worth 6345 USD/HH/yr.

Plate 3.5: The Crops Grown are an ES in the Western Himalayan Gurez Valley, Pakistan

Table 3.4: Economic Values of the Provisioning Ecosystem Services (ES) in Gurez Valley, Pakistan

(1 USD = 103 PKR in 2017)

CICES Class of ES	ES	Mean ± SE (USD /HH /yr)	Proportion of Respondents Using ES (%)	Proportion of Total Value of ES (%)
Cultivated crops	Crops	65.8 ± 6.5	100	1
Reared animals and their outputs	Milk	609 ± 34.6	94.7	9
Reared animals and their outputs	Meat	98 ± 10	44.7	1.5
Surface water for drinking	Water for household purpose	11.4	100	0.2
Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	766 ± 134.8	33.7	11.4
Materials from plants, algae and animals for agricultural use	Fodder for livestock	4105 ± 306	100	61
Surface water for non-drinking purposes	Water for livestock consumption	18.5 ± 0.5	100	0.3
Plant-based resources	Fuelwood	1044 ± 26.7	100	15.5
Animal-based energy	Donkey & horse physical labour to transport materials	13 ± 1.7	17.4	0.2
Total Economic Value		**6730 ± 520**		

3.3.3 Climate Change Perceptions

In the Gurez Valley, 90.7% of respondents reported a changing climate. 98.8% out of the total respondents mentioned that climate change had a more significant impact on 'water' ES (because of the reduction in quantity and quality of spring water). 95.8% of respondents stated that the climate negatively impacted the' fodder' ES. 88.5% of respondents revealed negative impacts of climate change on crop yield due to unpredictable climatic hazards such as floods, thunderstorms, irregular rain patterns, and hot weather events in the Valley. Table 3.5 outlines the perceived impacts of climate change on ES in the Gurez Valley.

The other perceived impacts mentioned by respondents have increased crop disease and pest attacks, livestock being more vulnerable to disease, and reduced water availability. Only a tiny fraction of respondents believed that the increased crop production was due to the increased precipitation and the change in weather conditions.

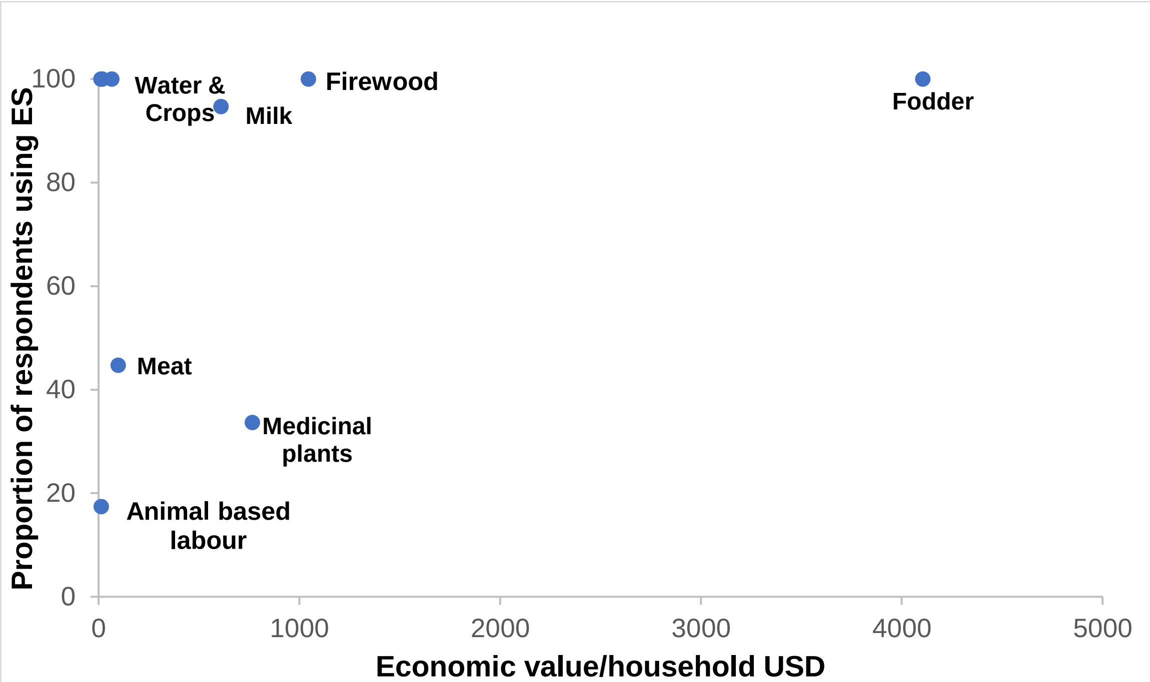


Figure 3.4: Economic Value of the Provisioning Ecosystem Services and the Proportion of Respondents using Them.

Table 3.5: Perceived Impacts of Climate Change on Provisioning Ecosystem Services (ES) by the Local Communities in Gurez Valley, Pakistan

ES	Perceived Impact of Climate Change	Nature of Impact	% Responses
Crop production	Negative	Reduction in crop yield due to flash flooding, thunderstorms, irregular rain, and hot weather	88.5
	Negative	Increase in crop disease and pests	9.3
	Positive	Increase in crop production due to more precipitation	3.2
Livestock	Negative	Decrease in milk production due to decreased fodder	95.8
	Negative	Disease in livestock	4.2
Water	Negative	Reduction in quantity and quality of spring water	98.8
	Negative	Decrease in the water table	2.1

3.3.4 Medicinal Plants

We are providing extra details on medicinal plants as an ES because they are highly valued and an essential source of income in the Gurez Valley. *Morchella esculenta* (price/kg = 155 USD) was the most valued medicinal fungus species, followed by *Aconitum heterophyllum* (price/kg = 68 USD), *Acacia senegal* (price/kg = 29 USD), *Picrorhiza kurroo* (price/kg = 15 USD), *Saussurea lappa* (price/kg = 10 USD), *Valeriana jatamansi* and *Viola biflora* (price/kg = 8 USD). *Berginea ciliate*, *Adiantum venustum*, and *Geranium willichianum* were not sold and had the most negligible economic value. The local communities collected these plants for the treatment of different ailments. Table 3.6 lists the medicinal plant species collected by the communities in the Gurez Valley, along with the percentage of collection, usage, and price annually.

Medicinal plants were collected in considerable amounts by communities in Gurez Valley. *Aconitum heterophyllum* was collected in the highest quantity (1,452 kg/yr), followed by *Acacia senegal* (523 kg/yr), *Picrorhiza kurroo* (424 kg/y), *Morchella esculenta* (23 kg/yr) and *Saussurea lappa* (8 kg/yr). These plants are sold in the nearby herbal markets for supplementary income. In addition, the communities utilize roots, rhizomes, leaves, flowers, and, in some cases, the whole medicinal plant to treat ailments. Ailments such as flu, cough, fever, stomach ulcers, headaches, and joint pain are treated with medicinal plants at the household level.

3.4 DISCUSSION

3.4.1 ES Identification

Our study revealed a range of provisioning ES identified and valued by Gurez Valley communities in the Western Himalayan part of Pakistan. The communities in this study revealed awareness and concern for provisioning ES, a similar pattern found in other studies in the arid mountain regions (Murali et al., 2017a; Murali et al., 2017b; Din et al., 2020). Nearly all the respondents used the provisioning ES belonging to CICES classes (Haines-Young & Potschin, 2010), such as the cultivated crops, reared animals and their outputs, surface water for drinking, fibres and other materials from plants, surface water for non-drinking purposes, plant-based resources, and animal-based energy. A slight difference was found among the respondents of Gurez Valley communities concerning the types of ES used, but rather the extent of use in terms of the proportion of people using ES and the quantity of ES used at the community level (see section 3.1). A similar trend has also been reported in the arid region of the Pamir Karakoram landscape in Pakistan for forage, fuelwood, and domestic water usage of about 90–94% (Din et al., 2020).

Table 3.6: Details on the Economic Values of the Collection of Medicinal Plants by Six Communities in Gurez Valley

(1 USD = 103 PKR in 2017)

	Medicinal Plant	Family	Local Name	Parts Used	Local Use	Quantity (kg)	Collection (%)	Price/ kg USD
Sold	*Acacia senegal*	*Fabaceae*	*Trapetra*	*Roots*	*Stomach Alcer*	523	16.3	29
	Aconitum heterophyllum	*Ranunculaceae*	*Patris/ Sarba vala*	*Rhizome*	*Cough & asthma*	1,452	32.5	68
Not sold	*Adiantum venustum*	*Liliaceae*	*Sumbal*	*Whole plant*	*Cough*	-	3.48	01
	Bergenia ciliate	*Apiaceae*	*Batbhyva*	*Root, flowers, and leaves*	*Coughs and colds, asthma*	-	3.48	-
	Geranium willichianum	*Geraniaceae*	*Rattan Jog*	*Rhizome /Roots*	*Backache, WeaknES*	-	0.58	-
Sold	*Morchella esculenta*	*Morchellaceae*	*Ghuchi*	*Plant*	*For energy and physical fitnES*	23	11.6	155
	Picrorhiza kurroo	*Scrophulariaceae*	*Kohr*	*Root*	*Asthma*	424	4.65	15
	Saussurea lappa	*Asteraceae*	*Kuth*	*Rhizome*	*Joint pain*	8	6.39	10
	Valeriana jatamansi	*Valerianaceae*	*Mushk bala*	*Rhizome*	*Cough*	0.3	1.74	08
	Viola biflora	*Pteridaceae*	*Thandi jaree, Banafhsha*	*Flower / leaves*	*Cold & flu*	0.3	1.74	08

The Himalayas are a valuable source of ES for local communities. However, a much higher contribution of provisioning ES was observed in this study. Many studies only measured the importance of non-timber forest products (NTFPs), although the other studies included only some provisioning services. Examples include a high reliance on non-timber forest product revenue, such as honey in South-West Ethiopia (Endalamaw, 2005), Cameroon (Ingram & Njikeu, 2011), and Mwinilunga in North-West Zambia (personal communication, Dan Ball, October 2014). Likewise, Tanzanian beekeeping revenues have been estimated to be approximately USD 2.5 million in annual exports (Mwakalukwa, 2016). In Sudan, gum-arabic exports produced revenue of about USD100m (10% of overall exports) and USD153,000 for gum-luban alone (CBOS, 2006 and CBOS, 2007). In Pyuthan District, Nepal, NTFPs have a more excellent value than wood (Arun, 2004), while wild plants in South Africa generate income of around 1,200 USD/HH/yr (Shackleton et al., 2011). This survey attempted to quantify nearly all the provisioning ES identified by the respondents, and this may reflect the higher values in our study.

3.4.2 ES Total Economic Value

The total economic value of the provisioning ES in the Gurez Valley (6730 USD/HH/yr) was significantly higher than the economic benefits obtained in Pakistan's high-elevation Qurumbar National Park (5955 USD/HH/yr, Din et al., 2020) and India's Spiti Valley (3622 149 USD/HH/yr, Murali et al., 2017a). This value was ES when compared with the arid regions of Khunjerab National Park in Pakistan (8912 USD/HH/yr; Din et al., (2020); the Changtang livestock production system, India (79,303 ± 9204 USD/HH/yr); the Changtang crop production system, India, 15,083 ± 1656 USD/HH/yr; the Tost Nature Reserve, Mongolia (150,100 ± 13,290 USD/HH/yr); and Sarychat, India (25,544 ± 5236 USD/HH/yr; Murali et al., 2020).

3.4.3 Medicinal Plants Collection

.3Our results disclosed that most of the respondents in six communities in Gurez Valley collected medicinal plants (see Figure 3.3). About 70% of the Himalayan medicinal plants and animals are wild, and about 70%-80% of the population depends for their health needs on the indigenous medicines (Pie & Manadhar, 1987). The colossal amount of

Aconitum heterophyllum collected (1,452 kg/yr) in the Gurez Valley refers to its unsustainable harvesting. The overharvesting of medicinal plants, especially *Morchella esculenta* (morels or Black mushroom), has been reported to highly degrade the rangelands in the Western Himalayas (Awan et al., 2020). The average household annual collection of 3-5 kg dry weight of *Morchella esculenta* has been reported to be sold at 50,000-90,000 PKR/kg in the Western Himalayan Neelum Valley (Shaheen et al., 2017).

3.4.4 Livelihood Support Through ES

Our study shows that provisioning ES are integral to Gurez Valley's livelihoods. The total value of the provisioning ES was 3.1 times higher than the average household income in the Valley. This indicates that the people obtained a considerable part of their income by selling goods obtained through provisioning ES. This value was even higher in the case of Spiti Valley in the Indian Trans-Himalayas (3.6 X), in the Changtang region of the agro-pastoralists in India (3.7 X), for the nomadic pastoralists (26.1 X), in the Tost Nature Reserve, Mongolia (38.7 X), and in the Sarychat region, Kyrgyzstan (7.4 X; Murali et al., 2020).

Our results revealed that medicinal plants contributed significantly to the household incomes in the Valley (766 ± 134.8 USD/HH/yr, 11.4% of the total economic value). This contradicts the case Murali et al. (2020) mentioned in the arid regions, where medicinal plants were least economically valued. For example, in the Spiti Valley, medicinal plants are valued at only 3.4 ± 0.3 USD/HH/yr, with a total economic value share of 0.1%; in the Tost Nature Reserve, Mongolia, 6 ± 2 USD/HH/yr, 0% of the total economic value; in the Changtang region, India, ± 0 USD/HH/yr, 0% of the total economic value; for nomadic communities; and Sarychat region, Kyrgyzstan, 2.1 ± 0.6 USD/HH/yr, 0% of the total economic value. According to Din et al. (2020), the arid region of the Pamir-Karakoram landscape had lower economic values of medicinal plants. For example, the Qurumber National Park had an economic value of the medicinal plants of 06 USD/HH/yr with 0.03% of the total economic value. In contrast, the Khunjerab National Park had an economic value of the medicinal plants worth 10 USD/HH/yr, 0.1% of the total economic value.

3.4.5 ES Values Comparison in Similar Landscapes

Fodder for Livestock

According to our findings, the highest valued ES in the Gurez Valley was 'fodder for livestock,' accounting for more than 60% (4105 ± 306 USD/HH/yr) of the total economic value. Similar trends have been documented in the arid regions of the Indian Trans-Himalayan Spiti Valley (1960 ± 208 USD/HH/yr, 49.4% of the total economic value), Tost Nature Reserve, Mongolia (145,381 ± 13027 USD/HH/yr, 96.9% of the total economic value), Changtang region, India (75,025 ± 8848 USD/HH/yr, 94.6% of the total economic value in the livestock production system), and Sarychat region, Kyrgyzstan (24,073 ± 5115 USD/HH/yr, 94.5% of the total economic value, Murali et al., 2020). Similar results of the high economic value of fodder were also reported from the Qurumber National Park and Khunjerab National Park in the arid landscape of Pamir Karakoram in Pakistan (2436 USD/HH/yr, 59.6% of the total economic value and 1944 USD/HH/yr, 54.5% of the total economic value, respectively, Din et al., 2020).

Fuelwood

According to our findings, fuelwood was the second highest ES, accounting for 15.5% of the total economic value in the Valley after fodder for livestock, with a total economic value of 1044 ± 26.7 USD/HH/yr. This value exceeded the economic value of fuelwood estimated by Murali et al. (2020) in the arid regions of Indian Trans-Himalayan Spiti Valley (201 ± 17 USD/HH/yr, 5.1% of the total economic value), Tost Nature Reserve, Mongolia (206 ± 16 USD/HH/yr, 0.1% of the total economic value), Changtang region, India (900 ± 151 USD/HH/yr, 1.1% of the total economic value for nomadic communities), and Sarychat region, Kyrgyzstan (169 ± 25 USD/HH/yr, 0.7% of the total economic value). The arid region of the Pamir Karakoram had lower economic values of fuelwood, as estimated by Din et al. (2020). The fuelwood economic values were 432 USD/HH/yr, with 11.7% of the total economic value in Qurumber National Park, and 540 USD/HH/yr, with 9.9% of the total economic value, respectively). The fuelwood collection varies from Valley to Valley in the Western Himalayan landscape. At lower elevations, juniper, deodar, spruce, and pine forests are available, so locals depend on them for fuelwood, while at higher elevations, shrubs are used for this purpose. In some areas of the landscape, the annual needs of the communities exceed the cumulative annual increment of firewood (Snow Leopard Foundation-Pakistan, unpublished data, 2019).

Reared Animals and Their Products

This study indicates that people derive nutritional benefits from agricultural and livestock products such as milk and meat. The economic value of the CICES ES category 'reared animals and their outputs' was the fourth highest in the ES after the medicinal plants at 707 44.6 USD/HH/yr (milk = 609 ± 34.6 USD/HH/yr and meat = 98 ± 10 USD/HH/yr clubbed together). This value was lower in the arid region of Trans Himalayan Spiti Valley 523 46.2 USD/HH/yr, with a total economic value share of 13.2%; Tost Nature Reserve, Mongolia 3881 ± 360 USD/HH/yr, 2.6% of the total economic value; the Changtang region, India, 929 ± 67 USD/HH/yr, 6.2% of the TEV for nomadic communities; and the Sarychat region, Kyrgyzstan, 1182 ± 177 USD/HH/yr, 4.6% of total economic value. The economic value of cultivated crops was 65.8 ± 6.5 USD/HH/yr. Reared animals are an essential part of the cultural and religious aspects of the Muslim ethnic group in the Gurez Valley, which are bought and sold during the annual religious ceremonies.

Water

Water was the least valued ES in the Gurez Valley, with an economic value of 29.9 ± 0.5 USD/HH/yr (water for domestic usage was 11.4 USD/HH/yr, and water for livestock consumption was 18.5 ± 0.5 USD/HH/yr combined). A similar result has been documented in the other arid mountainous regions of the Indian Trans-Himalayan Spiti Valley (35 ± 4.3 USD/HH/yr, 0.9% of the total economic value), Tost Nature Reserve, Mongolia (533 ± 59.7 USD/HH/yr, 0.3% of the total economic value), Changtang region, India (41.5 ± 3.1 USD/HH/yr, 0.32% of the total economic value in the livestock production system), and Sarychat region, Kyrgyzstan (83.3 ± 11.9 USD/HH/yr, 0.35% of total economic value, Murali et al., 2020). The Qurumber National Park and Khunjerab National Park in the arid landscape of Pamir Karakoram in Pakistan had relatively higher water values (826 USD/HH/yr, 22.5% and 826 USD/HH/yr, 25.7% of the total economic value, respectively, Din et al., (2020). In the Gurez Valley, water is mainly obtained from nearby streams for household use and livestock consumption, free of charge.

3.4.6 Biodiversity Sustainability

Biodiversity helps the sustained provisioning of ES (Loreau et al., 2001), but the relationships between biodiversity and ES are yet to be understood (Balvadera et al., 2016; De Groot et al., 2016). Although the local communities are paying a cost to conserve the biodiversity in the Gurez Valley, the economic security these landscapes offer remains unmeasured. Ahmad et al. (2016) reported an annual economic loss of USD 28,145 (189 USD/HH) from the loss of 276 livestock by carnivores in the MDNP, in addition to the destruction of maize and potato crops by Asian black bears and brown bears, resulting in a loss of 16,330 USD/yr (110 USD/HH). Increased livestock depredation by big predators in the HKH highlands has been ascribed to increased livestock populations (Mishra, 1997). Compensation and environmental education have been recommended to support the coexistence of carnivores and humans in MDNP (Mishra et al., 2003).

3.4.7 Climate Change Perceptions

Climate change is increasing and significantly impacting natural resources such as pastures, agriculture areas, and water, particularly in arid mountain environments. The productivity of crops and seafood, droughts, and variable hydrological cycles have been reported to impact and endanger the sustainability of water (Nelson et al., 2013). A similar pattern of reported climate consequences has been reported from the Western Himalayan Naltar Valley and the Rakaposhi Valley in Gilgit-Baltistan, Pakistan (Bhatta et al., 2020; Azfar et al., 2019) and by the studies conducted in the Sarychat region, Kyrgyzstan and the Northeast of India and Bhutan as well (Tse-ring et al., 2010; Murali et al., 2017a).

In the Millennium Ecosystems Assessment, climate change has already been identified as a significant factor affecting biodiversity and related products and services (Lee, 2009; Samper, 2003). Most of the respondents in the Gurez Valley reported a change in climate with decreasing river water quality and quantity. Although the HKH has been designated as a climate change hotspot (Sharma et al., 2019), climate change impacts on ES and damage, such as water-induced catastrophes, are still not a key research subject. Several destructive floods caused by glacial lake outburst flooding have seriously harmed the Himalayan landscape and altered mountain communities' lifestyles. Thus, it is imperative to study future climate scenarios to provide insight into the types of agriculture that can be grown, lifestyles that can be adopted, and patterns of snowfall and rain to be expected in the landscape.

3.4.8 Policy Implications

The ES provided by the mountain ecosystem in the Gurez Valley is considered vital for local livelihoods and serves as a primary support to the economic security of Gurez Valley communities (Murali et al., 2017a). Most people in the mountainous and arid region of the Western Himalayas are agro-pastoralists and live in villages (88%), where they practice subsistence agriculture and pastoralism. This entitlement grants them traditional rights and concessions on nearby pastures and natural areas to meet their daily fuelwood, forage, and fodder needs (Awan et al., 2020). The population of the mountain regions of Pakistan is predicted to grow from 51.47 million people in 2017 to 72.64 million people by 2030 (Sharma et al., 2019). This scenario is a severe concern for the sustainable ES provision by the Western Himalayan landscape beyond its potential in general.

A bibliometric analysis of the ES research trends in the HKH region revealed only a few studies on ES in Pakistan (n = 10, 2%), which reflects the limited interest and investment in the ES discourse (Kandel et al., 2021; Martin-Lopez et al., 2019). Pakistan devised the 'National Forest Policy' (MoCC, 2017) and 'National Climate Change Policy' (MoCC, updated version, 2021), where no specific policy interventions acknowledge 'ecosystem services' and hence their implementation and governance. The lack of a sufficient regulatory and policy framework in economically developing nations is seen as a significant impediment to programs to ensure the long-term management of natural resources (FAO, 2015a). Moreover, in this region, the lack of official recognition of ES, especially by policymakers, can be seen as a significant barrier to the persistence of ES in this region, including foraging to maintain pastoral lifestyles.

The government of Azad Jammu and Kashmir devised a 'Climate Change Policy' (Climate Change Center, 2017). However, establishing an overarching framework for climate action is still the way to consider the local contexts, capacities, and vulnerabilities to be regulated and adopted by the indigenous communities. In the Gurez Valley, only 48%

of the households had viable occupation options as their primary source of income, putting the remaining households in the less privileged category and hence mainly reliant on the ES for survival. This study, as well as others on comparable themes (Gerlitz et al., 2014), has underlined the contagiousness of adaptation. Pakistan is the only one of the five South Asian states (Bangladesh, Bhutan, India, Nepal, and Pakistan) that has not seen a decline in the rate of poverty ever since the mid-1990s (Kumar & Yashiro, 2014). Vulnerability varies by social group, so the less privileged have fewer alternatives to cope with or adjust to changing circumstances. Therefore, the inherent reasons for vulnerability, such as poverty and social inequity, restricted income possibilities, and political and economic marginalization, must be addressed to improve mountain peoples' resistance to change.

3.4.9 Limitations of The Study

ES is an under-researched topic in Pakistan's mountains. In this study, we could only focus our analysis on the provisioning ES. When regulatory and cultural ES are factored in, the economic worth of ES in the Gurez Valley will likely increase substantially. Due to time and resource constraints, we could only sample 6 communities; nevertheless, sampling more communities might have provided a different picture of ES use and its economic value in the Valley. Future research on this topic could concentrate on regulatory and cultural ES and the trade-offs between the provisioning and regulating ES.

3.5 CONCLUSIONS

This study highlighted the Gurez Valley communities' considerable reliance on the ES offered by Asia's high mountain arid landscapes. Our study is the first to examine community views and identifications of ES in the Western Himalayas in Gurez Valley. It can serve as a model for future research in similar environments and ecosystems throughout Pakistan. This study, in which community members identified eight provisioning ES in the Gurez Valley, supports the idea that this and similar mountain areas promote community livelihoods and well-being through providing ES. Therefore, sustainable harvesting of the ES and official acknowledgment of ES in the regulatory systems by concerned policymaking institutions and authorities is needed.

Further, this study underscores the Gurez Valley communities' vulnerability to climate change as a natural and severe threat to their livelihoods and sustenance. The indigenous people there, regardless of their socio-economic status, have observed a shift in the climate. Water stress is seen as being more severe than the other ES components. Increasing water paucity, as well as reductions in the crop yield due to disease and pests, flash floods, storms, irregular rain patterns, hot weather, and disease in livestock, have had adverse consequences on yields, harming already existing food, water, and income insecurity. On the other hand, specific changes present possibilities, such as more than one farming season each year at higher elevations or favourable temperatures and more precipitation for specific crops.

Medicinal plant collection is an essential source of revenue for many households in the Valley, for which coherent and sustainable harvesting policy measures are needed on an urgent basis to conserve the endangered medicinal plant species. In the HKH region, medicinal plants are one of the most common and valuable natural resources, and they play an essential role in local lifestyles and economies (Kalita et al., 2014; MoAF, 2014). To develop a sustainable plan for harvesting medicinal plants in the Gurez Valley, it is essential to closely examine their current state and level of use.

Other than evaluating the identified ES, social, and climatic effects, our findings highlight the need to disclose the sustainable use of ES. Comprehensive and urgent climate adaptation initiatives by local communities and the government are essential to secure living conditions at acute risk from the consequences of climate change. Unfortunately, no such mechanism exists to be adopted by the communities. The participatory rural approach might help in building local climate change adaptation plans. Since the mountain communities remain politically and economically marginalized, enough resources must be allocated to execute current policies to enable avenues for anticipatory and targeted adaptation and increased resilience among the most vulnerable.

3.6 ACKNOWLEDGEMENTS

We thank the Snow Leopard Trust, USA, for funding this study. We appreciate the cooperation and support of the Gurez Valley communities. We also acknowledge the support of the Snow Leopard Foundation-Pakistan for fieldwork in terms of equipment and trained field staff. We are highly grateful to Tahir Mehmood, Shakeel Malik, Barkatullah Khan, and Muhammad Amir for helping with data collection and compilation. We thank Doost Ali Nawaz, Shakeel Ahmad, and ESRI for providing GIS support. Finally, we owe special thanks to Dr. Ranjini Murali, Snow Leopard Trust, for all the virtual guidance, support, and technical help in executing this study, followed by the valuable comments, and proofreading of the paper.

3.7 REFERENCES

Ahmad, S., Hameed, S., Ali, H., Khan, T. U., Mehmood, T., & Nawaz, M. A. (2016). Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. European *Journal of Wildlife Research*, *62*(5), 565–576. https://doi.org/10.1007/s10344-016-1029-6

Ahmed, J., Mahmood, F., & Mayers, J. (1998). *Changing perspectives on forest policy*. International Institute for Environment and Development. Accessed online 2nd March 2024 https://www.iied.org/sites/default/files/pdfs/migrate/7533IIED.pdf

Arora, R. K., & Nayar, E. R. (1984). Wild relatives of crop plants in India. *Wild relatives of crop plants in India.* Accessed online 2nd March 2024 http://www.cropwildrelatives.org/fileadmin/templates/cropwildrelatives.org/upload/documents/Wild_relatives_of_crops_plants_in_India_collection_and_conservation_Pandey_2005.pdf

Arun, K. C. (2004). Extraction of NTFPs from the community forest: Analysis of benefit distribution pattern in household level. *Journal of forest and Livelihood*, *4*(1), 38-43. Accessed online 2nd March 2024 https://forestaction.org/app/webroot/vendor/tinymce/editor/plugins/filemanager/files/6.%20Arun%20KC%20May%202004_final%20june%2029.pdf

Awan, M. N., Kabir, M., Ahmad, S., & Huettmann, F. (2020). The Future of biodiversity in the changing watersheds of Kashmir Himalaya, Pakistan: Conservation challenges and opportunities. *Hindu Kush-Himalaya Watersheds Downhill: Landscape*

Ecology and Conservation Perspectives, 113. https://doi.org/10.1007/978-3-030-36275-1_7

Awan, M. N., Saqib, Z., Buner, F., Lee, D. C., & Pervez, A. (2021). Using ensemble modeling to predict breeding habitat of the red-listed Western Tragopan (*Tragopan melanocephalus*) in the Western Himalayas of Pakistan. *Global Ecology and Conservation, 31*, e01864. http://dx.doi.org/10.1016/j.gecco.2021.e01864

Azfar Hussain, S. A., Begum, S., & Ali, I. H. H. (2019). Climate change perspective in mountain area: impact and adaptations in Naltar Valley, Western Himalaya, Pakistan. *Fresenius Environ Bull, 28,* 6683-6691.

Balvanera, P., Quijas, S., Martin-Lopez, B., Barrios, E., Dee, L., Isbell, F., Durance, I., White, P., Blanchard, R., & de Groot, R. S. (2015). The links between Biodiversity and Ecosystem Services. In M. Potchin, R. Haines-Young, & K. Turner (Eds.), *Handbook of Ecosystems Services* Earthscan. https://doi.org/10.4324/9781315775302-5

Bhatta, L.D., Udas, E., Khan, B., Ajmal, A., Amir, R. and Ranabhat, S. (2020), Local knowledge based perceptions on climate change and its impacts in the Rakaposhi Valley of Gilgit-Baltistan, Pakistan, *International Journal of Climate Change Strategies and Management*, *12*(2), 222-237. https://doi.org/10.1108/IJCCSM-05-2019-0024

Bischof, R., Ali, H., Kabir, M., Hameed, S., & Nawaz, M. A. (2014). Being the underdog: An elusive small carnivore uses space with prey and time without enemies. *Journal of Zoology*, *293*(1), 40–48. https://doi.org/10.1111/jzo.12100

Carpenter, S. R., DeFries, R., Dietz, T., Mooney, H. A., Polasky, S., Reid, W. V., & Scholes, R. J. (2006). Millennium ecosystem assessment: research needs. *Science*, 314(5797), 257-258. https://doi.org/10.1126/science.1131946

Cavendish, W., (2002). Quantitative methods for estimating the economic value of resource use to rural households. In: Luckert, M.K., Campbell, B.M. (Eds.), *Uncovering the Hidden Harvest Valuation Methods for Woodland and Forest Resources.* Earthscan Publications, London, 17–63.

CBOS, (2006). *Annual Report 2006*, Central bank of Sudan. Retrieved 14 June 2021, from https://cbos.gov.sd/en/content/annual-report-2006

CBOS, (2007). *Annual Report 2006*, Central bank of Sudan. Retrieved 14 June 2021, https://cbos.gov.sd/en/content/annual-report-2007

Climate Change Center (2017). AJ&K Climate Change Policy. Planning & Development Department, Azad Government of the State of Jammu & Kashmir. Accessed online 2nd March 2024 https://pndajk.gov.pk/uploadfiles/downloads/CC%20AJK%20Policy%202017.pdf

De Groot, R.; Jax, K. and P. Harrison (2016): *Links between Biodiversity and Ecosystem Services. In: Potschin, M. and K. Jax (eds): Openness Ecosystem Services Reference Book.* EC FP7 Grant Agreement no. 308428. Available via: http://opennes-project.eu/library/reference-book

Din, J. U., Nawaz, M. A., Norma-Rashid, Y., Ahmad, F., Hussain, K., Ali, H., & Adli, D. S. H. (2020). Ecosystem Services in a Snow Leopard Landscape: A Comparative Analysis of Two High-elevation National Parks in the Karakoram–Pamir. *Mountain Research and Development*, *40* (2), R11. https://doi.org/10.1659/MRD-JOURNAL-D-19-00047.1

Egan, P. Price, MF. (2016). Mountain ecosystem services and climate change—a global overview of potential threats and strategies for adaptation. UNESCO, Paris

Endalamaw, TB. (2005). Dynamics in the management of honey production in the forest environment in Southwest Ethiopia. MSc Thesis. Wageningen University. Accessed online 2nd March 2024 https://edepot.wur.nl/184631

Epstein, G. (2017). Local rulemaking, enforcement, and compliance in state-owned forest commons. *Ecological Economics*, *131*, 312-321. https://doi.org/10.1016/j.ecolecon.2016.09.012

Erdozain, M., Freeman, E. C., Ouellet Dallaire, C., Teichert, S., Nelson, H. W., & Creed, I. F. (2019). Demand for provisioning ecosystem services as a driver of change in the Canadian boreal zone1. *Environmental Reviews*, *27*(2), 166-184. https://doi.org/10.1139/er-2018-0064

FAO. (2010). Global Forest Resources Assessment 2010: Main Reports. Accessed online 2nd March 2024 https://www.fao.org/3/i1757e/i1757e.pdf

FAO. (2015a). In R. Romeo, A. Vita, R. Testolin, T. Hofer, (Ed.), Mapping the vulnerability of mountain peoples to food insecurity. Rome. http://www.fao.org/3/a-i5175e.pdf

FAO. (2015b). Combating Land Degradation for Food Security and Provision of Soil Ecosystem Services in Europe and Central Asia – International Year of Soils. European Commission on Agriculture, 39th Session, Budapest, Hungary. Accessed online 2nd March 2024 https://www.fao.org/3/mo297e/mo297e.pdf

Farber, S. C., Costanza, R., & Wilson, M. A. (2002). Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*, *41*(3), 375–392. https://doi.org/10.1016/S0921-8009(02)00088-5

Farley, J. (2012). Ecosystem services: The economics debate. *Ecosystem Services*, *1*(1), 40–49. https://doi.org/10.1016/j.ecoser.2012.07.002

Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science & Policy*, *21*, 24–34. https://doi.org/10.1016/j.envsci.2012.03.007

Gerlitz, L., Conrad, O., Thomas, A., & Böhner, J. (2014). Warming patterns over the Tibetan Plateau and adjacent lowlands derived from elevation-and bias-corrected ERA-Interim data. *Climate Research*, *58*(3), 235-246. http://dx.doi.org/10.3354/cr01193

Haines-Young, R., & Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being. In D. G. Raffaelli & C. L. J. Frid (Eds.), *Ecosystem Ecology* 110–139. Cambridge University Pres. https://doi.org/10.1017/CBO9780511750458.007

Huddleston, B., Ataman, E., de Salvo, P., Zanetti, M., Bloise, M., Bel, J., & Fe d'Ostiani, L. (2003). Towards a GIS-based analysis of mountain environments and populations. Environment and Natural Resources. Working Paper (FAO). Accessed online 2nd March 2024 https://www.fao.org/3/y4558e/y4558e.pdf

Ingram, V., & Njikeu, J. (2011). Sweet, sticky, and sustainable social business. *Ecology and Society*, *16*(1). http://dx.doi.org/10.5751/ES-03930-160137

IPCC (2021). Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Pres. http://doi:10.1017/9781009157896.001.

Jalil, A., Khan, K., Arshad, M., & Yiping, L. (2016). Socio-economic Impact on Natural Resources in Musk Deer National Park (MDNP)-Guraiz Valley, District Neelum, Azad Kashmir, Pakistan. *Science, Technology and Development*, *35*(3), 110–116. https://doi.org/10.3923/std.2016.110.116

Kalita, P., Tag, H., Sarma, H. N., & Das, A. K. (2014). Evaluation of nutritional potential of five unexplored wild edible food plants from Eastern Himalayan biodiversity hotspot region (India). *International Journal of Biological, Food, Veterinary Agricultural Engineering*, *8*, 207–210. Accessed online 2nd March 2024 https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=05c48381c6441ec3c837d5b502aa90826a1fe48b

Kandel, P., Chettri, N., Chaudhary, S., Sharma, P., & Uddin, K. (2021). Ecosystem services research trends in the water tower of Asia: A bibliometric analysis from the Hindu Kush Himalaya. *Ecological Indicators*, *121*, 107-152. https://doi.org/10.1016/j.ecolind.2020.107152

Krishnan, R. et al., (2019) Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes. In: Wester P., Mishra A., Mukherji A., Shrestha A. (eds) The Hindu Kush Himalaya Assessment. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_3

Kumar, P., Martinez-Alier, J. (2011). The Economics of Ecosystem Services and Biodiversity: An International Assessment. *Economic and Political Weekly*, *46* (24), 76-80. Accessed online June 17, 2021http://www.jstor.org/stable/23018249

Kumar, P., Yashiro M. (2014) The Marginal Poor and Their Dependence on Ecosystem Services: Evidence from South Asia and Sub-Saharan Africa. In: von Braun J., Gatzweiler F. (eds) Marginality. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7061-4_11

Lee, M., & Diop, S. (2009). Millennium ecosystem assessment: Findings of the Group of Experts Pursuant to UNGA Resolution 60/30, 1, 361.

Lindberg, V., (2000). Uncertainties and error propagation. Manual on Uncertainties, Graphing and the Vernier Caliper, Part I. Rochester Institute of Technology, New York, USA.http://www.rit.edu/uphysics/uncertinities/Uncertinitiespart2.html#addsub

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper DU, Huston M., Raffaelli D, Schmid B, Tilman D, & Wardle, D. A. (2001). Biodiversity and ecosystem functioning: current knowledge and future challenges. *science*, *294*(5543), 804-808. https://doi.org/10.1126/science.1064088

Macchi, M. (2010). Mountains of the World–Ecosystem Services in a Time of Global and Climate Change: Seizing Opportunities–Meeting Challenges. International Centre for Integrated Mountain Development (ICIMOD). https://doi.org/10.53055/ICIMOD.537

Maitane Erdozain, Erika C. Freeman, Camille Ouellet Dallaire, Sonja Teichert, Harry W. Nelson, and Irena F. Creed. (2019). Demand for provisioning ecosystem services as a driver of change in the Canadian boreal zone1. The Boreal 2050 project: a road map towards sustainability of the boreal zone. 01(01): 166-184. https://doi.org/10.1139/er-2018-0064@er-bor.issue01

Martín-López, B., Leister, I., Lorenzo Cruz, P., Palomo, I., Grêt-Regamey, A., Harrison, P. A., & Walz, A. (2019). Nature's contributions to people in mountains: a review. *PloS ONE*, *14*(6), e0217847. https://doi.org/10.1371/journal.pone.0217847

Millenium Ecosystem Assessment (2005). Millennium Ecosystem Assessment: Ecosystems and Human Well-being - Synthesis. Island Press. Accessed online 2nd March 2024 https://www.millenniumassessment.org/documents/document.356.aspx.pdf

MISHRA, C. (1997). Livestock depredation by large carnivores in the Indian trans-Himalaya: conflict perceptions and conservation prospects. Environmental Conservation, 24(4), 338–343. https://doi:10.1017/S0376892997000441

Mishra, C., Allen, P., McCarthy, T., Madhusudan, M. D., Bayarjargal, A., & Herbert H. T. Prins. (2003). The Role of Incentive Programs in Conserving the Snow Leopard. Conservation Biology, 17(6), 1512–1520. http://www.jstor.org/stable/3588899

MoAF, (2014). *National biodiversity strategies and action plan, Bhutan 2014.* Ministry of Agriculture and Forest, Royal Government of Bhutan, Thimphu, Bhutan. Accessed online 2nd March 2024 https://www.cbd.int/doc/world/bt/bt-nbsap-v4-en.pdf

MoCC, (2017). *National forest policy 2015*. Ministry of Climate Change, Government of Pakistan, Islamabad, Pakistan. Accessed online 2nd March 2024 https://pbit.punjab.gov.pk/system/files/National%20Forest%20Policy%202016.pdf

MoCC, (2021). *National climate change policy* (updated version). Ministry of Climate Change, Government of Pakistan, Islamabad, Pakistan. Accessed online 2nd March 2024 https://mocc.gov.pk/SiteImage/Policy/NCCP%20Report.pdf

Murali R, Lkhagvajav P, Saeed U, Kizi VA, Zhumbai-Uulu K, Nawaz MA, Bhatnagar YV, Sharma K, Mishra C. (2017a). *Valuation of ecosystem services in snow leopard landscapes of Asia*. Snow Leopard Trust, Nature Conservation Foundation, Snow Leopard Conservation Foundation, Snow Leopard Foundation Kyrgyzstan, and Snow Leopard Foundation Pakistan. Report Submitted to the Global Environment Facility (GEF) funded United Nations Development Program (UNDP) project on Transboundary Cooperation for Snow Leopard and Ecosystem Conservation. Accessed online 2nd March

2024 https://globalsnowleopard.org/wp-content/uploads/2018/12/Valuation-of-ecosystem-services-in-snow-leopard-landscapes.pdf

Murali, R., Ikhagvajav, P., Amankul, V., Jumabay, K., Sharma, K., Bhatnagar, Y. V., Suryawanshi, K., & Mishra, C. (2020). Ecosystem service dependence in livestock and crop-based production systems in Asia's high mountains. *Journal of Arid Environments*, *180*, 104204. https://doi.org/10.1016/j.jaridenv.2020.104204

Murali, R., Redpath, S., & Mishra, C. (2017b). The value of ecosystem services in the high altitude Spiti Valley, Indian Trans-Himalaya. *Ecosystem Services*, *28*, 115–123. https://doi.org/10.1016/j.ecoser.2017.10.018

Mwakalukwa, EE (2016). Beekeeping in Tanzania: Country situation paper. Presented at ApiExpo Africa. Camp Kigali, Rwanda. https://www.apitradeafrica.org/Documents/ApiExpoAfrica_2016/Tanzania_Honeybee_Industry_situation_paper.pdf Accessed 15 Jan 2018

Nelson, E. J., Kareiva, P., Ruckelshaus, M., Arkema, K., Geller, G., Girvetz, E., Goodrich, D., Matzek, V., Pinsky, M., Reid, W., Saunders, M., Semmens, D., & Tallis, H. (2013). Climate change's impact on key ecosystem services and the human well-being they support in the US. *Frontiers in Ecology and the Environment*, *11*(9), 483–893. https://doi.org/10.1890/120312

Pei, S. J. (1992). Mountain culture and forest resource management of Himalaya. *Himalaya Ecosystem*, 114-120. http://refhub.elsevier.com/S0140-1963(20)30108-7/sref39

Pie, S. J., & Manandhar, N. P. (1987). Sources of some local medicines in the Himalayan Regions. Himalayan Ecosystem, 97-112.

Pomfret, R. (2014). *The economies of central Asia*. Princeton University Pres.

Pritchard H. D. (2017). Asia's glaciers are a regionally important buffer against drought. *Nature*, 545(7653), 169–174. https://doi.org/10.1038/nature22062 (Retraction published Nature. 2018 Feb 14;:null)

Qureshi, B. D., Anwar, M., Hussain, I., & Beg, M. A. (2013). Habitat utilization of Himalayan musk deer (*Moschus chrysogaster*) in the musk deer National Park Guraiz, Azad Jammu and Kashmir, Pakistan. *The Journal of Animal and Plant Science*, 23(5), 1366-1369.

Rahbek, C., Borregaard, M. K., Colwell, R. K., Dalsgaard, B. O., Holt, B. G., Morueta-Holme, N., ... & Fjeldså, J. (2019). Humboldt's enigma: What causes global patterns of mountain biodiversity? Science, 365(6458), 1108-1113. https://doi.org/10.1126/science.aax0149

Samper, C. (2003). The Millennium Ecosystem Assessment: science and policy for sustainable development. *BioScience*, *53*(12), 1148-1149. Accessed online 2nd March 2024 https://repository.si.edu/bitstream/handle/10088/12162/stri_Samper_in_BioScience.pdf

Shackleton, C., Shackleton, S., Shanley, P. (2011). Building a holistic picture: an integrative analysis of current and future prospects for non-timber forest products in a changing world. Tropical Forestry No.7. In: Shackleton, S., C. Shackleton, and P. Shanley (eds.). Non-timber forest products in the global context. :255-280. Heidelberg, Springer-Verlag. ISBN: 978-3-642-17982-2. https://www.cifor.org/knowledge/publication/3410

Shaheen, H., Aziz, S., & Dar, M. E. U. I. (2017). Ecosystem services and structure of western Himalayan temperate forests stands in Neelum Valley, Pakistan. *Pakistan Journal of Botany*, *49*(2), 707-714. Accessed online 2nd March 2024 https://www.pakbs.org/pjbot/PDFs/49(2)/40.pdf

Sharma, E., Molden, D., Rahman, A., Khatiwada, Y. R., Zhang, L., Singh, S. P., ... & Wester, P. (2019). Introduction to the Hindu Kush Himalaya Assessment. In The Hindu Kush Himalaya Assessment, pp. 1-16. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_1

Tse-ring, K., Sharma, E., Chettri, N., & Shrestha, A. B. (2010). Climate change vulnerability of mountain ecosystems in the Eastern Himalayas. International centre for integrated mountain development (ICIMOD). Accessed online 2nd March 2024 https://www.cbd.int/doc/pa/tools/Climate%20change%20impacts%20and%20vulnerabilities%20in%20the%20Eastern%20Himalayas.pdf

Van Oort, B., Bhatta, L.D., Baral, H., Rai, R.K., Dhakal, M., Rucevska, I., Adhikari, R., (2015). Assessing community values to support mapping of ecosystem services in the Koshi river basin. Nepal. *Ecosystem Services 13*, 70–80. http://dx.doi.org/10.1016/j.ecoser.2014.11.004

Ward, D., & McKague, K. (2007). *Water requirements of livestock.* Ministry of agriculture, food, and rural affairs, Government of Canada. Accessed online 12 June 2021 http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm

Wertime, M.B. et al., (2011). International Forestry Resources and Institutions (IFRI) Research Program: Field Manual, Michigan, USA. Accessed online 2nd March 2024 http://www.ifriresearch.net/wp-content/uploads/2012/09/IFRI_Manual.pdf

Wester, P., Mishra, A., Mukherji, A., & Shrestha, A. B. (2019). In P. Wester, A. Mishra, A. Mukherji, & A. B. Shrestha (Eds.), *The Hindu Kush Himalaya Assessment Mountains, climate change, sustainability, and people.* Springer. https://doi.org/10.1007/978-3-319-92288-1_5

Wyatt, P. (2009). "Replacement cost and market value," *Journal of Property Investment & Finance*, Emerald Group Publishing Limited, vol. 27(6), pages 593-602, September. https://doi:10.1108/14635780910993186

Xu, J. et al. (2019). Sustaining Biodiversity and Ecosystem Services in the Hindu Kush Himalaya. In: Wester, P., Mishra, A., Mukherji, A., Shrestha, A. (eds) *The Hindu Kush Himalaya Assessment*. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_5

APPENDIX 3.1: SCRIPT USED FOR ECOSYSTEM SERVICES VALUATION ASSESSMENT AND CLIMATE CHANGE PERCEPTIONS

Asked for every interview.

Village name:

Respondent name:

Number of people in the household:

Number of people employed in the household:

Kind of employment:

What are their main sources of income?

Compiling a list of ecosystem services used from the area (only the first three interviews or this can even be a focal group discussion).

1. Do you feel that nature gives you benefits? What are the benefits that nature in the valley gives you?

   This question will have to be phrased in such a way that they understand it. Local people have different expressions and names for "nature" or the pastures. Try a few variations of nature and see the one that they can understand or relate to the most. Make sure that this question is asked first, so that responses are not biased, based on the previous questions that they might have been asked.

   - Have you experienced any changes in climate in the last five years?

2. What are the crops grown in the village? Which crops are sold? How much is one kg of this crop sold for?
3. What are the other crops used for?
4. Can you please tell me what you do for agriculture through the year? Are there are any wild plants or wild animal products that you collect for agriculture? For examples, for either fertilizing the land or levelling the land? Can you please name them? (Make a list of the different plants/animals they name)

5. How do you bring water from the pastures for agriculture? How do you share your water in the village?
6. What do you use for fertilizer? How much fertilizer is needed for one acre of land in a year?
7. Can you please describe how you herd the different livestock in the village? When are they taken to the pastures? How are they fed during the winter months? Do you collect forage? Are there any special wild plants that you collect from the pastures to feed the livestock? Can you name the plants that are collected?
8. What do they use livestock for?
9. How much is one kg of meat?
10. How much is one kg of wool?
11. How much is one litre of milk?
12. How much does 1kg of livestock feed/fodder cost?
13. What are the rates for selling the livestock? Age/sex rates.
14. Do you collect any other wild plants or animal products from the pastures? For example, do you collect any plants to eat, or for religious or decorative purposes? Can you please list them?
15. What else do you collect from the pastures? (Give them some time to respond, if they don't respond, you can prompt them by asking Do you collect dung or firewood?)
16. Is anything collected from the pastures for roofing or other housing material? If you, what is collected? For people who don't collect this for their houses, what do they use as a replacement?
17. Do you sell any products that are collected from the pastures? If so, how much do you sell them for? (Get a price per kg, if possible)
18. How much does wood/gas cost if it is bought?

Economically valuing ecosystem services (this must be asked on every respondent)

Agriculture:

1. What are the crops that you grow?
2. How much land do you have? How much land do you cultivate?
3. How much of crops did you sell last year?
4. How much of the other crops did you harvest last year?
5. Do you hire labour in your farm? If so, how many and for how many days in a year and at what rate?
6. Do you buy any fertilizers or pesticides? If so, how much do you spend on these?
7. How much local fertilizer do you use?
8. How do you plough the land? If you use a tractor what are the rates/hour and how many hours do you use it for?
9. If you have noticed changes in climate, how have they impacted your crops?

Livestock:

1. What are the livestock that you own? Age/sex composition? How many wool producing sheep/goats do you have?
2. What do you use livestock for?
3. How much milk do you get per day?
4. How much meat did you sell last year?
5. How much wool/pashmina did you sell last year?
6. Do you use livestock to plough your land? If so, which one, and for how long?
7. Do you buy any animal feed or fodder for your livestock? If so, how much do you spend on it?
8. If you have noticed changes in climate, how have they impacted your Livestock?

Pasture use:

From the list of plants collected from the previous set of questions in section 1, ask them how much and of each service do they collect? How much time do they spend collecting these services? This would also include wood and dung if they mentioned it in the first set.

1. How much water does your household consume in a day? Where do you get your water from? Do you pay for water? If so, how much do you pay per month? (Sometimes they collect water in cans, and will be able to say how many cans they collect in a day)
2. If you have noticed changes in climate, how have they impacted your access to/sources of and water availability?
3. Do you collect any medicinal plants from the pastures? What do you use it for? How much do you collect in a year?

Housing Cost:

If they say they collect plants from the pasture for housing material, then ask the following questions: (You may visually estimate the house size as small, medium, large and mention the number of floors the house has).

1. How old is the house?
2. How much of the plant material did you collect from the pasture for your house? When did you collect it?
3. When you are sick, do you go to a traditional healer to a doctor? If the last year, what illnesses did you and people in your family, go to for the traditional healer and how many times?

Measurement units: People are often comfortable answering the amount they collect/use in the units that they are familiar with. So, if they say they collect in boris or cans or on animal back then let them give it in that unit. Afterward we can measure and find out how many kilograms are in a bag.

APPENDIX 3.2: LOCAL MARKET PRICE AND REPLACEMENT COST VALUES FOR PROVISIONING ES CALCULATION IN THE GUREZ VALLEY

(1 USD = 103 PKR in 2017)

CICES Class of Provisioning ES	ES	ES / External Inputs	Local Market Value (PKR)	Source
Cultivated crops	Crops	Beans	150 / kg	Himalayan Wildlife Foundation, Muhammad Arshad, personal communication, 2017
		Potato	30 / kg	
		Fertilizer	90 / kg	
		Chemical	60 / kg	
		Tractor	1500 / hr	
		Ox (pair)	1500 / day	
		Worker hired	900 / day	
Reared animals and their outputs	Milk	Milk	110 / litre	
Reared animals and their outputs	Meat	Sheep	12000 / animal	
		Goat	10500 / animal	
		Cow	40000 / animal	
Surface water for drinking	Water for HH purpose (natural stream)	Labour cost to bring water	10 / day	
Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	*Aconitum heterophyllum*	7000 / kg	
		Trapetra	3000 / kg	
		Kohr	1500 / kg	
		Morchella esculenta	16000 / kg	
		Saussurea lappa	1000 / kg	
		Valeriana jatamansi	800 / kg	
		Viola biflora	800 / kg	
		Butmeva	50 / kg	
		Sumbal	100 / kg	

CICES Class of Provisioning ES	ES	ES / External Inputs	Local Market Value (PKR)	Source
		Rattan Jog	40 / kg	
Materials from plants, algae, and animals for agricultural use	Fodder for livestock	Fodder	40 / kg	
Surface water for non-drinking purposes	Water for livestock (natural stream)	Labour cost to bring water	40 / day	
Plant-based resources	Fuelwood	Fuelwood	10 / kg	
Animal-based energy	Ox to plough the land	Ox pair labour (valued for cultivated crops only)	1500 / day	
	Donkey & Horse to transport materials	Horse physical labour cost	600 / day	
		Donkey physical labour cost	500 / day	

APPENDIX 3.3: FORMULAE USED TO CALCULATE ECONOMIC VALUES OF ES IN THE GUREZ VALLEY

CICES Class of Provisioning ES	ES	ES Valuation Formula
Cultivated crops	Crops	Σ ($crop_1$ / kg * total kg sold + $crop_2$ / kg * total kg sold) - (cost of labour hired - cost of chemicals - cost of tractor/ox - cost of fertilizer) Where numbers in subscript represent different crops
Reared animals and their outputs	Milk	Price / litre * number of litres / HH / day * number of days / yr
	Meat	Price of an animal sold / HH * number of animals sold / yr
Surface water for drinking	Water for HH purposes	Water consumed / HH / yr * price of water
Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	Σ (price / kg of mp_1 / HH / yr * kg collected) + (price / kg of mp_2 / HH / yr * kg collected) + (price / kg of mp_n / HH / yr * kg collected) Where mp = medicinal plants and numbers in subscript represent different medicinal plant species
Materials from plants, algae, and animals for agricultural use	Fodder for livestock	Σ (Price / kg of fodder * (forage by ls_1 + forage ls_2 + forage ls_n / year) Where ls = livestock and the numbers in subscript represent different livestock species
Surface water for non-drinking purposes	Water for livestock	Σ water consumed by (ls_1 + ls_2 + ls_n) / yr * price of water
Plant-based resources	Fuelwood	Fuelwood quantity /HH/yr * price of fuelwood
Animal-based energy	Donkey & horse physical labour employed to transport materials	Σ (Price of physical labour by (horse + donkey) / HH * number of days / yr

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

CHAPTER 4

Economic Valuation of Ecosystem Services for Indigenous Communities of Chitral Valley in the Hindukush Range, Pakistan

4 ECONOMIC VALUATION OF ECOSYSTEM SERVICES FOR INDIGENOUS COMMUNITIES OF CHITRAL VALLEY IN THE HINDU KUSH RANGE, PAKISTAN

ABSTRACT

Understanding montane communities' dependence on ecosystem services (ES) is essential to develop relevant climate adaptation strategies. The ES in Chitral Valley, in the Hindu Kush range of Pakistan, provides a unique opportunity to explore this question. This understudied area is increasingly exposed to global climate change and the overexploitation of resources. Hence, this study aimed to identify the ES in this region and delineate indigenous communities' reliance on ES based on valuation in the Chitral Valley. ES were classified using semi-structured interviews and focus group discussions using the CICES (Common International Classification on Ecosystem Services) and the Total Economic Valuation Framework. Findings show indigenous communities' high dependence on the ES. The provisioning ES have 3.7 times higher total economic value than a household's (HH) average income, worth 7272 ± 481.6 USD/HH/yr. Forage for livestock holds the highest value as an ES in the Valley 2219 ± 83 USD per household per year. The sustainable use of ES and climate change adaptation and mitigation have substantial cultural, economic, and ecological benefits for the Hindu Kush range.

Keywords: Economic valuation, ecosystem services, focus group interview, Chitral Valley, Hindu Kush landscape, Pakistan.

4.1 INTRODUCTION

The concept of "ecosystem services" (ES) was first introduced in 1981 and gained importance in the 1990s after a global assessment of natural capital and ES (Ehrlich & Ehrlich, 1981; Costanza et al., 1997). The Millennium Ecosystem Assessment (MEA) and its synthesis reports were important milestones that firmly established ES as a critical issue in global policy (Millenium Ecosystem Assessment, 2001 and 2005). The Economics of Ecosystems and Biodiversity (TEEB) documentation helped to bring environmental economics into decision-making (Chaudhary et al., 2015; TEEB, 2010b). ES have been incorporated into international policies, such as the Convention on Biological Diversity (CBD) as well.

ES refers to the benefits, both direct and indirect, that ecosystems provide to people (as stated in the TEEB Foundations, 2010). These benefits can come in two forms: provisioning services, such as timber and minerals that can be consumed, and non-provisioning services, like carbon sequestration, soil formation, recreation, and spiritual enrichment, which are not directly consumed or experienced in situ (Erdozain et al., 2018). Mountainous regions are particularly rich in biodiversity and have high ES production values due to their crucial role in the terrestrial ecosystem and their vulnerability to environmental changes (Yu et al., 2021; Liu et al., 2019). By 2050, it is estimated that more than 24% of people living in low-lying areas worldwide will heavily depend on mountain runoff (Viviroli et al., 2020).

Pastoral and agro-pastoral communities in Asia's high mountain ranges rely on ES for their livelihoods and subsistence (Murali et al., 2017a). Previous studies have shown that the economic benefits from ES in the Gurez Valley were estimated to be 6730 ± 520 USD/HH/yr (Saeed et al., 2022), 5955 USD/HH/yr in the high-elevation Qurumbar National Park Pakistan (Din et al., 2020), 3622 ± 149 USD per household per year in Spiti Valley, India (Murali et al., 2017b), 150,100 ± 13,290 per household per year in Tost, 79303 ± 9204 USD/HH/yr in Changtang, and 25,544 ± 5236 USD/HH/yr in Sarychat (Murali et al., 2020).

This work aims to identify the ES in the Chitral Valley and assess the dependence of indigenous communities on these services based on their value. This study marks the first attempt to quantify the reliance of indigenous communities in the Chitral Valley on ES and compare the results with previous studies conducted in similar landscapes, such as the Gurez Valley in Western Himalayas Pakistan (Saeed et al., 2022), the Spiti Valley in the Indian Trans-Himalayas (Murali et al., 2017a), the Tost Nature Reserve in Mongolia, the Changtang region in Ladakh, and the Sarychat region in Kyrgyzstan.

4.2 MATERIALS AND METHODS

4.2.1 Conceptual Steps

We first conducted household-level interviews using questionnaires. We selected 11 communities and sampled 10% from each community. The questionnaire was created based on the IFRI field manual and formed the foundation for the focus group discussion questions and the more detailed household interview questions. A focus group discussion was held in each community to gather a list of ES. To value these ES, we used the Common International Classification on Ecosystem Services (CICES) and the Total Economic Valuation (TEV) framework as suggested by The Economics of Ecosystems & Biodiversity (TEEB). The valuation was made using the market price-based approach and the replacement cost method (Wyatt, 2009). The total economic value was determined by summing up the means and standard errors for each ES. These valuations were then compared across local and regional contexts (Figure 4.1).

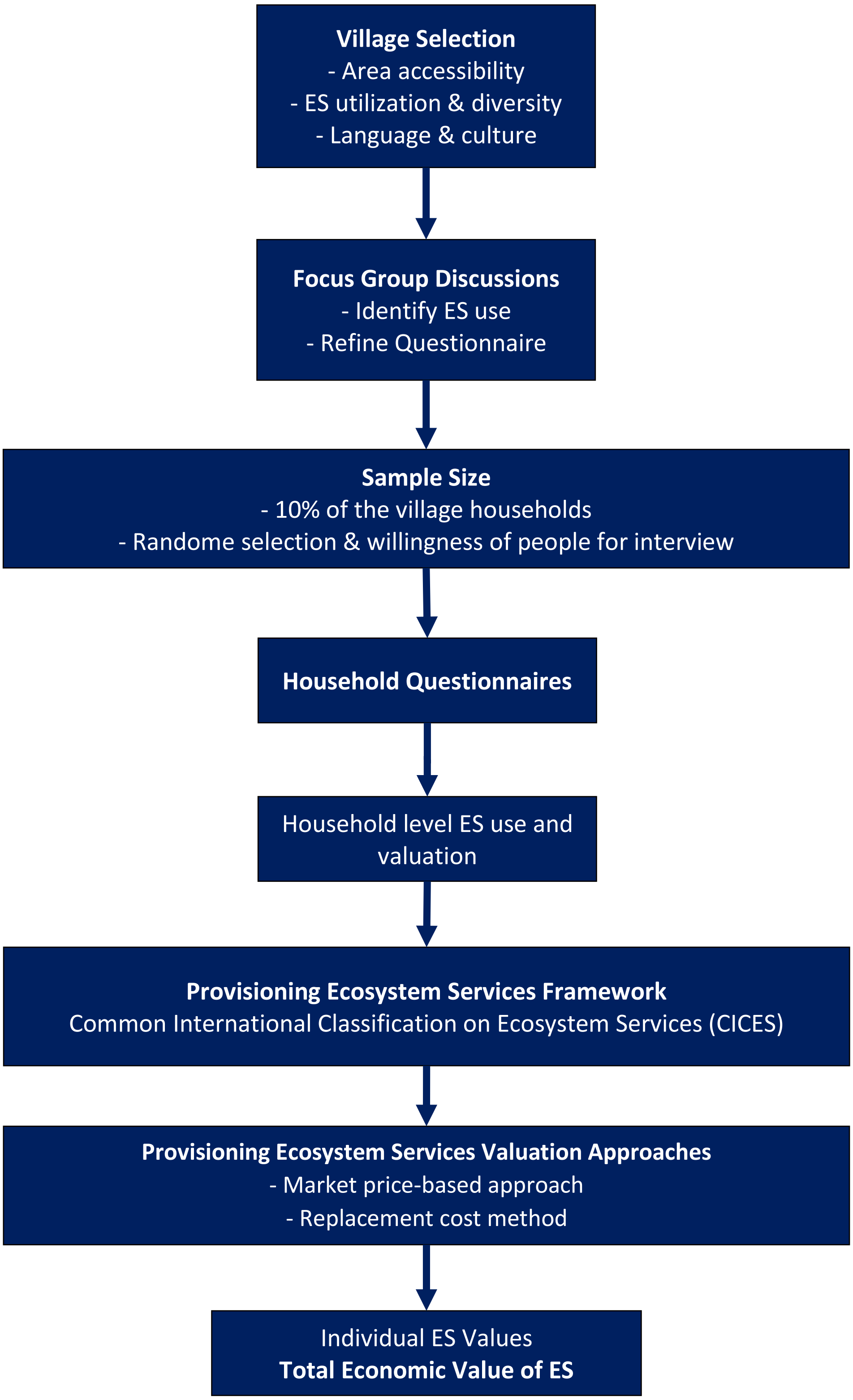


Figure 4.1: Conceptual Steps Adopted to Value ES in Chitral Valley

4.2.2 Study Area

The study was conducted in the Chitral district of Pakistan, renowned for its cultural and touristic significance. The mountainous region is situated in the Khyber Pakhtunkhwa province of Pakistan, between 36°15′ N and 37°8′ N latitude and 72°22′ E and 74°6′ E longitude. It is located at elevations ranging from 1070 to 7700 meters above sea level (Nüsser & Dickoré, 2002). The district's population density is 21 people per km^2, covering an area of 14,850 km^2 (Khan et al., 2013). It is bordered by the Afghan provinces of Wakhan, Badakhshan, and Nuristan to the north and west, Upper Dir and Swat districts to the east, and the Northern Areas to the south. The district experiences a continental climate, with temperatures varying from hot at lower elevations in summer to mild in the middle and chilly at higher elevations. Plate 4.1 shows Chitral Valley landscape in the Hindu Kush landscape in Pakistan.

Chitral, located in the Khyber Pakhtunkhwa province of Pakistan, is well-known for its captivating natural beauty, simple and unique culture, and the charm of its residents. The region, part of the Hindukush range, is considered one of the world's most alluring and fascinating places. Its landscape, with towering Rocky Mountains, verdant valleys, gorgeous meadows, massive glaciers, sulfur springs, juniper forests, and rivers abundant with trout, is both fascinating and challenging due to its inaccessibility and topographical features, including the highest mountains, surging rivers, glaciers, the traditional Kailash culture, rich musical heritage, and festivals. The world's highest polo field, Shandoor, is in the northeast of the Chitral Valley (Nomination Dossier, 2022).

Chitral is known for its diverse wildlife, with records showing the presence of 26 species of mammals, 118 species of birds, 28 species of reptiles, three species of amphibians, and seven species of fish. It is in the center of two geographical regions, the Palearctic faunal region and the region with a small oriental influence, providing ideal conditions for high biodiversity (Nomination Dossier, 2022).

Plate 4.1: Photo of Hindu Kush Range's Chitral Valley in Pakistan taken in November 2018

4.2.3 Data Collection

Village Selection

For the study, 11 communities were selected in the Chitral Valley based on the accessibility and willingness of participants to participate in the interviews (Figure 4.2). Our local team had conversations with community members beforehand to ensure the accurate representation of ecosystem services utilization, such as crops grown, livestock raised, and resources harvested, such as medicinal plants, forage, and fuelwood. The household-level data was collected for a 10% sample from each community to give a comprehensive view of ecosystem service usage in the Chitral Valley. The fieldwork was conducted in November 2018.

Generally, the inhabitants of these communities conduct subsistence agriculture by cultivating maize, beans, and barley in fields. For example, only one crop is grown in six months per year, while the rest of the year, the agriculture fields remain snow-covered. The inhabitants collect grass, fuelwood, and medicinal plants from the communal and forest land near their villages. The crops are grown mainly for household use, but some individuals sell surplus production for income. The agricultural fields surround the settlements and the border of the forest. The community uses a lot of the nearby forest land as pasture for their animals.

To obtain primary data for the subject study, 158 interviews were conducted, including 11 focus group discussions. The number of interviews in each selected community included households from Sor laspur (n = 41), Brook (n = 30), Ghast (n = 20), Morder (n = 19), Mughlandeh (n = 5), Gazodokeh (n = 5), Afghaniandeh (n = 4), Singoor (n = 19), Thingshan (n = 7), Dangrikandeh (n = 6), Shahmirandeh (n = 2). The interviewees were adults above the age of 18 years and included both men and women at the household level. The survey and participatory rural appraisal were used to gather information about the social structure, livestock, agriculture, and use of wood for fuel and building purposes. Plate 4.2 shows community members interviewed in Brook Village in the Hindu Kush Range's Chitral Valley in Pakistan.

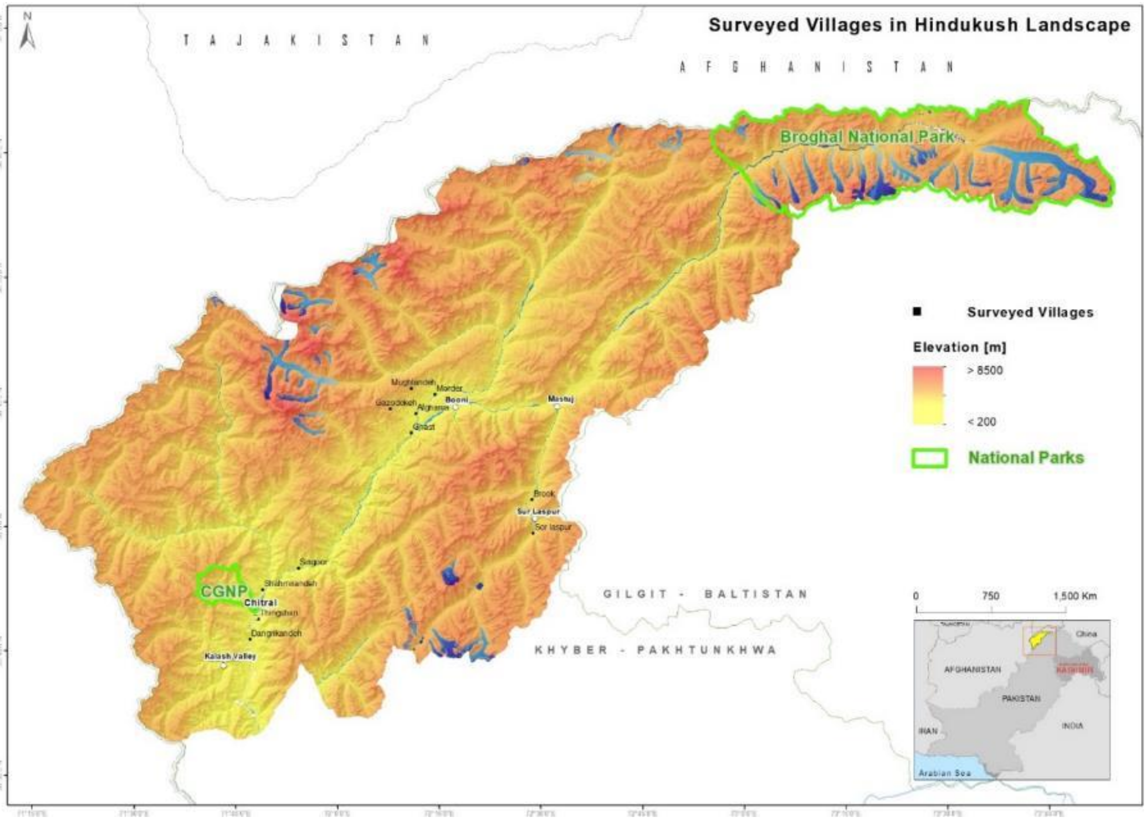


Figure 4.2: Map of Chitral Valley in Hindu Kush Range, Showing (11) Survey Villages

Focus Group Discussion Procedure

To determine the ES harnessed by local people at the household level in the Chitral Valley, one focus group discussion was conducted in each of the 11 communities. Following an explanation of the study's topic and objective, participants were asked to mention the ES in the respective survey village. The questions and responses were conducted verbally, with facilitators using local vernacular to the extent feasible to ensure that participants understood what was being said. Each focus group discussion lasted no more than two hours and was moderated by a member of the study team, who were all local and fluent in the local language. The group facilitator ensured that all participants contributed to the discussion to support the group's perspective (Van Oort et al., 2015). The discussions were noted in the questionnaire and the team members' notebooks for later analysis. We started by talking to various key informants to better understand how ES is used. We inquired about the quantity of agricultural products, subsistence crops harvested, livestock owned (age and gender categorization), water utilized, fodder, fuelwood, wild animal and plant products, and manure collected from the pastures (Appendix 4.1). The focus group discussions centered on compiling the ES list for each of the 11 communities. The questions are shown in Table 4.1.

Plate 4.2: Community Members Interviewed in Brook Village in the Hindu Kush Range's Chitral Valley in November 2018

Questionnaire

A questionnaire, forming the basis for focus group discussion, was developed following the guidelines provided by the modified version of the "International Forestry Resources and Institutions" (IFRI) field manual to obtain information at the household level (Wertime et al., 2011). The IFRI questionnaire has been extensively used to understand the human use of common pool resources in forest systems (Epstein, 2017). The specific questions asked to each household related to the ES obtained through the crop's cultivation in 11 communities are shown in Table 4.1.

ES identification and Economic Valuation

The interview responses were recorded and compared against each provisioning ES typology for the economic valuation. These were assigned codes and allocated to the groups of provisioning ES built upon the CICES (Common International Classification of Ecosystem Services) table (Haines-Young & Potschin, 2010). The 'Total Economic Valuation Framework' (TEV) suggested by 'The Economics of Ecosystems & Biodiversity' (TEEB) was used for calculating the economic value of provisioning ES (Kumar and Martinez Alier., 2011).

The TEV framework is a well-organized method for delineating all the benefits that an ecosystem provides. It is a well-known tool for economic valuations of ES because it represents value in economics or other market-based units that can be compared across ES types (Pomfret, 2014; Table 4.2). Using this framework, the provisioning ES is evaluated using direct and indirect use values that humans utilize. To determine the values of ES, we used market price-based and replacement cost methods. This framework has been used in earlier studies as well, those that were conducted by Saeed et al. (2022), Murali et al. (2017a), Murali et al. (2017b), and Murali et al. (2020) in similar mountainous and arid environments. Furthermore, we also wanted to verify if the results of our study were validated with the findings of the earlier studies.

Table 4.1: Focus Group Discussion and Specific Interview Questions

Focus Group Discussion Questions	
i	What are the benefits provided by nature in the valley
ii	What crops are grown in the village, which ones are sold, and how much is one kg of a particular crop sold for?
iii	Are any wild plants or animal products collected for agriculture to fertilize or levelling the land?
iv	How is the water brought from the pastures for agriculture and shared in the village?
v	What is used for fertilizer, and how much fertilizer is needed for one acre of land in a year?
vi	How are the different livestock herded in the village? When are they taken to the pastures? How are they fed during the winter months?
vii	Is the forage collected and names of the plants that are collected?
viii	What is livestock used for, and what are the prices per kg and liter of meat, fodder, livestock feed, and milk, respectively?
ix	What are the rates for selling the livestock according to age/sex?
x	Are any wild plants or animal products collected and sold from pasture? (xi) What is the price of firewood if bought from the market?
General Interview Questions	
i	What are the crops that they grow?
ii	How much land do they own?
iii	How much land do they cultivate?
iv	How much of crops did they harvest and sell last year?
v	Do they hire labor on the farms?
vi	If so, how many and for how many days in a year, and at what rate?
vii	Do they buy any fertilizers or pesticides?
viii	If so, how much do they spend on these?
ix	How much local fertilizer do you use?
x	How do they plough land?
xi	What is the rate/hour if they use a tractor, and how many hours do they use it for?
Specific Questions – Ecosystem Services Obtained Through Livestock Rearing	
i	What are the livestock that they own?
ii	what is the age/sex composition?
iii	What is the livestock used for?
iv	How much milk do they get per day?

v	How much meat did they sell last year?
vi	Do they use livestock to plough land?
vii	If so, which one, and for how long?
viii	Do they buy any animal feed or fodder for your livestock?
ix	If so, how much do they spend on it?
Specific Questions – Ecosystem Services Obtained Through Pasture Use.	
i	How much wild plants, wood, and dung do they collect?
ii	How much time do they spend collecting these services?
iii	How much water does their household consume in a day?
iv	Where do they get water from?
v	Do they pay for water?
vi	If so, how much do they pay per month?
vii	Do they collect any medicinal plants from the pastures?
viii	What do they use it for?
ix	How much do they collect in a year?

ES Valuation Based on Market Price

The market price-based method was used to assess the value of provisioning ES. Since provisioning ES are often sold, market prices are considered to provide reliable information on value (Pomfret, 2014). This strategy was adopted for the ES with a market price in the Chitral Valley. Table 4.2 details the economic valuation method (Kumar & Yashiro, 2014) for each ES considered in this study.

The economic values of the ES were analyzed as per the market price-based method under CICES classes for the following categories: (i) "cultivated crops" (e.g., wheat and maize), (ii) "livestock and their outputs" (e.g., milk and meat), (iii) "fibers and other materials from plants, algae, and animals for direct use or processing" (e.g., medicinal plants) and (iv) "plant-based resources" (e.g., firewood). Details on the local market prices used to value these ES and the formulae used to get the economic value of each ES are given in Appendix 4.2 and 4.3.

The economic value of crops was analyzed by determining the total amount of crops gathered yearly and multiplying it by the market value. The value of the crops produced was subtracted from the value of all the external inputs, such as chemical fertilizers, manure, and tractor costs, to get the ES value of the crop yield.

The economic value of milk was estimated by multiplying the market value per liter by the liters per household per day multiplied by the total number of days in a year. The economic value of meat was estimated by multiplying the market price of an animal per household by the number of animals sold annually. To estimate the economic value of medicinal plants, the annual collection of medicinal plants per household was multiplied by the local market prices. The economic value of the firewood was estimated by multiplying the annual per-household consumption of the firewood with its local price.

Table 4.2: Methods Used and Units of Measurement for Valuation of Ecosystem Services in Chitral Valley

Sr#	CICES Ecosystem Services Class	Ecosystem Services	Economic Valuation Method	Unit Price
1	Cultivated crops	Wheat & Maize	Market price-based approach	Kg/HH/yr
2	Reared animals and their outputs	Milk	Market price-based approach	L/HH/yr
		Meat	Market price-based approach	Animals/HH/yr
3	Surface water for drinking	Water for drinking	Replacement cost method	L/HH/yr
4	Fibers and other materials from plants, algae, and animals for direct use or processing	Medicinal plants	Market price-based approach	Kg/HH/yr
5	Materials from plants, algae, and animals for agricultural use	Forage for livestock	Replacement cost method	Kg/HH/yr
6	Surface water for non-drinking purposes	Water for household consumption	Replacement cost method	L/HH/yr
7	Plant-based resources	Firewood	Market price-based approach	Kg/HH/yr

ES Valuation Using the Replacement Cost Method

The cost of replacing ES with artificial technologies is estimated using the replacement cost approach. This strategy was utilized in Chitral Valley to replace ES that lacked a market price and might be replaced by comparable materials available for purchase. The prices chosen were those found on the local market. Table 4.2 details the economic valuation method (Kumar & Yashiro, 2014) for each ES considered in this study.

The economic values of the ES were calculated using the replacement cost method for the following CICES classes: (i) "surface water for drinking" (e.g., for drinking purposes), (ii) "materials from plants, algae, and animals for agricultural use" (e.g., fodder for livestock), and (iii) "surface water for non-drinking purposes" (e.g., for household consumption). The local values used to calculate each ES in the Chitral Valley, and the formulae used to get the economic value of an ES under this approach are provided in the Appendices.

The value of water for drinking for daily household consumption was calculated by multiplying the known water volume by the number of people in the household and the price of water. The local price of water was considered as the monthly water charge. The stream water is the primary water source for Chitral Valley communities and is free of charge. The value of water for household consumption was determined by multiplying the annual collection of water per household with the local water price (Ward, 2007). The economic value of the forage for livestock was estimated primarily for the different livestock species individually. The amounts of forage consumed were multiplied by the local price of forage annually and then added up to get the value of forage for livestock in the Valley.

Total Economic Value

The overall economic benefit was determined by assigning to each household the economic value for each provisioning ES by adding up the means and standard errors for each household service (Lindberg, 2000). The household earning values were calculated by the respondents for all their various sources of income (Cavendish, 2002) to determine the Chitral Valley’s average income.

4.3 RESULTS

4.3.1 Ecosystem Services

The identified Ecosystem Services represented 8 of the 16 CICES classes (Table 4.3, Haines-Young and Potschin, 2010). The most frequently used ES were 'plant-based resources', i.e., firewood (99% usage) followed by 'surface water for drinking' (98% usage), 'surface water for non-drinking,' i.e., water for household use (98% usage), 'materials from plants, algae, and animals for agricultural use,' i.e., 'forage for livestock' (83% usage), 'reared animals and their outputs', e.g., milk and meat (80% & 5% usage), and 'cultivated crops' (64% usage) in the Chitral Valley. The other services used were 'fibers and other materials from plants, algae, and animals for direct use or processing,' such as medicinal plants (29% usage). Table 4.3 lists the identified ES used by the Chitral Valley communities, indicating the percentage of respondents using these services.

Table 4.3: Ecosystem Services (ES) in Chitral Valley According to CICES Classification System

CICES Section	CICES Division	CICES Group	CICES Class	Class Type	ES identified	% Responses
Provisioning Services	Nutrition	Biomass	Cultivated crops	Crops by amount, type	Akhroot, Apple, Bajra, Barley, Carrot, Cherry, French beans, Gram Seed, Jawar, Khobani, Lobia, Maize, Masoor Daal, Onion, Peanut, Piyaz, Potato, Rice, Shaftal, Shaljam, Sonf, Tomato, Wheat (valuation done for wheat and maize only)	64
			Reared animals and their outputs	Animals, products by amount, type	Horse, cow, goat, sheep, donkey, yak. Cow used for milk and meat, goat and sheep used for meat, horses and donkeys used for transport. (Valuation done for milk and meat only)	85
		Water	Surface water for drinking	By amount, type	Water for household purpose	98
	Materials	Biomass	Fibers and other materials from plants, algae and animals for direct use or processing	Materials by amount type, use, media, (land, soil, freshwater, marine)	Medicinal plants	29

CICES Section	CICES Division	CICES Group	CICES Class	Class Type	ES identified	% Responses
			Materials from plants, algae, and animals for agricultural use		Forage for livestock	83
		Water	Surface water for non-drinking purposes	By amount, type, and use	Water for Household use	98
	Energy	Biomass based energy	Plant-based resources	By amount, type, source	Firewood	99
Cultural Services	Physical	Physical and experiential interactions	Physical use of land-/seascapes in different environmental settings	By visits/use data, plants, animals, ecosystem type	Walking, hiking, climbing	73

The central Chitral Valley communities (Gasht, Morder, Gazodokh, Mughlandeh and Afghaniandeh) used the most ES (80.3%) on average, followed by the eastern Chitral Valley communities (71.4%) on average (Brook Laspur & Sor Laspur) and the southern Chitral Valley communities (64.3%) on average (Dangrikandeh, Shahmirandeh, Singoor and Thingshan). Figure 4.3 details each ES percentage used by the selected communities in the Chitral Valley.

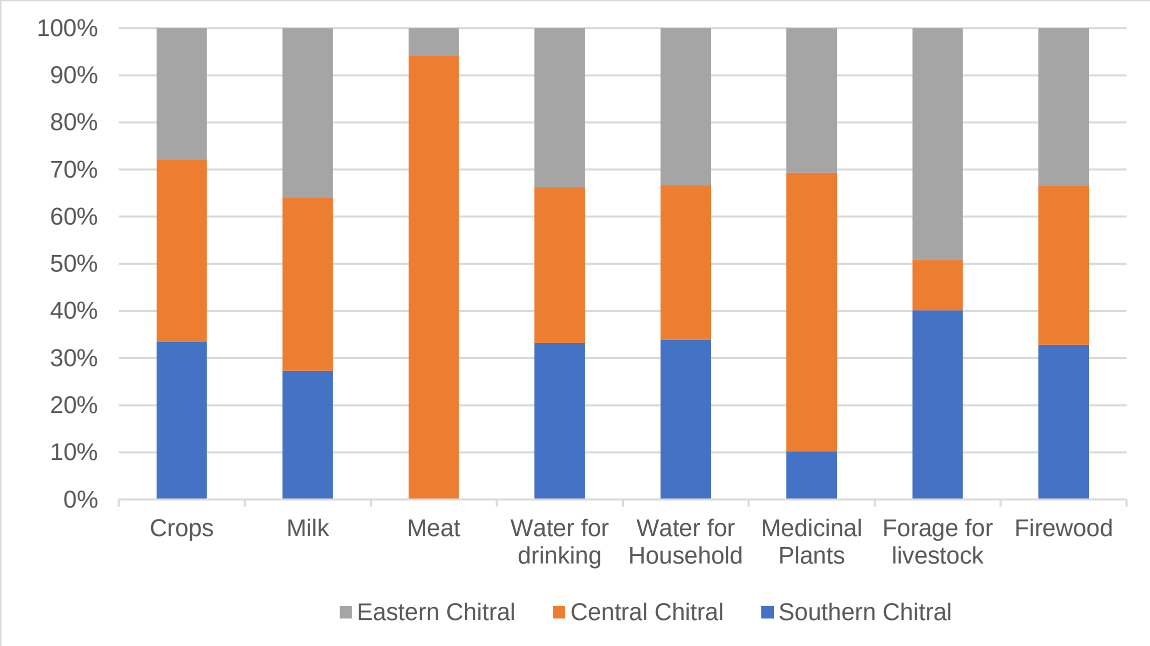


Figure 4.3: Ecosystem Services (ES) Percentage Used by each Selected Community in the Eastern, Central and Southern Chital Valley

4.3.2 Economic Values

The most economically valued ES was 'forage for livestock' 2219 ± 164.8 USD/HH/yr, contributing around 30.5% of the total economic importance of ES supply. This was followed by 'water for non-drinking uses' 1842 ± 127.2 USD/HH/yr (25.3%), 'firewood' 1416 ± 96.3 USD/HH/yr (19.5%), and 'water for drinking purposes' 898 ± 28.8 USD/HH/yr (12.3%). 'Meat from reared animals' contributed to 6.3% of the total ES supply 458 ± 23.8 USD/HH/yr followed by 'Milk from reared animals' 359 ± 31.8 USD/HH/yr (4.9%), 'cultivated crops' 74.6 ± 8.1 USD/HH/yr (1.0%), and 'medicinal plants' 6 ± 29 USD/HH/yr (0.1%). The medicinal plants were the least economically valued service and were collected by the local communities to treat different ailments (Table 4.4).

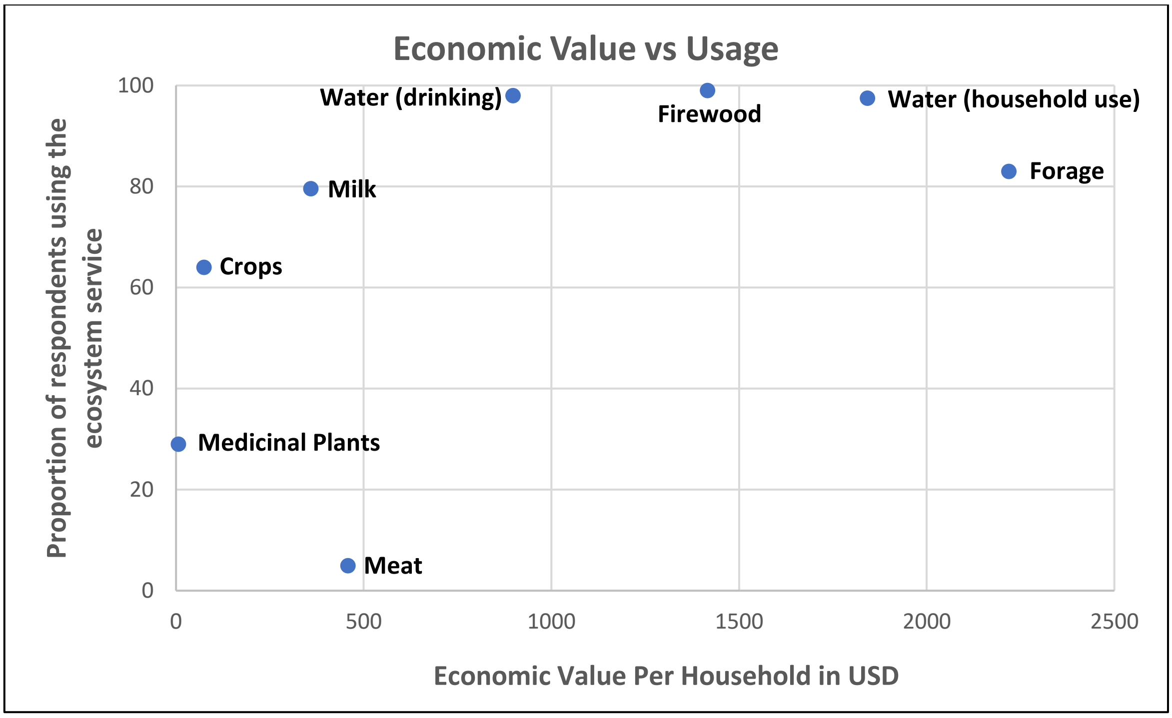


Figure 4.4: Economic Values of the Ecosystem Services and the Proportion of Respondents Using Them

In the Chitral Valley, people's livelihood depended on local ES such as 'cultivated crops', 'reared animals and their outputs', whereas the other sources included employment. The gross economic value of the identified ES amounted to 7272 ± 481.6 USD/HH/yr (Table 4.4).

The dependency on local ES was not captured by the economic values alone. The approximate economic support of the ES of 7272 ± 481.6 USD/HH/yr was 3.7 times the annual household income in the Chitral Valley (Figure 4.5). The 7.3% share of the total economic value of ES directly contributed to the household income worth 533 USD/HH/yr (the economic support sought from the ES such as cultivated crops, livestock rearing, and their outputs), whereas the remaining 92.7% share contributed to the cost's worth 6740 USD/HH/yr.

Table 4.4: Economic Values of Ecosystem Services (ES) in Chitral Valley.

(1 USD = 133 PKR in 2018)

CICES Class of ES	ES utilized	Mean ± SE (USD /HH /yr)	Proportion of Respondents Using ES (%)	Proportion of Total Value of ES (%)
Cultivated crops	Crops	74.6 ± 8.1	64	1
Reared animals and their outputs	Milk	359 ± 31.8	80	4.9
Reared animals and their outputs	Meat	458 ± 23.8	5	6.3
Surface water for drinking	Water for drinking purpose	898 ± 28.8	98	12.3
Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	6 ± 0.8	29	0.1
Materials from plants, algae and animals for agricultural use	Forage for livestock	2219 ± 165	83	30.5
Surface water for non-drinking purposes	Water for household use	1842 ± 127	98	25.3
Plant-based resources	Firewood	1416 ± 96.3	99	19.5
Total Economic Value		7272 ± 481.6	-	

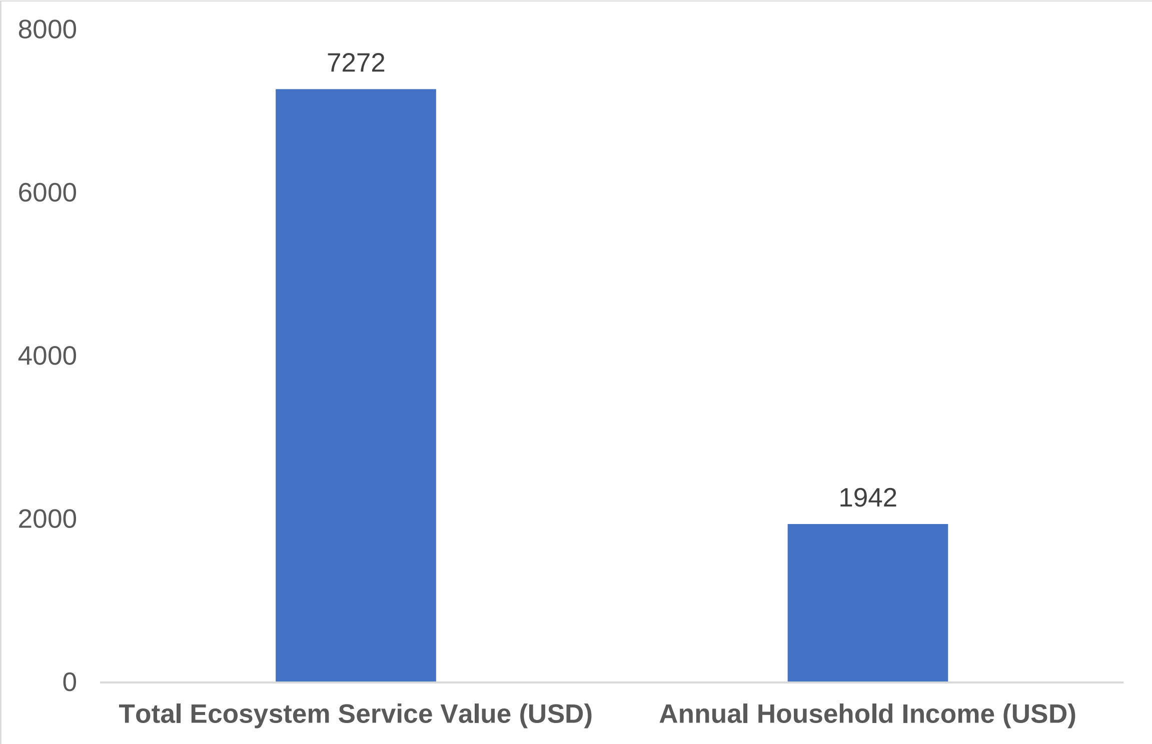


Figure 4.5: The Total Economic Value of the Ecosystem Services (ES) in USD/HH/Year vs. the Annual Household Income in USD/Household/Year

4.4 DISCUSSION

4.4.1 ES Identification

Our study revealed a range of ES identified and valued by the Chitral Valley communities in the Hindukush region in Pakistan. The communities in this study showed awareness and concern for ES, which complements other studies in the arid mountain regions (Saeed et al., 2022; Din et al., 2020; Murali et al., 2017b). Nearly all the respondents used the ES belonging to CICES classes, such as the cultivated crops, reared animals and their outputs, surface water for drinking, fibres and other materials from plants, surface water for non-drinking purposes, and plant-based resources. We could find slight differences among the Chitral Valley community groups made on a spatial basis with respect to the types of ES used (see Section 4.3.1). The Hindu Kush landscape in Pakistan provides a valuable source of different kinds of ES for local communities. A higher contribution of provisioning ES was observed in this study which might reflect quantification of nearly all the provisioning ES identified by the respondents, and this may reflect the higher values in our study.

4.4.2 ES Total Economic Value

The economic value of the ES in the Chitral Valley (7272 ± 481 USD/HH/yr) was significantly more than the Gurez Valley (6730 ± 520 USD/Household /yr, Saeed et al., 2022), Qurumbar National Park (5955 USD/Household /yr, Din et al., 2020) and India's Spiti Valley (3622 ± 149 USD/Household/yr, Murali et al., 2017a). However this value was less than some other arid regions, namely Khunjerab National Park in Pakistan (8912 USD/Household/yr; Din et al., (2020); livestock rearing system in Changtang, India (79,303 ± 9204 USD/Household/yr); crop yield system, in Changtang India, 15,083 ± 1656 USD/Household/yr; the Tost Nature Reserve, Mongolia (150,100 ± 13,290 USD/Household/yr); and Sarychat, India (25,544 ± 5236 USD/Household/yr; Murali et al., 2020).

Our results revealed that medicinal plants contributed non-significantly to the household incomes in the Chitral Valley (6 ± 0.8 USD/Household/yr, 0.1% contribution). This is contrary to the case mentioned by Saeed et al., (2022) in the Gurez Valley but complements the findings by Din et al., (2020) for the Pamir-Karakoram landscape and Murali et al., (2020) for Spiti Valley, India, Tost Nature Reserve, Mongolia Changtang region, India, for the nomadic communities; and Sarychat region, Kyrgyzstan.

In our study, the economic value of the ES was 3.7 times higher than the average income of a family in the Chitral Valley. This refers to people's dependence on income from selling goods obtained through provisioning ES. This value was even higher in the Changtang region of the nomadic pastoralists (26.1 X), in the Tost Nature Reserve, Mongolia (38.7 X), and in the Sarychat region, Kyrgyzstan (7.4 X; Murali et al., 2020).

4.4.3 Ecosystem Service Values Comparison in Similar Landscapes

Forage for Livestock

'Forage for livestock' was the highest valued (30.5%) ES in the Chitral Valley (2219 ± 164.8 USD/HH/yr). Similar trends have been documented in the Spiti Valley (1960 ±

208 USD/HH/yr), Sarychat region, Kyrgyzstan (24,073 ± 5115 USD/HH/yr) Changtang region, India (75,025 ± 8848 USD/HH/yr, in livestock rearing system), and Tost Nature Reserve, Mongolia (145,381 ± 13027 USD/HH/yr, Murali et al, 2020). Similar results of the high economic value of forage were also reported from the Qurumber National Park and Khunjerab National Park in the Pamir Karakoram landscape in Pakistan, (2436 USD/Household/yr, and 1944 USD/Household/yr, separately, Din et al., 2020).

Firewood

The firewood had the third highest economic value, accounting for 19.5% of total ESs value in the Valley worth 1416 ± 96.3 USD/HH/yr. This value was more than estimated in the Spiti Valley (201 ± 17 USD/HH/yr), Tost nature reserve, Mongolia (206 ± 16 USD/HH/yr), Changtang, India (900 ± 151 USD/HH/yr), and Sarychat, Kyrgyzstan (169 ± 25 USD/HH/yr, Murali et al., 2020). Firewood had lower economic values in the Pamir Karakoram landscape as well, i.e., 432 USD/HH/yr in the Qurumber National Park and 540 USD/HH/yr in the Khunjerab National Park (Din et al., 2020).

Reared Animals and their Products

The ES 'livestock (reared animals) and their outputs' had the fifth highest economic value 817 ± 55.6 USD/HH/yr (meat 458 ± 23.8 USD/HH/yr and milk 359 ± 31.8 USD/HH/yr clubbed together). This value was lower in the Spiti Valley 523 ± 46.2 USD/HH/yr; Tost nature reserve, Mongolia 3881 ± 360 USD/HH/yr; Sarychat, Kyrgyzstan, 1182 ± 177 USD/HH/yr; and Changtang, India, 929 ± 67 USD/HH/yr. Reared animals are an important part of the cultural and religious aspects of the Muslim ethnic group in the Chitral Valley, which are bought and sold during the annual religious ceremonies.

Water

Water for household use had the second highest value of 1842 ± 127 USD/HH/yr, whereas water for drinking purposes had the fourth highest value of 898 ± 28 USD/HH/yr in the Chitral Valley. These values complement the study by Din et al. (2020), where the Qurumber National Park and the Khunjerab National Park in Pakistan had water values of

826 USD/HH/yr each. In the Chitral Valley, water is mainly obtained from nearby streams for household use and livestock consumption, free of charge. The higher water values in this study are contrary to the case of other arid mountainous regions of the Indian Trans-Himalayan Spiti Valley, 35 ± 4.3 USD/HH/yr, in Tost Nature Reserve, Mongolia 533 ± 59.7 USD/HH/yr, in Changtang region, India 41.5 ± 3.1 USD/HH/yr (livestock production system), and Sarychat region, Kyrgyzstan 83.3 ± 11.9 USD/HH/yr, (Murali et al., 2020).

4.4.4 Policy Implications

The impacts of the climatic, weather, and land use changes on the various ES and communities are anticipated to have unprecedented implications on human well-being since ES are extremely geographically and temporally varied (IPBES, 2019). Despite the global concerns of population growth and climatic change, governance or social values that influence positive and negative change are hardly ever considered (Balvanera et al., 2019). People in the Global South, who have a relatively poorer adaptive capacity but are more exposed, are disproportionately affected by environmental degradation brought on by climatic or direct anthropogenic factors (IPCC, 2018). Asia's droughts and floods harmed 34% of developing nations' agriculture and animal production, resulting in economic losses of $48 billion (FAO, 2021). Additionally, an analysis of the supply and demand of ecosystem services has drawn attention to the increasing scarcity of essential ecosystem services, such as water, food, and forage, in mountainous areas of the Global South (Grêt-Regamey, 2020). Climate change is reportedly affecting the productivity of crops, livestock rearing, water quality, and the provision of ecosystem services in Gurez Valley (Saeed et al., 2022).

Most people in the HKH region are agro-pastoralists and live in villages, where they practice subsistence agriculture and pastoralism, whereas in Pakistan, the mountain region's population is growing (Sharma et al., 2019). This scenario concerns the sustainable ES provision by the HKH landscape. Moreover, the limited knowledge of the ES discourse is seen in the HKH region, with only a few studies on ES in Pakistan. For example, the national policy documents do not mention any policy interventions to acknowledge 'ecosystem services' and their implementation and governance. Establishing an overarching framework for climate action must be devised to consider the local contexts, capacities, and vulnerabilities to be adopted by the indigenous communities. However, the government of Khyber Pakhtunkhwa developed a 'Climate Change Policy' (2022).

4.4.5 Limitations of the Study

ES is an under-researched topic in Pakistan's mountains. In this study, we could only focus our analysis on the provisioning and cultural ES. We anticipate that when regulatory ES are factored in, the economic worth of ES in the Chitral Valley will likely increase substantially. Due to time and resource constraints, we could only sample 11 communities; nevertheless, sampling more communities, especially in the Broghil National Park, might have provided a different picture of ES use and its economic value in the entire Valley. Future research on this topic could concentrate on regulatory ES, as well as the trade-offs that exist between provisioning and regulating ES.

4.5 CONCLUSION

This research attempted to monetize and evaluate the key ES of Chitral Valley in the Hindukush range, Pakistan, and highlight the Chitral Valley communities' considerable reliance on these services. This is a pilot study to identify community views and ES in the Pakistani Hindukush range in Chitral Valley. This study supports the idea that this and similar mountain areas promote community livelihoods and well-being through providing ES. Therefore, sustainable harvesting of the ES and official acknowledgment of ES in the regulatory systems by concerned policymaking institutions and authorities is needed.

4.6 ACKNOWLEDGEMENTS

We thank the Snow Leopard Trust, USA, for funding this study. We really appreciate the cooperation and support of the Chitral Valley communities. We also acknowledge the support of the Snow Leopard Foundation-Pakistan for fieldwork in terms of equipment and trained field staff. We are highly grateful to, Barkatullah Khan, Muhammad Amir, Sana Ullah, Syed Ur Rehman, Abuzar Razi, and Sara Razi for helping with data collection and compilation. We are thankful to Fathul Bari, Ejaz Ahmad, and Muhammad Jahangir for providing local market price information to monetize ecosystem services. We thank Doost Ali Nawaz, and ESRI for providing GIS support. We owe special thanks to Mr. Saeed, KP Wildlife Department, for all the field support and technical help in carrying out this study.

4.7 REFERENCES

Balvanera, P., Pfaff, A., Viña, A., García Frapolli, E., Merino, L., Minang, P. A., … Sidorovich, A. (2019). Status and trends – Drivers of change. In E. S. Brondízio, J. Settele, S. Díaz, & H. Ngo (Eds.), *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany: IPBES. https://doi.org/10.5281/zenodo.3831882

Cavendish, W., (2002). Quantitative methods for estimating the economic value of resource use to rural households. In: Luckert, M.K., Campbell, B.M. (Eds.), *Uncovering the Hidden Harvest Valuation Methods for Woodland and Forest Resources.* Earthscan Publications, London, 17–63.

Chaudhary S, McGregor A, Houston D, Chettri N (2015) The evolution of ecosystem services: A time series and discourse-centered analysis. *Environmental Science & Policy* 54: 25-34. https://doi.org/10.1016/j.envsci.2015.04.025

Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J, Raskin RG (1997) The value of the world's ecosystem services and natural capital. *Nature* 387 (6630): 253-260. https://doi.org/10.1038/387253a0

Din, J. U., Nawaz, M. A., Norma-Rashid, Y., Ahmad, F., Hussain, K., Ali, H., & Adli, D. S. H. (2020). Ecosystem Services in a Snow Leopard Landscape: A Comparative Analysis of Two High-elevation National Parks in the Karakoram–Pamir. *Mountain Research and Development*, 40 (2), R11. https://doi.org/10.1659/MRD-JOURNAL-D-19-00047.1

Ehrlich, P., & Ehrlich, A. (1981). Extinction: The causes and consequences of the disappearance of species. eweb:35542, 305. https://doi.org/10.4236/jbm.2020.83010

Erdozain, M., Freeman, E. C., Ouellet Dallaire, C., Teichert, S., Nelson, H. W., & Creed, I. F. (2018). Demand for provisioning ecosystem services as a driver of change in the Canadian boreal zone1. *Environmental Reviews*, 27(2), 166-184. https://doi.org/10.1139/er-2018-0064@er-bor.issue01

FAO, (2021) The impact of disasters and crises on agriculture and food security. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). Accessed 22 December 2022 https://www.fao.org/documents/card/en/c/cb3673en

Grêt-Regamey, A., & Weibel, B. (2020). Global assessment of mountain ecosystem services using earth observation data. *Ecosystem Services*, 46, 101213. https://doi.org/10.1016/j.ecoser.2020.101213

Haines-Young, R., & Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being. In D. G. Raffaelli & C. L. J. Frid (Eds.), *Ecosystem Ecology* 110–139. Cambridge University Press. https://doi.org/10.1017/CBO9780511750458.007

IPBES, (2019). In: Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Roy Chowdhury, R., Shin, Y.J., Visseren-Hamakers, I.J., Willis, K.J., Zayas, C.N. (Eds.), *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* IPBES Secretariat, Bonn, Germany 56 pages. https://doi.org/10.5281/zenodo.3553579

IPCC, (2018). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (p. 32). Geneva, Switzerland: *World Meteorological Organization*. Accessed online 2nd March 2024 https://archive.ipcc.ch/pdf/special-reports/sr15/sr15_spm_final.pdf

Khan, N., Shaukat, S. S., Ahmed, M., & Siddiqui, M. F. (2013). Vegetation-environment relationships in the forests of Chitral district Hindukush range of Pakistan. *Journal of Forestry Research*, 24(2), 205–216. https://doi.org/10.1016/j.ecolecon.2009.04.018.

Khyber Pakhtunkhwa Climate Change Policy (2022). Environmental Protection Agency. Forestry, Environment & Wildlife Department, Government of Khyber Pakhtunkhwa. Accessed online December 14th, 2022 https://epakp.gov.pk/wp-content/uploads/2022/03/KP-Climate-Change-Policy-Approved-2017.pdf.

Kumar Epstein, G. (2017). Local rulemaking, enforcement, and compliance in state-owned forest commons. *Ecological Economics*, pp. 131, 312-321. https://DOI:10.1016/j.ecolecon.2016.09.012

Kumar, P., Martinez-Alier, J. (2011). The Economics of Ecosystem Services and Biodiversity: An International Assessment. *Economic and Political Weekly*, 46 (24), 76-80. Retrieved June 17, 2021, from http://www.jstor.org/stable/23018249

Kumar, P., Yashiro M. (2014) The Marginal Poor and Their Dependence on Ecosystem Services: Evidence from South Asia and Sub-Saharan Africa. In: von Braun J., Gatzweiler F. (eds) Marginality. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7061-4_11

Lindberg, V., (2000). Uncertainties and error propagation. Manual on Uncertainties, Graphing and the Vernier Caliper, Part I. Rochester Institute of Technology, New York, USA. http://www.rit.edu/uphysics/uncertinities/Uncertinitiespart2.html#addsub

Liu, L., Wang, Z., Wang, Y., Zhang, Y., Shen, J., Qin, D., & Li, S. (2019). Trade-off analyses of multiple mountain ecosystem services along elevation, vegetation cover and precipitation gradients: A case study in the Taihang Mountains. *Ecological Indicators*, 103, 94-104. https://doi:10.1016/j.ecolind.2019.03.034

Millenium Ecosystem Assessment, (2005). *Millennium Ecosystem Assessment: Ecosystems and Human Well-being - Synthesis*. Island Press. Accessed online 2nd March 2024 https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Murali R, Lkhagvajav P, Saeed U, Kizi VA, Zhumbai-Uulu K, Nawaz MA, Bhatnagar YV, Sharma K, Mishra C. (2017a). Valuation of ecosystem services in snow leopard landscapes of Asia. Snow Leopard Trust, Nature Conservation Foundation, Snow Leopard Conservation Foundation, Snow Leopard Foundation Kyrgyzstan, and Snow Leopard Foundation Pakistan. Report Submitted to the Global Environment Facility (GEF) funded United Nations Development Program (UNDP) project on Transboundary Cooperation for Snow Leopard and Ecosystem Conservation. Accessed online 2nd March 2024https://globalsnowleopard.org/wp-content/uploads/2018/12/Valuation-of-ecosystem-services-in-snow-leopard-landscapes.pdf

Murali, R., Ikhagvajav, P., Amankul, V., Jumabay, K., Sharma, K., Bhatnagar, Y. V., Suryawanshi, K., & Mishra, C. (2020). Ecosystem service dependence in livestock and crop-based production systems in Asia's high mountains. *Journal of Arid Environments*, 180, 104204. https://doi.org/10.1016/j.jaridenv.2020.104204

Murali, R., Redpath, S., & Mishra, C. (2017b). The value of ecosystem services in the high altitude Spiti Valley, Indian Trans-Himalaya. *Ecosystem Services*, 28, 115–123. https://doi.org/10.1016/j.ecoser.2017.10.018

Nomination Dossier, (2022). Chitral Bashkar Garm chashma Biosphere Reserve (CBGBR), Wildlife Department, Khyber Pakhtunkhwa, Pakistan.

Nüsser, M., & Dickoré, W. B. (2002). A tangle in the triangle: Vegetation map of the eastern Hindukush (Chitral, northern Pakistan). Erdkunde https://www.jstor.org/stable/23218603.

Pomfret, R. (2014). The economies of central Asia. Princeton University Press.

Saeed, U., Arshad, M., Hayat, S., Morelli, T. L., & Nawaz, M. A. (2022). Analysis of provisioning ecosystem services and perceptions of climate change for indigenous communities in the Western Himalayan Gurez Valley, Pakistan. *Ecosystem Services*, 56, 101453. https://doi.org/10.1016/j.ecoser.2022.101453

Sharma, E., Molden, D., Rahman, A., Khatiwada, Y. R., Zhang, L., Singh, S. P., ... & Wester, P. (2019). Introduction to the Hindu Kush Himalaya Assessment. In The Hindu Kush Himalaya Assessment, pp. 1-16. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_1

TEEB, (2010) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. Earthscan, London-Washington. Accessed online 2nd March 2024 https://www.teebweb.org/wpcontent/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf

TEEB Foundations, (2010). The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Earthscan, London. Accessed online 2nd March 2024https://www.teebweb.org/wpcontent/uploads/Study%20and%20Reports/Reports/Ecological%20and%20Economic%20Foundations/TEEB%20Ecological%20and%20Economic%20Foundations%20report/TEEB%20Foundations.pdf

Van Oort, B., Bhatta, L.D., Baral, H., Rai, R.K., Dhakal, M., Rucevska, I., Adhikari, R., (2015). Assessing community values to support mapping of ecosystem services in the Koshi river basin. Nepal. *Ecosystem Services* 13, 70–80. http://dx.doi.org/10.1016/j.ecoser.2014.11.004

Viviroli D, Kummu M, Meybeck M et al (2020) Increasing dependence of lowland populations on mountain water resources. *Nat Sustain* 3:917–928. https://doi.org/10.1038/s41893-020-0559-9

Ward, D., & McKague, K. (2007). Water requirements of livestock. Ministry of agriculture, food, and rural affairs, Government of Canada. Retrieved 12 June 2021, from http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm

Wertime, M.B. et al., 2011. International Forestry Resources and Institutions (IFRI) Research Program: Field Manual, Michigan, USA. Available at: http://www.ifriresearch.net/wp-content/uploads/2012/09/IFRI_Manual.pdf

Wyatt, P. (2009). Replacement cost and market value. Journal of Property Investment & Finance. https://doi:10.1108/14635780910993186

Yu, Y., Li, J., Zhou, Z., Ma, X., & Zhang, X. (2021). Response of multiple mountain ecosystem services on environmental gradients: How to respond, and where should be priority conservation?. *Journal of Cleaner Production*, 278, 123264. https://doi.org/10.1016/j.jclepro.2020.123264

APPENDIX 4.1: SCRIPT USED FOR ECOSYSTEM SERVICES VALUATION ASSESSMENT AND CLIMATE CHANGE PERCEPTIONS

Asked for Every Interview

1. Village name:
2. Respondent name:
3. Number of people in the household:
4. Number of people employed in the household:
5. Kind of employment:
6. What are their main sources of income?

Compiling a list of ecosystem services used from the area (only the first three interviews or this can even be a focal group discussion).

1. Do you feel that nature gives you benefits? What are the benefits that nature in the valley gives you?

   This question will have to be phrased in such a way that they understand it. Local people have different expressions and names for "nature" or the pastures. Try a few variations of nature and see the one that they can understand or relate to the most. Make sure that this question is asked first, so that responses are not biased, based on the previous questions that they might have been asked.

   ▷ Have you experienced any changes in climate in the last five years?

2. What are the crops grown in the village? Which crops are sold? How much is one kg of this crop sold for?
3. What are the other crops used for?
4. Can you please tell me what you do for agriculture throughout the year? Are there are any wild plants or wild animal products that you collect for agriculture? For

example, for either fertilizing the land or levelling the land? Can you please name them? (Make a list of the different plants/animals they name)

5. How do you get water from the pastures for agriculture? How do you share your water in the village?
6. What do you use for fertilizer? How much fertilizer is needed for one acre of land in a year?
7. Can you please describe how you herd the different livestock in the village? When are they taken to the pastures? How are they fed during the winter months? Do you collect forage? Are there any special wild plants that you collect from the pastures to feed the livestock? Can you name the plants that are collected?
8. What do they use livestock for?
9. How much is one kg of meat?
10. How much is one kg of wool?
11. How much is one litre of milk?
12. How much does 1kg of livestock feed/fodder cost?
13. What are the rates for selling livestock? Age/sex rates.
14. Do you collect any other wild plants or animal products from the pastures? For example, do you collect any plants to eat, or for religious or decorative purposes? Can you please list them?
15. What else do you collect from the pastures? (Give them some time to respond, if they don't respond, you can prompt them by asking Do you collect dung or firewood?)
16. Is anything collected from the pastures for roofing or other housing material? If you, what is collected? For people who don't collect this for their houses, what do they use as a replacement?
17. Do you sell any products that are collected from pastures? If so, how much do you sell them for? (Get a price per kg, if possible)

18. How much does wood/gas cost if it is bought?

Economically valuing ecosystem services (this must be asked on every respondent)

Agriculture

1. What are the crops that you grow?
2. How much land do you have? How much land do you cultivate?
3. How much of crops did you sell last year?
4. How much of the other crops did you harvest last year?
5. Do you hire labour in your farm? If so, how many and for how many days in a year and at what rate?
6. Do you buy any fertilizers or pesticides? If so, how much do you spend on these?
7. How much local fertilizer do you use?
8. How do you plough the land? If you use a tractor what are the rates/hour and how many hours do you use it for?

Livestock

1. What are the livestock that you own? Age/sex composition? How many wool producing sheep/goats do you have?
2. What do you use livestock for?
3. How much milk do you get per day?
4. How much meat did you sell last year?
5. How much wool/pashmina did you sell last year?
6. Do you use livestock to plough your land? If so, which one, and for how long?
7. Do you buy any animal feed or fodder for your livestock? If so, how much do you spend on it?

Pasture use

From the list of plants collected from the previous set of questions in section 1, ask them how much and of each service do they collect? How much time do they spend collecting these services? This would also include wood and dung if they mentioned it in the first set.

1. How much water does your household consume in a day? Where do you get your water from? Do you pay for water? If so, how much do you pay per month? (Sometimes, they collect water in cans, and will be able to say how many cans they collect in a day)
2. Do you collect any medicinal plants from the pastures? What do you use it for? How much do you collect in a year?

Housing Cost

If they say they collect plants from the pasture for housing material, then ask the following questions: (You may visually estimate the house size as small, medium, large and mention the number of floors the house has).

1. How old is the house?
2. How much of the plant material did you collect from the pasture for your house? When did you collect it?
3. When you are sick, do you go to a traditional healer or to a doctor? If the last year, what illnesses did you and people in your family, go to for the traditional healer and how many times?

Measurement units: People are often comfortable answering the amount they collect/use in the units they are familiar with. So, if they say they collect in Boris, cans, or animal backs, then let them give it in that unit. Afterward, we can measure and find out how many kilograms are in a bag.

APPENDIX 4.2: LIST OF CHITRAL VALLEY'S LOCAL MARKET PRICE AND REPLACEMENT COST VALUES

(1 USD = 133 PKR in 2018)

CICES Class of Ecosystem Service (ES)	ES	ES / External Inputs	Local Market Value (PKR)	Source
Cultivated crops	Crops	Wheat	35 / kg	Chitral Gol Community Development and conservation Association, Muhammad Jahangir, personal communication, 2018
		Maize	35 / kg	
		Urea	160 / kg	
		ADP	80 / kg	
		Tractor	1500 / hr	
Reared animals and their outputs	Milk	Milk	100 / litre	
Reared animals and their outputs	Meat	Sheep	9000 / animal	
		Goat	12500 / animal	
		Cow	55000 / animal	
Surface water for drinking	Water for household drinking (natural stream)	Govt water charge	5 / day	
Fibers and other materials from plants, algae, and animals for direct use or processing	Medicinal plants	*Ishpersiri (Ishpur)*	55 / kg	
		Capparis spinosa Linnaeus. (Kaveer)	900 / kg	
		Matricaria chamomilla L. (Shirisht)	250 / kg	
Materials from plants, algae, and animals for agricultural use	Forage for livestock	Forage	42.5 / kg	
Surface water for non-drinking purposes	Water for household use (natural stream)	Govt water charge	5 / day	
Plant-based resources	Firewood	Firewood	18.75 / kg	

APPENDIX 4.3: FORMULAE USED FOR ECONOMIC VALUES OF ECOSYSTEM SERVICES (ES) IN CHITRAL VALLEY

CICES Class of ES	ES	ES valuation formula
Cultivated crops	Crops	Σ (crop1 / kg * total kg sold + crop2 / kg * total kg sold) - (cost of chemicals - cost of tractor - cost of fertilizer) Where numbers in subscript represent different crops
Reared animals and their outputs	Milk	Price / litre * number of litres / HH / day * number of days / yr
	Meat	Price of an animal sold / HH * number of animals sold / yr
Surface water for drinking	Water for household purposes	Water consumed / HH / yr * number of people/ HH * price of water
Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	Σ (price / kg of mp1 / HH / yr * kg collected) + (price / kg of mp2 / HH / yr * kg collected) + (price / kg of mpn / HH / yr * kg collected) Where mp = medicinal plants and numbers in subscript represent different medicinal plant species
Materials from plants, algae, and animals for agricultural use	Forage for livestock	Σ (Price / kg of fodder * (forage by ls1 + forage ls2 + forage lsn / year) Where ls = livestock and the numbers in subscript represent different livestock species
Surface water for non-drinking purposes	Water for household use	Σ water consumed / HH / yr * price of water
Plant-based resources	Firewood	Firewood quantity / HH/ yr * price of firewood

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

CHAPTER 5

Understanding Climate Change in the Hindu Kush Range: Perceptions and Adaptation Strategies of Local Communities in Pakistan

5 UNDERSTANDING CLIMATE CHANGE IN THE HINDU KUSH RANGE: PERCEPTIONS AND ADAPTATION STRATEGIES OF LOCAL COMMUNITIES IN PAKISTAN

ABSTRACT

The communities of Chitral Valley, in the Hindu Kush Range of Pakistan, heavily rely on the natural resource base adversely affected by human activities and climatic changes. This study analyzed the communities' perceptions of climate change and the resulting adaptation strategies using the WWF-US climate crowd approach and statistical techniques such as the chi-square test and counting and frequency distributions. We found a significant difference in communities' perceptions about the biggest changes in weather and climatic hazards observed over the past 10-20 years, such as the hotter temperatures (66%), less rainfall (87%), delayed rainy season (39%), less rainfall in summer (45%), less snowfall in mid-winter (53%), more glacier melt (50%), more frequent flooding events (47%), more frequent drought events (50%), and significantly increased pest attacks (58%). These findings complement the meteorological record of Chitral Valley for the temperature and rainfall, which indicates an increase of 0.32ºC on average per decade between 1973 and 2022 and a gradual decrease in the amount of precipitation. These climatic changes are the main driving factors impacting the livelihoods of mountain communities through reduced crop yield and livestock rearing, water scarcity, pastureland productivity, increased health expenses, low business, and increased disease in humans and livestock. The communities have employed several adaptation strategies, including water management, changing crop types, infrastructure development, institutional supports, migration, livelihood diversification, and transitioning from fossil fuels to clean energy for domestic use. The human-wildlife conflict heavily impacts apex predator loss, such as the snow leopard. The government should provide accessible livelihood means, market access, knowledge, and information on climate change and facilitate the ability of local communities to adapt to and withstand climate shocks and natural hazards.

Key Words: Climate Change, Hindu Kush Range, Perceptions, Adaptation Strategies, Indigenous Communities, Chitral Valley, Pakistan.

5.1 INTRODUCTION

Numerous global studies, including those by Gillett et al. (2021) and Pokhrel et al. (2021), provide evidence of the symptoms and consequences of climate change. The IPCC (Intergovernmental Panel on Climate Change) notes that global average temperatures have risen since the early 20th century, making climate change one of the most significant environmental issues (IPCC, 2021; Koley, 2020). Climate variability results in various impacts, including changes in precipitation and temperature patterns, vegetation alterations, glacier melting, water resource depletion, land degradation, and a decline in biodiversity (IPCC, 2013). Failure to take timely mitigation and adaptation actions will result in more severe and damaging effects, as predicted by Van Meijl et al. (2018).

The effects of climate change differ by region. In South Asia, which is classified as arid and semi-arid, the average annual temperature is expected to increase up to 5.8°C by the end of the century, exceeding the widely accepted threshold of 2°C to avoid irreversible damage to the climate and ecosystems (IPCC, 2021). Climate change will have pronounced effects on various sectors, such as water, agriculture, health, forestry, biodiversity, and human health in South Asia. Meteorological records suggest that most of these impacts have already been observed in Pakistan, particularly since 1990. The average temperature in Pakistan has increased by approximately 0.5°C over the past 50 years and is projected to rise between 3°C and 6°C by the end of the century (Chaudhry, 2017). The Pakistan Meteorological Department and Global Change Impact Studies Centre predict that the most significant temperature increase by 2050 will occur in the Northern Areas, central and southern Punjab, and southern Khyber Pakhtunkhwa. Moreover, while some regions may experience increased precipitation, others may face a decrease (Government of Pakistan, 2013).

Recognizing the importance of local perceptions of climate change, Ruiz et al. (2020) suggest that a comprehensive understanding of climate change requires consideration of both atmospheric physical parameters and community values. Adaptation strategies must be developed with the perspectives of affected communities in mind. Studies conducted by Bhandari and Kim (2017) and Thornton and Scheer (2012) have highlighted the significance of local perceptions as a complement to meteorological data. Furthermore, better adaptation strategies necessitate a thorough understanding of people's views on climate change (Azócar et al., 2021; Becerra et al., 2020; Jellason et al., 2019; Bennet, 2016). Therefore, people's perceptions aid in comprehending and devising scientific approaches to tackle climatic changes (Brugnach et al., 2017).

The Chitral Valley lies in the Hindu Kush Mountain Range, an area identified as one of the most vulnerable areas to climate change in Pakistan (Government of Pakistan, 2013), due to fluctuating temperature and precipitation patterns. This will inevitably impact people's livelihoods (Zafar et al., 2018). Given the importance of local knowledge on climate change, this study aims to investigate and analyze the perceptions of local communities in the Hindu Kush Range regarding climate change. The study aims to explore the impacts of climate change on these communities and identify the adaptation strategies they employ. By gaining insights into local perspectives and adaptive practices, the research seeks to contribute valuable information for enhancing community resilience and informing future climate change adaptation policies in the region.

We wanted to test whether a relationship exists between climate change impacts and mountain communities' livelihoods, natural resources, and biodiversity of Chitral Valley. Hence, we hypothesized that:

- **Hypothesis:** Climate change is impacting mountain communities' livelihoods, natural resources, and biodiversity in the Chitral Valley.

5.2 METHODOLOGY

5.2.1 Study Area

Located in the northwest of Pakistan, the Chitral Valley is situated in the central part of the Hindu Kush Mountain Range and is the most extensive District of the Khyber Pakhtunkhwa province, with approximately 500,000 inhabitants. Chitral is a valley located in the lower part and at an altitude of 1500 meters above sea level, with an approximate latitude and longitude of 35-51°N and 71-50°E, respectively. The climate in the valley can be described as dry temperate, featuring hot summers at lower elevations and cooler summers at higher altitudes. The average annual precipitation totals 445 mm, primarily falling as rain in winter and spring (Ali, 2008). As per Hussain et al., (2013), the weather in Chitral is moderate and influenced by a winter pattern that brings rain due to western disturbances from December to March. The average annual temperature in Chitral district is 16°C, with the lowest average temperature being 8°C and the highest average temperature being 24°C. Winter temperatures can drop below freezing, and the district receives an annual rainfall of 451 mm, with heavy snowfall common in the surrounding mountains. Plate 5.1 shows the Chitral Valley landscape in the Hindu Kush Range in Pakistan.

Plate 5.1: Photo of Hindu Kush Range's Chitral Valley in Pakistan taken in November 2018

The wildlife found in the Chitral District displays a strong connection to the fauna of the Palearctic region, with a limited connection to the Oriental region in the southern part of the district. The plant life at altitudes below 2400 meters primarily consists of arid oak forests dominated by Quercus ilex. As one ascends to higher altitudes, this vegetation transitions into a dry temperate coniferous forest, characterized by *Cedrus deodara* and

Pinus gerardiana. Notable plant species in this region include *Betula utillis* (Birch), *Juniperus excelsa* (Juniper), *Salix spp*., *Poplar spp*., *Ephedra spp*., *Artemisia spp*., as well as various wild sedges and grasses (Din & Nawaz, 2010).

The primary sources of income in Chitral are subsistence agriculture and natural resources, and landholdings are typically small. Wheat, maize, pulses, potato, rice, and fodder are the primary crops grown, with high-value fruits, such as apples, apricots, pomegranates, walnuts, grapes, and pears being cultivated. Because of the low temperatures, approximately 60% of the area is monoculture with either wheat or maize, while the remaining 40% of the area situated in the valley is double-cropped and depends on irrigation from springs. Chitral contains abundant natural resources, including forests, wildlife, and minerals. This region has considerable tourism potential, which could improve the local economy. However, the district is vulnerable to frequent natural disasters, such as flash floods, soil erosion, avalanches, landslides, earthquakes, drought, and other extreme weather events (District Government Chitral, 2015).

Despite its natural beauty and ecological importance, Chitral is one of Pakistan's largest and least developed districts, facing challenges such as physical isolation, limited mobility, and weak infrastructure due to harsh seasonality and changing trends. The district government has been committed to implementing a sustainable development agenda aligned with the United Nations' Sustainable Development Goals. The uneven distribution of resources and multiple crises, despite the economic growth in the district, has resulted in almost half of the population living below the poverty line. In the past, sectoral development plans have been proposed to address these challenges, covering human, physical, natural, financial, and social assets, power generation, and climate change/DRM sectors (District Government Chitral, 2015).

5.2.2 Data Collection

Community Selection

Eleven (11) communities were selected for the study based on their accessibility to the Chitral Valley and the willingness of people to participate in interviews (Figure 5.1).

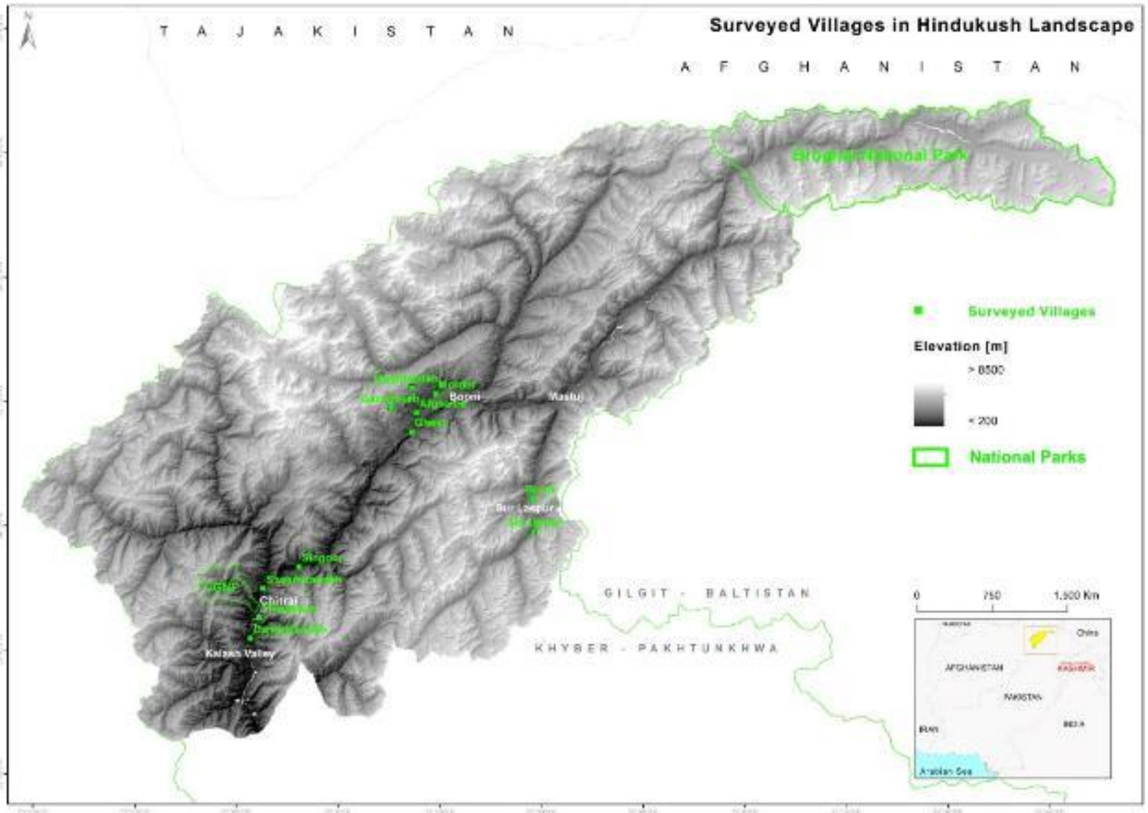


Figure 5.1: Villages Surveyed in the Hindu Kush Range's Chitral Valley in Pakistan

To provide a comprehensive picture of the perceived impacts of climate change in the Chitral Valley, data were collected at the household level from a 10% sample size for each community. All the data were collected in November 2018. In general, the communities in the valley practice subsistence agriculture and grow crops such as maize, wheat, and barley in fields. Only one crop is cultivated six months out of the year, while the fields remain snow-covered for the remainder of the year. The inhabitants collect grass and fuelwood from communal and nearby forestlands. Crops are grown primarily for household use, with some selling excess production for income. The agricultural fields surround the settlements and the forest border, with nearby forest land often used by the community as a pasture for their animals. Plate 5.2 shows local communities in the Gazodokh Village in Chitral Valley.

Questionnaire

To explore the study objectives, a questionnaire was adopted from Climate Crowd WWF-US (https://wwfclimatecrowd.org/) to conduct the interviews at the household level. We compared these perceptions across the local and regional contexts. The research team conducted 161 interviews to obtain primary data for the study. The number of interviews in each community varied, with household numbers ranging from 2 to 41. The interviewees were adults above the age of 18 years, and both men and women participated at the household level. The survey and participatory rural appraisal were used to gather information about social structure, livestock, agriculture, and the use of wood for fuel and building purposes. The answers from the survey were converted into a digital format and analyzed through content analysis, which involved using statistical techniques such as counting and frequency distributions (Bennett et al., 2003; Moore, 2010; Utts, 2014). The Chi-square test was also applied to the data to determine statistical significance. This study evaluated the effects of climate change on the livelihoods of local communities, natural resources, and biodiversity. We also examined how these communities responded to these effects.

Temperature and Rainfall Data

The temperature (1973 - 2022) and rainfall data (1993 - 2022) for the Chitral Valley were obtained from the Department of Meteorology, Government of Pakistan (temperature and precipitation were measured daily in the valley and then converted to mean monthly and annual data). Data on temperature and rainfall were imported into Microsoft Excel and graphically examined.

Plate 5.2: A Photo of Interviews Conducted with Local Communities in Chitral Valley's Site, Gazodokh in November 2018

5.3 RESULTS

5.3.1 Socioeconomic Profile

The socioeconomic profiles of the selected areas were created using indicators such as age, education, household size, and profession (Table 5.1). Most respondents from the valley were young to middle-aged (18 to 53 years old), having a large household size (more than six members). The main profession of most respondents was farming (41%), whereas other professions included business, services, and student status (28%, 18%, and 13%, respectively). Concerning education, 46% of the respondents had matric to intermediate level literacy, 22% no literacy, followed by basic education (primary to middle, 17%), and graduation and above (15%). Most families in the Chitral Valley consist of more than six people, thus falling under the large household category (66%).

5.3.2 Meteorological Data Trends

Figure 5.2 illustrates that the mean annual temperature in the Chitral Valley has been increasing gradually over 50-year time span, starting from 15.6°C in 1973 to 17.1 °C in 2022, a rate of approximately 0.32°C/ decade. This used linear least square regression lines. The positive slope coefficient in the equation (y = 0.0081, inferred an increasing annual temperature trend by roughly 0.01 ºC. The R^2 value of 0.9987 also depicts how much the selected trend line fits with the set of data or the accuracy of the correlation of the data set. In this regard, the closer R^2 to 1.0 is, the better it fits. Between 1965 and 2003, annual maximum temperatures increased while annual minimum temperatures decreased (Figure 5.3).

The Chitral Valley's mean annual rainfall data for 30 years (1993 – 2022) was 444 mm (SE = 18.3), with a decreasing trend from 485 mm to 373 mm (Figure 5.4). This was obtained using linear least square regression lines. The negative slope coefficient in the equation ($y = -4.1511x + 8777.6$), inferred a decreasing trend of mean annual rainfall by roughly 4.1mm. The R^2 value of 0.1317 also depicts how much the selected trend line fits with the data set or the accuracy of the correlation of the data set. In this regard, the closer R^2 to 1.0 is better to fit.

Table 5.1: Socio-economic Profile of the Respondents in Chitral Valley, District Chitral

Socio-economic Variables	Categories	Response	X Squared	df	p-value
Age	18-35	47	50.24	3	7.10^{e-11}
	36-53	37			
	54-70	13			
	>71	3			
Main livelihood	Farming	41	18.32	3	0.0003
	Services (teaching, govt job etc.)	18			
	Business	28			
	Student	13			
Education	Illiterate	22	24.56	3	1.91^{e-05}
	Primary to Middle	17			
	Matric to Intermediate	46			
	Graduation & above	15			
Household size	Small household (≤3 persons)	5	56.66	2	4.97^{e-13}
	Medium household (4-6 persons)	29			
	Large household (>6 persons)	66			

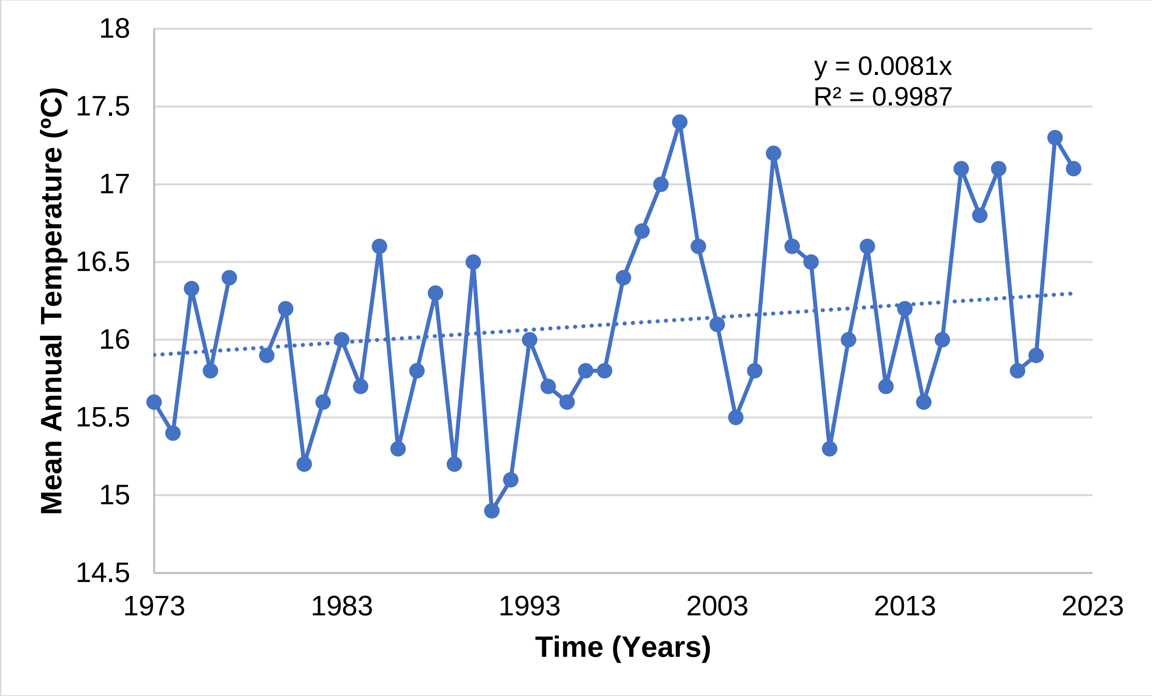


Figure 5.2: Mean Annual Temperature in Chitral Valley (1973 – 2022)

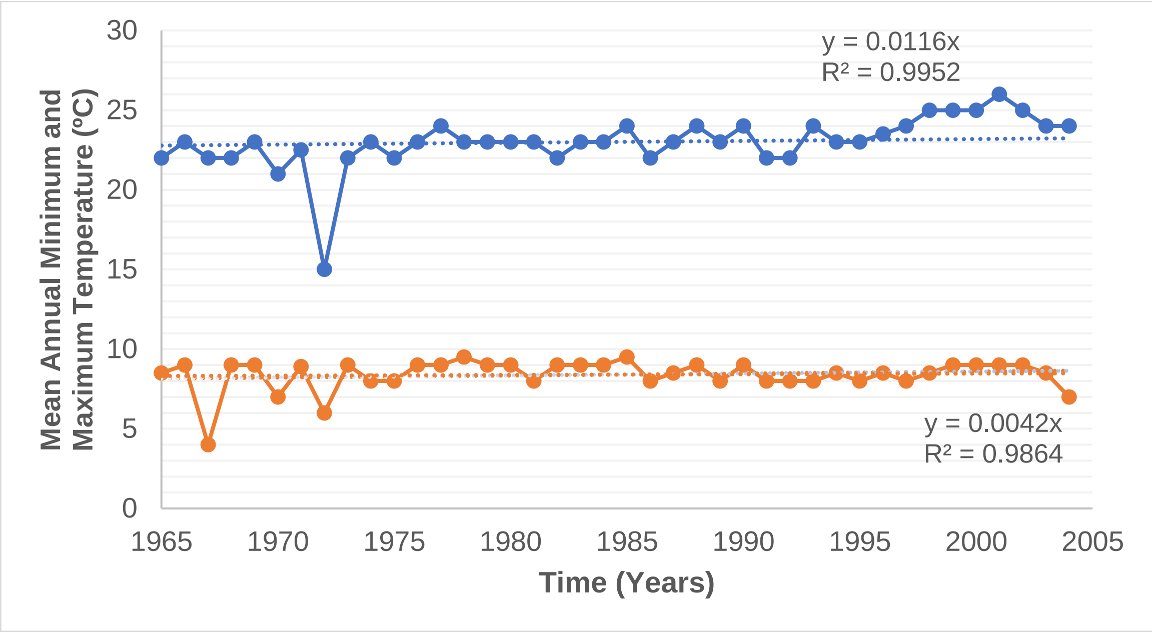


Figure 5.3: Mean Annual Maximum and Minimum Temperatures in Chitral Valley (1965 – 2003)

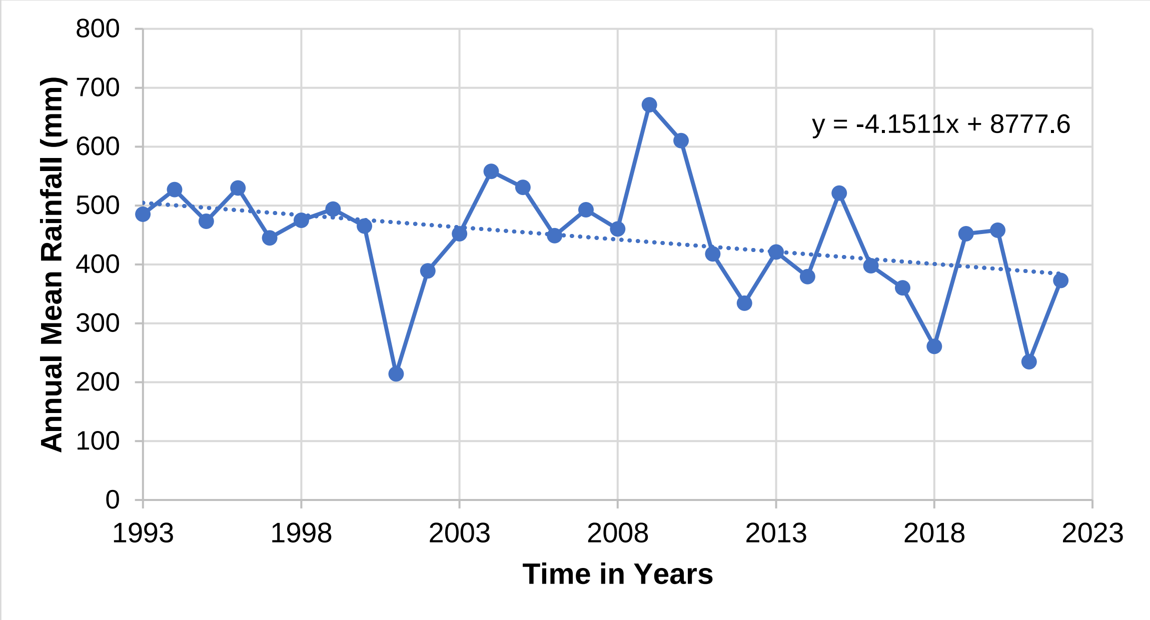


Figure 5.4: Mean Annual Rainfall in Chitral Valley (1993 – 2022)

5.3.3 Changes in Weather and Climate

All respondents generally agreed that there had been an overall change in climatic conditions in the Chitral Valley. Approximately 51% of the respondents showed extreme concern, 40% showed concern, and 9% did not show any concern. In addition to concerns about trends, the respondents further mentioned significant changes in weather and extreme climatic events (Table 5.2). Most respondents mentioned that the temperature is getting hotter in the valley (106, n=161, X^2=213, p=2.20^{e-16}); in addition, many noticed a decrease in the amount of rainfall (140, n=161, X^2=452, p=2.20^{e-16}). Less rainfall in the summer season was mentioned (69, n=161, X^2=97, p=2.20^{e-16}), followed by a decrease in the number of rainy days throughout the seasons (54, n=161, X^2=452, p=2.2^{e-16}).

Most respondents mentioned less snowfall in the mid-winter season (72, n=161, X^2=452, p=2.20^{e-16}), whereas the lowest temperatures were observed in January (the winter season is considered for three months, i.e., December, January, and February). The majority chose a significant statistical difference in the change in summer temperature as 'slightly warmed' (33, n=161, X^2=43, p=8.75^{e-09}). Concerning the changes in winter temperature, most respondents witnessed a slightly cool temperature category (55, n=161, X^2=43, p=8.75^{e-09}).

Regarding the changes in the ice or glacier melt in the Chitral Valley, most respondents said that it has been happening at a massive level, followed by those who mentioned fewer changes to this phenomenon and more variability due to the changing climate. Mentioning extreme climatic events, such as flooding, most interviewees mentioned it as a more frequent event, followed by those who said that this event is more variable now (Table 5.2). The flooding events in the Chitral Valley are linked to Glacial Lake Outburst Flood (GLOF) events, where high temperatures can increase the speed at which glaciers melt, which may increase the likelihood of flooding in the river. The water from these glaciers is the primary source of drinking water and irrigation for the local communities in the Chitral Valley.

The respondents mentioned drought as an extreme climatic event, and the majority agreed that it was more frequent due to less precipitation and fewer rainy days 92, n=161, X^2=145, p = 2.2^{e-16}. Further, most mentioned the 'significant increase' in pest attacks, followed by a 'slight increase. '

5.3.4 Weather and Climate Effects on The Community and Their Livelihoods

About 52% of respondents mentioned the 'reduced yield and livestock impacts' as the biggest hurdle in earning livelihoods in the Valley owing to the hotter temperatures, rainfall seasonality, changes in the wind patterns, extreme weather events such as drought and floods, and pest attacks (Figure 5.5). This was followed by 'water scarcity' (49%), and 'pasturelands impacts' (25%). The respondents agreed that the water scarcity is owing to less snowfall and rainfall seasonality. In contrast, the pastureland's impacts are due to water scarcity, flooding, earthquakes, and extreme hot and cold temperature changes. About 21% of respondents mentioned 'increased heath expenses' for humans due to extreme weather events, such as flooding and landslide events.

Five percent of respondents mentioned 'low business' as an outcome of the prevailing climatic changes (such as extreme cold events) because of the low tourism in the Valley. Four percent of respondents mentioned increased diseases in the livestock. Interestingly, 3% of respondents stated that the weather and climatic changes, such as longer summer durations, help them get more livelihood options, for example, through tourism. Two percent mentioned ‘no changes in the weather events.

Table 5.2: The Biggest Changes in Weather and Climatic Hazards Observed Over the Past 10-20 Years

Temperature	**Hotter**	**Cooler**	**No Change**	**More variable**	**No Response**	**Chi Value X^2**	**df**	**P Value**
	106	16	12	19	8	213.5	4	2.20^{e-16}
Rainfall	More	Less	No Change	More variable	6	452.3	4	2.20^{e-16}
	3	140	10	2				
Timing of rainy season	Earlier	Later	No Change	More variable	15	47.1	4	1.43^{e-09}
	39	57	10	41				
Seasonal pattern of rainfall	Less rainfall in summer	Heavy rainfall in winter	Rainy days increased	Rainy days decreased	0	97.5	4	2.20^{e-16}
	69	17	23	54				
Seasonal pattern of snowfall	No snowfall in early winter	Less snowfall in mid-winter	Heavy snowfall in late winter	More variable	13	65.6	4	1.91^{e-13}
	28	72	26	22				
Changes in summer temperature	Slightly warmed	Significantly warmed	Slightly cooled	Significantly cooled	14	95.3	4	2.20^{e-16}
	63	62	12	10				
Changes in winter temperature	Slightly warmed	Significantly warmed	Slightly cooled	Significantly cooled	10	43.3	4	8.75^{e-09}
	33	15	55	35				
Changes in Ice/glacier melt	More	Less	No Change	More variable	17	90.2	4	2.20^{e-16}
	74	36	2	32				
Flooding	More frequent	Less frequent	No Change	More variable	13	87	4	2.20^{e-16}
	77	31	12	28				
Drought	More frequent	Less frequent	No Change	More variable	16	145.3	4	2.20^{e-16}
	92	22	6	25				
Pest attack	Slightly increased	Significantly increased	Slightly decreased	Significantly decreased	11	182.9	4	2.20^{e-16}
	65	82	2	1				

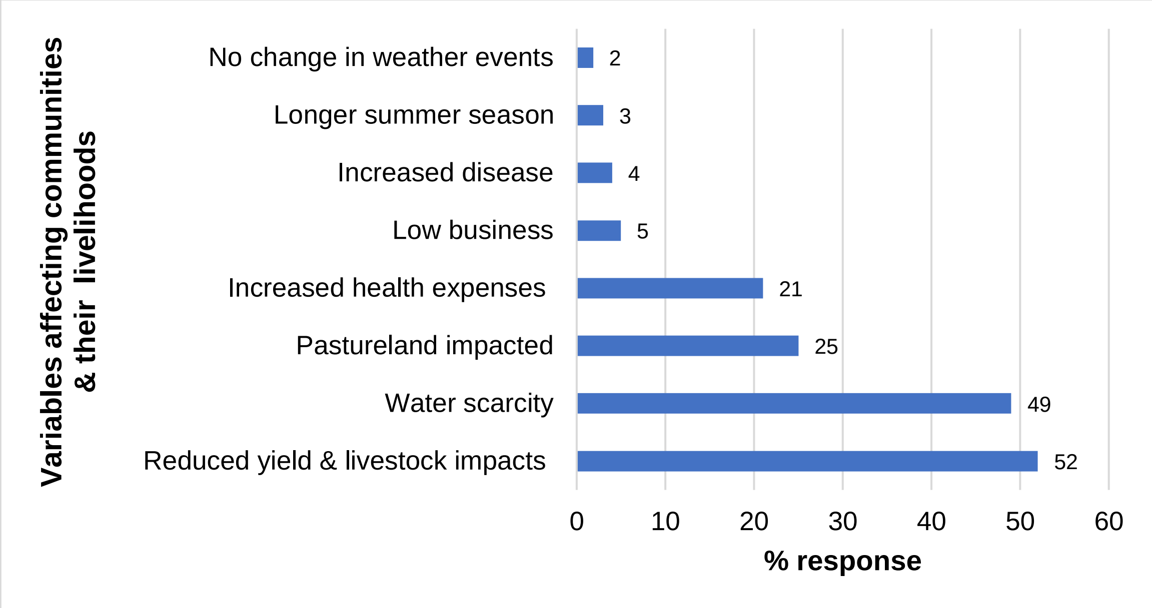


Figure 5.5: Variables Affecting Community Livelihoods in Chitral Valley (n=161, X^2 = 148.32, df = 7, p < 2.2^{e-16})

5.3.5 Community Responses to The Climatic Changes

To address the declining freshwater resources, especially for farming, most respondents (55%) are implementing water retention techniques, primarily by constructing ditches and government-initiated rainwater harvesting techniques other than changing the crop varieties (Figure 5.6). Furthermore, the locals (55% of respondents) stored water by constructing cement tanks in houses or using plastic drums for water storage. Communities (34%) have started using more chemical-based pesticides to avoid pest attacks on crop fields and have invested more money in treating livestock diseases. Communities (33%) now have to invest more to treat the new health conditions owing to weather and climatic changes, such as itching and dry skin problems due to dry and hot weather, whereas to fulfill their financial needs, people are increasingly relying on government aid and support from NGOs, such as the Agha Khan Rural Support Program.

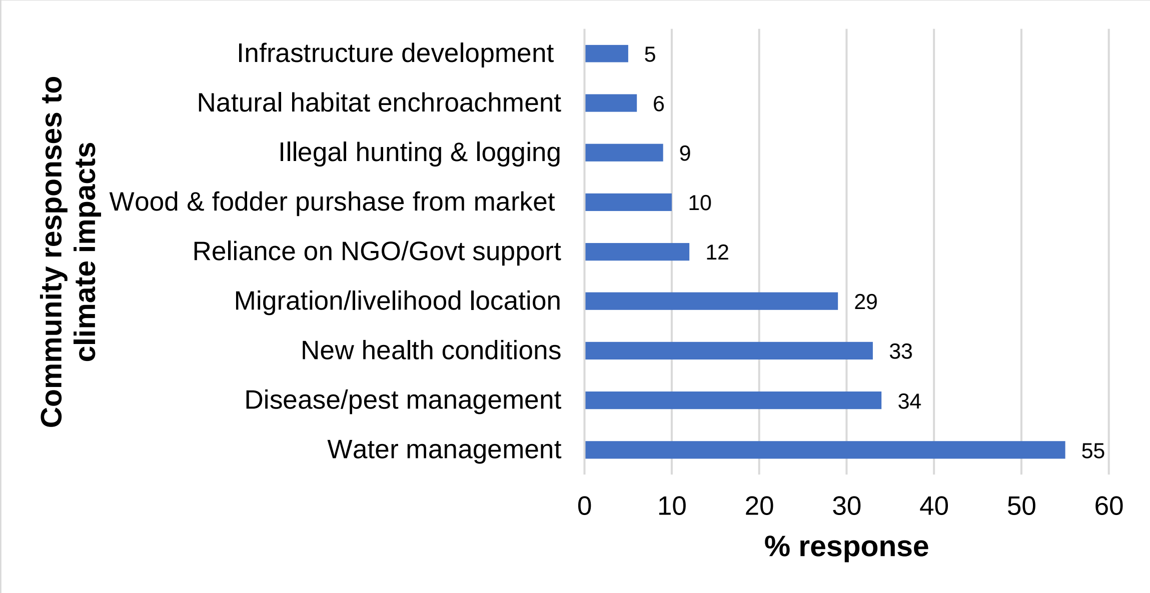


Figure 5.6: Adaptation Strategies Adopted by Chitral Valley Communities (n=161, X^2 = 109.97, df = 8, p < 2.2^{e-16})

To seek off-farm employment or education, many people, especially the younger generation, migrate to cities or nearby towns, such as Karachi, Peshawar, Islamabad, Mastuj, and Booni (29%). Additionally, some farmers are changing their grazing practices by taking their livestock into parks such as the Chitral Gol National Park and pastures in the upper Chitral area during summer. However, this trend has also been diversifying through alternative livelihood options such as employment in the lower Chitral Valley. Around 10% of respondents suggested purchasing firewood and fodder from the market is a strategy for adaptation. To maximize their livelihood needs, some respondents (7%) used destructive practices, including illegal bird hunting by geese and ducks, illegal logging, and encroachment of natural habitats, such as collecting wild plants. To fulfill the energy requirements at the domestic level, most Chitral residents have started using electric appliances for cooking, heating, and cleaning purposes. About 5% of the respondents mentioned infrastructure development, such as constructing new hotels in the Valley, as an adaptation measure to secure income options.

5.3.6 Impacts on Biodiversity

With respect to the climatic impacts on the biodiversity in the Chitral Valley, more than half of the survey participants have witnessed an increase in human-wildlife conflicts

(61%, Figure 5.7). Many attribute this to a shortage of food and water within their habitat, causing animals such as snow leopards, brown bears, foxes, and jackals to venture into farms and settlements in search of these resources. To counteract these conflicts, the Snow Leopard Foundation has resorted to constructing predator-proof corrals for the local communities in the snow leopard habitat. Respondents also noted that adaptation measures such as natural habitat encroachment and illegal hunting and logging have led to the loss of species (9% of respondents) and habitat degradation (26%). These consequences have resulted from land expansion for agriculture, competition for water and grazing lands, and resource extraction/encroachment.

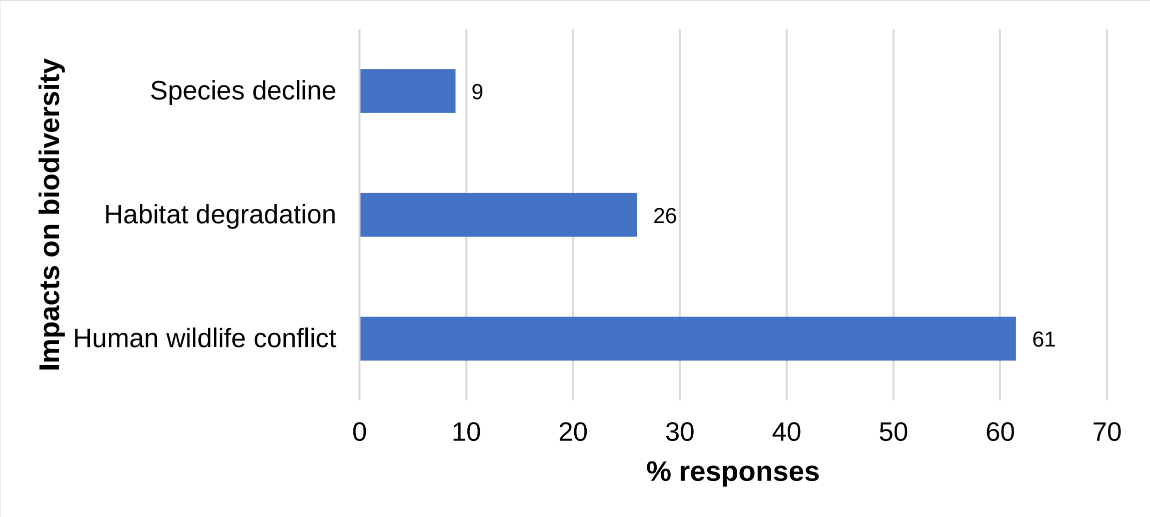


Figure 5.7: Perceived Climatic Impacts on Biodiversity in Chitral Valley (n=161, X^2 = 43.938, df = 2, p = 2.878^{e-10})

5.4 DISCUSSION

Global warming impacts Earth’s ecosystems, and the northern latitudes have warmed up at an especially high rate (IPCC, 2021). The Global Climate Risk Index indicates Pakistan as the 8^{th} most vulnerable country regarding water stress, desertification, glacier melting, extreme weather events, and the spread of diseases (Eckstein et al., 2021). Pakistan's Hindu Kush Himalaya mountains are experiencing the detrimental impacts of climate change, biodiversity loss, and pollution, leading to increased glacial melting, species extinction, and water pollution.

The Chitral Valley communities in Pakistan's Hindu Kush mountains are aware of climate change and agree that there have been changes in temperature and rainfall patterns over the past few decades. The key indicator of climate change is the alteration in temperature, which has affected the ways of life of the communities in the Chitral Valley. Our results complement the literature on the meteorological data trends for Chitral Valley (ICIMOD, 2023; Zafar et al., 2018), showing a rise in annual mean temperature (1973-2022) and a concurrent decrease in precipitation trends (1993-2022) in addition to the rise in annual maximum temperatures and a decline in annual minimum temperatures (1965-2003). Furthermore, Zafar et al. (2018) reported a rise in mean winter temperature at a rate of 0.45°C per decade, with daytime temperatures increasing by 1.0°C per decade. This indicates that winters will have warmer days than usual in the future. Additionally, they found that the average summer temperature was increasing at a rate of 0.3°C per decade, indicating that future summers will be warmer.

Due to climate change, Pakistan faces an escalating water crisis, necessitating urgent adaptation measures. Increasing temperatures are anticipated to intensify evapotranspiration rates and alter rainfall patterns, affecting crop yields significantly. Climatic factors are estimated to account for a considerable portion of variations in rice, wheat, and maize productivity. Predictions indicate a potential 30% decline in crop yields in Pakistan by 2080. Agriculture, the most vulnerable sector, faces challenges in sustainable water use and food security due to climate change, impacting water availability, run-off patterns, and temperature fluctuations.

Hotter temperatures and seasonal rainfall changes have significantly impacted livelihoods in the Chitral Valley, where agriculture is crucial. However, contrasting predictions suggest a potential increase in crop and fodder yields in the Chitral Valley, accompanied by a shift in the cropping zone. The urgency for successful adaptation measures is emphasized due to climate change's role in exacerbating the water crisis in Pakistan, affecting irrigation requirements. Our results complement the literature on the negative trend of snow cover extent in the Hindu Kush Himalayan (HKH) region and the resultant water scarcity in the HKH river basins (ICIMOD, 2023) in addition to the drought conditions negatively affecting mountain grasslands, as reported in Tyrol (Austria), Nepal, Afghanistan, Pakistan, and China, resulting in a decline in agrobiodiversity (Ashraf et al., 2014; Zomer et al., 2014b; Grüneis et al., 2018; Adhikari et al., 2019; Chaudhary et al., 2020; and Hussain & Qamar 2020). Our results also complement studies on extreme events for floods, avalanches, and landslides in Afghanistan, Pakistan, Peru, Thailand, and Uganda for mountain communities' migration, habitability, and displacement (Iribarren Anacona et al., 2015; Stäubli et al., 2018; IDMC, 2020; & Wang et al., 2020).

Harsh weather events, such as droughts and floods, pose significant challenges to agropastoral systems in the present time (Kurdy´s-Kujawska et al., 2021; Zukowska et al., 2016; Duong et al., 2019). In the Chitral Valley, warmer temperatures have increased the frequency of snow avalanches and glacial lake outburst floods (GLOFs). The most extensively recorded GLOF occurred roughly 350 years ago and originated from the Chiantar Glacier in the Broghil Valley. However, in the twenty-first century, the occurrence rate and strength of GLOF incidents have risen significantly in the Chitral Valley, with occurrences in 2003, 2005, 2007, 2010, 2011, 2013, 2015, 2021, and 2022 resulting in damage to human life, infrastructure, and agriculture (Hussain et al., 2019).

Climate change can lead to the proliferation of pests and diseases, affecting crops, livestock, and humans due to extreme weather events such as heat waves (Hari & Chandra, 2014). Consistent with our findings, Khanal et al. (2019) have reported that Chepang communities in Nepal perceive climate change as causing crop disease and insect infestation, adversely affecting their livelihoods. Xie et al. (2022) also observed crop and livestock disease in the Qilian Mountains in China, which is associated with changing climatic conditions.

Rising average annual and spring season temperatures concern the well-being of the local communities, biodiversity, and ecosystem in the Hindukush range, Pakistan (Anjum et al., 2021; Saeed et al., 2022). Communities face challenging socioeconomic circumstances (Alfthan et al., 2018) and a high dependence on ecosystem services, worth 7,272 ± 520 USD/Household/yr, as documented by Saeed et al., (Chapter 4, unpublished work) in Chitral Valley. For instance, approximately 16.5% of the population in the Chitral district relies on forests for their livelihood, with 60% obtaining fuel wood from these wooded areas. Livestock rearing contributes to 21% of the local livelihood, and 36% of the population relies on the forest for fodder (Ahmad et al., 2022a). Additionally, the agricultural sector plays a significant role, constituting about 26% of the local livelihood, but poses a threat as communities encroach on forest land.

To combat the impacts of climate change, the communities in the Chitral Valley have adopted various adaptation strategies, such as producing alternative crops like potatoes, tomatoes, and peas, implementing water conservation techniques, reducing cultivated areas, and adopting rainwater harvesting and ditch systems. These strategies align with the findings of Rai et al. (2022), Li et al. (2021), and Diallo et al. (2020). The communities also use electric appliances for cooking and heating and invest in chemical-based pesticides to combat pest attacks on crops and treat livestock diseases.

Adaptation strategies employed by indigenous communities globally include cultivating diverse crops to mitigate the risk of failures, supplementing food supply through hunting, fishing, gathering wild plants, and selling surplus crops and handmade goods in markets. During crises, these communities may shift to planting new crop varieties, altering harvesting schedules, and adapting resource exploitation timing. Facing severe climate-related challenges, some may relocate agricultural activities and settlements to less vulnerable areas. Resource exchange with external sources is a crucial strategy, and traditional management techniques are utilized to conserve and enhance scarce, climate-sensitive resources (Sujakhu, 2019).

Our study also found that younger people are migrating to nearby towns and cities for off-farm employment or education, which is consistent with the research of Rai et al. (2022), Nizami and Ali (2017), and the United Nations Development Programme (UNDP) in 2016. Unfortunately, some individuals engage in destructive practices such as illegal bird hunting, logging, and encroaching on natural habitats. Additionally, constructing new hotels in the valley is seen as a means of securing income options.

Our findings on the climatic impacts of biodiversity in Chitral Valley suggest a considerable weightage on human-wildlife conflicts. Due to these conflicts, snow leopards and brown bears face serious threats in northern Pakistan (Hameed, 2021). Areas where people rely on livestock for their livelihood are particularly vulnerable to human-carnivore conflicts, as livestock depredation is the primary cause of these conflicts and can lead to significant economic losses (Augugliaro et al., 2020; Talbert et al., 2020). Additionally, habitat degradation and species loss have been linked with climate change, as Mijiddorj et al. (2020) and Aryal et al. (2014) suggested. Livestock insurance, predator-proof corrals, and watch-and-ward practices can help mitigate this problem (Hameed, 2021; Ugarte et al., 2019).

Local communities must be involved in the inclusive decision-making process, resource management, and defining governance structures for sustainable mountain development (Klein et al., 2019). Harnessing traditional knowledge systems can be key to sustainable management in Chitral Valley as these systems provide a holistic understanding of the communities and the environment (Foggin M., 2012). Moreover, to enhance the conservation and management of forest resources, it is suggested to implement strategies such as providing agricultural incentives, increasing agricultural production, promoting ecotourism, ensuring proper utilization of Non-Timber Forest Products (NTFPs), engaging in trophy hunting, fish farming, carbon trading, carbon financing, and implementing REDD+ initiatives.

5.5 CONCLUSION

The reality of climate change in arid regions like the Chitral Valley cannot be ignored, and prompt adjustments are essential. This study highlights a noticeable shift in climate, as perceived by Chitral's communities and observed in the climate data. Therefore, it is imperative to analyze climate data and assess the perceptions, impacts, and adaptation strategies of the local community. The rising temperatures and irregular rainfall patterns have adversely affected crop and livestock yields and increased exposure to floods, droughts, and landslides, thus jeopardizing livelihoods. The resulting financial pressures have compelled local communities to seek alternative sources of income, such as employment in urban areas through migration, and institutional support from government and NGOs. Unfortunately, some members of the community engage in natural habitat encroachment, illegal hunting, and logging, thereby destroying the environment. Moreover, some community members take no measures to adapt to the changing climate.

Due to their close association with natural habitats, Indigenous communities are particularly vulnerable to climate change impacts (Green & Raygorodetsky, 2010). To minimize their exposure to climate change impacts, involving them in discussions and incorporating their knowledge in adaptation strategies (Brugnach et al., 2017; Deressa et al., 2011; Green & Raygorodetsky, 2010). The ability of communities to survive climate change will ultimately depend on their ability to adapt to changing weather patterns. To facilitate farming in future, it is necessary to develop new strains of crops, fruits, and vegetables that can withstand extreme climate conditions. Future research should address issues such as the timing of crop planting, sowing methods, and seed treatment techniques. Conservation of soil moisture, rainwater harvesting, and improved water-use efficiency are also necessary for broader adaptability. Developing district-level climate adaptation plans rather than uniform province-level plans is also important, especially for the soil and water conservation and management departments.

Human-wildlife conflict, arising mainly from livestock depredations, has a huge impact on biodiversity in the area. Due to the complexity of human-wildlife interactions, conservationists must provide solutions to mitigate and minimize their impacts (Hameed, 2021; Ugarte et al., 2019). Livestock insurance schemes, construction of predator-proof corrals, and improved watch-and-ward practices can help address the issue. Further, creating an integrated early warning system that utilizes targeted climate services, remote sensing data, and indigenous knowledge can help minimize the harm caused by floods and glacial lake outburst floods in remote mountainous areas. The government must establish effective adaptation and mitigation policies for the Chitral Valley.

5.6 ACKNOWLEDGEMENTS

We would like to thank the Snow Leopard Trust, USA, for funding this study. We really appreciate the cooperation and support of the Chitral Valley communities. We also acknowledge the support of the Snow Leopard Foundation-Pakistan for fieldwork in terms of equipment and trained field staff. We are highly grateful to, Barkatullah Khan, Muhammad Amir, Sana Ullah, Syed Ur Rehman, Abuzar Razi, and Sara Razi for helping with data collection and compilation. We thank Fathul Bari, Ejaz Ahmad, and Muhammad Jahangir for providing local market price information to monetize ecosystem services. We thank Doost Ali Nawaz, and ESRI for providing GIS support. We owe special thanks to Mr. Saeed, KP Wildlife Department, for all the field support and technical help in carrying out this study. Special thanks are due to the Pakistan Meteorological Department for providing the weather data for District Chitral.

5.7 REFERENCES

Adhikari, L., S. Tuladhar, A. Hussain and K. Aryal, (2019) Are traditional food crops really ‘future smart foods?’A sustainability perspective. *Sustainability*, 11(19), 5236, http://doi:10.3390/su11195236.

Ahmad A, Ahmad S, Nabi G, Zeb A, Rajpar MN, Ullah S, Khalid F, Rahman M, Liu Q, Zu K, Guo X and Wanghe K (2022) Carbon Emissions With Forest Cover Change and Wood Harvest in the Dry Temperate Region of Pakistan Between 1908 and 2015. *Front. Environ. Sci.* 10:876225. https://doi:10.3389/fenvs.2022.876225.

Ali, S., Li, G., Li, Z., & Ali, Z. (2017). Impacts of climate change on agriculture and adaptation strategies: a review. *Environmental Science and Pollution Research*, 24(21), 17092-17103.

Ali, Sajjad, "CONSERVATION AND STATUS OF MARKHOR (*Capra falconeri*) IN THE NORTHEN PARTS OF NORTH WEST FRONTIER PROVINCE, PAKISTAN" (2008). *Graduate Student Theses, Dissertations, & Professional Papers*. 10919.https://scholarworks.umt.edu/etd/10919

Anjum, M. N., Cheema, M. J. M., Hashmi, M. Z. U. R., Azam, M., Afzal, A., & Ijaz, M. W. (2021). Climate change in the mountains of Pakistan and its water availability implications. *Water resources of Pakistan: issues and impacts*, 79-94. http://dx.doi.org/10.1007/978-3-030-65679-9_5

Aryal, A., Brunton, D., & Raubenheimer, D. (2014). Impact of climate change on human wildlife ecosystem interactions in the Trans Himalaya region of Nepal. *Theoretical and applied climatology*, 115, 517-529. https://doi.org/10.1007/s00704-013-0902-4

Ashraf, M., J.K. Routray and M. Saeed, (2014): Determinants of farmers' choice of coping and adaptation measures to the drought hazard in northwest Balochistan, *Pakistan. Nat. Hazards*, 73(3), 1451–1473. https://doi:10.1007/s11069-014-1149-9.

Augugliaro, C., Christe, P., Janchivlamdan, C., Baymanday, H., & Zimmermann, F. (2020). Patterns of human interaction with snow leopard and co predators in the Mongolian western Altai: Current issues and perspectives. *Global Ecology and Conservation*, e01378. https://doi.org/10.1016/j.gecco.2020.e01378

Azfar Hussain, S. A., Begum, S., & Ali, I. H. H. (2019). Climate change perspective in mountain area: Impact and adaptations in Naltar valley, western Himalaya, Pakistan. *Fresenius Environ. Bull*, 28, 6683-6691.

Azócar, G., Bustos-Marún, R., Contreras-Romero, E., Gómez-Fernández, F., & Hormazábal-Aguayo, I. (2021). Machine learning for predicting student performance in engineering: *A systematic review. Computers & Education*, 159, 104042. https://doi.org/10.1016/j.compedu.2020.104042

Bagheri, M., & Teymouri, A. (2022). The impact of climate change on agriculture: a systematic review of the literature. *Environmental Science and Pollution Research*, 29(1), 1-16.

Becerra, L. R., Palma-Ruiz, J. M., Pérez-Vega, R., & Muñoz-Meléndez, A. (2020). A systematic review of machine learning for detecting fraudulent financial statements. *Journal of Business Research*, 118, 346-365. https://doi.org/10.1016/j.jbusres.2020.06.024

Bennett, J. O., Briggs, W. L., & Triola, M. F. (2003). *Statistical reasoning for everyday life*. Boston, MA: Addison-Wesley.

Bennett, N. J. (2016). Using perceptions as evidence to improve conservation and environmental management. *Conservation Biology*, *30*(3), 582-592.

Brugnach, M., Dewulf, A., Pahl-Wostl, C., & Taillieu, T. (2008). Toward a relational concept of uncertainty: about knowing too little, knowing too differently, and accepting not to know. *Ecology and society, 13*(2).

Chaudhary, P., Bhatta, S., Aryal, K., Joshi, B. K., & Gauchan, D. (2020). Threats, drivers, and conservation imperative of agrobiodiversity. *Journal of Agriculture and Environment*, *21*, 44-61.

Chaudhry, Q. U. Z. (2017). *Climate change profile of Pakistan*. Asian Development Bank.

Cline, W. R. (2007). *Global warming and agriculture: Impact estimates by country*. Peterson Institute.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *The Journal of Agricultural Science*, 149(1), 23-31. https://doi.org/10.1017/S0021859610000687

Diallo, A. L., Diouf, B., & Taal, M. A. (2020). Climate change and agriculture in Africa: impacts, adaptation and mitigation strategies. *Environmental Science and Pollution Research*, 27(7), 7145-7161.

Diallo, M. S., Diouf, A. A., Cisse, F., Fofana, M., Diakite, S. S., & Amane, D. (2020). Climate change adaptation strategies and livelihood diversification in the Kaffrine region of Senegal. *Journal of Environmental Management*, 254, 109779. Accessed online 2nd March 2024 https://www.iied.org/sites/default/files/pdfs/migrate/10598IIED.pdf

Din, J. U., & Nawaz, M. A. (2010). Status of the Himalayan lynx in district Chitral, NWFP, Pakistan. *Journal of Animal and Plant Sciences*, *20*, 17-22.

District Development Plan, District Chitral (2015). District Planning and Project Development Unit, District Government, Chitral. Report prepared by Hamid Ahmad Mir.

Duong, T. T., Brewer, T., Luck, J., & Zander, K. (2019). A global review of farmers' perceptions of agricultural risks and risk management strategies. *Agriculture*, 9(1), 10. https://doi.org/10.3390/agriculture9010010

Eckstein, D., Künzel, V., & Schäfer, L. (2021). *The global climate risk index 2021*. Bonn: Germanwatch.

Feulner, G. (2017). On the origin of climate ethics. *Environmental Values*, 26(1), 1-24.

Foggin, M. (2012) Pastoralists and wildlife conservation in western China: collaborative management within protected areas on the Tibetan Plateau. *Pastoralism: Research, Policy and Practice*, 2(1), p.17. https://doi.org/10.1186/2041-7136-2-17

Gillett, N. P., Jackson, R. B., Jones, P. D., Levine, R. C., Nicoll, K., & Forster, P. M. (2021). Improved constraints on anthropogenic warming from multiple indices of variability. *Nature Climate Change*, 11(2), 128-132.

Government of Pakistan. (2013). Framework for Implementation of Climate Change Policy. Islamabad: Climate Change Division Islamabad: Government of Pakistan.

Green D, Raygorodetsky G (2010) Indigenous knowledge of a changing climate. *Clim Change* 100:239–242. https://doi.org/10.1007/s10584-010-9804-y

Grüneis, H., et al., (2018) Why do we not pick the low-hanging fruit? Governing adaptation to climate change and resilience in Tyrolean mountain agriculture. *Land Use Policy*, 79, 386–396, https://doi:10.1016/j.landusepol.2018.08.025.

Hameed S. (2021). Ecology and conflict dynamics of apex predators in Northern Pakistan. Unpublished doctoral' s dissertation. Quaid-i-Azam University, Islamabad.

Hameed, K., Riaz Ch, F., Nawaz, M. A., Naqvi, S. M. S., Gräser, Y., Kupsch, C., … Peano, A. (2017). Trichophyton verrucosum infection in livestock in the Chitral district of Pakistan. *The Journal of Infection in Developing Countries*, *11*(04), 326–333. https://doi.org/10.3855/jidc.7925

Hari, C. S., & Chandra, S. P. (2014). Impact of climate change on pest management and food security: Integrated pest management. In Academic Press (Ed.), *Integrated Pest Management* (pp. 23-36). https://doi.org/10.1016/B978-0-12-398529-3.00003-8

Hussain, A. and F.M. Qamar, (2020). Dual challenge of climate change and agrobiodiversity loss in mountain food systems in the Hindu-Kush Himalaya. *One Earth*, https://doi:10.1016/j.oneear.2020.10.016.

Hussain, I., Younis, J., & Lu, X. (2019). Climate change and glacial lake outburst floods in the Hindu Kush-Himalaya region: A review of current knowledge and future prospects. *Science of the Total Environment*, 663, 863-876.

Hussain, S. S., Hussain, S., Hanif, M., Nizami, A., Pakistan, I., Salim, M. A., ... & Beenish, S. (2013). Climate change scenarios and possible adaptation measures. *Districts Chitral and DI Khan. Islamabad, Pakistan: Intercooperation Pakistan*. https://doi:10.13140/RG.2.1.3123.7849

ICIMOD. (2023). *Water, ice, society, and ecosystems in the Hindu Kush Himalaya: An outlook*. (P. Wester, S. Chaudhary, N. Chettri, M. Jackson, A. Maharjan, S. Nepal, & J. F. Steiner [Eds.]). ICIMOD. https://doi.org/10.53055/ICIMOD.1028

IDMC, (2020). Internal Displacement Index 2020 Report. Internal Displacement Monitoring Centre, Geneva, Switzerland. Accessed online December 2021. https://www.internal-displacement.org/global-report/grid2020/.

IPCC, (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, Intergovernmental Panel on Climate Change (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment*

Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

Iribarren Anacona, P., A. Mackintosh and K. Norton, (2015). Reconstruction of a glacial lake outburst flood (GLOF) in the Engaño Valley, Chilean Patagonia: Lessons for GLOF risk management. *Sci. Total Environ.*, 527–528, 1–11.https://doi:10.1016/j.scitotenv.2015.04.096.

Jagermeyr, J. (2020). Climate change, water and food security. *Environmental Science and Policy*, 109, 54-56.

Jellason, N. P., N. Baines, R., S. Conway, J., & Ogbaga, C. C. (2019). Climate change perceptions and attitudes to smallholder adaptation in Northwestern Nigerian Drylands. *Social Sciences*, 8(2), 31. https://doi.org/10.3390/socsci8020031

Khalid, S., Hassan, Z., & Ali, R. (2021). Impacts of Climate Change on Temperature Trends in Chitral District of Pakistan. *Sustainability*, 13(11), 6173.

Khan, M. Z., Baig, T., Ali, S., & Shah, A. (2022). Mountain Studies: Understanding and Managing Mountains for People and Nature. *Karakoram International University, Gilgit. Pakistan, VII*.

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

Khanal, P., Wagle, B. H., Upadhaya, S., Ghimire, P., & Acharya, S. (2019). Perceived Climate change impacts and adaptation strategy of indigenous community (Chepangs) in rural mid-hills of Nepal. Forestry: *Journal of Institute of Forestry*, Nepal. https://doi.org/10.3126/forestry.v16i0.28353

Khanal, U., Mishra, A. K., & Pradhananga, R. R. (2021). Climate change impacts and adaptation strategies in agriculture: A review. *Journal of Environmental Management*, 292, 112868.

Klein, J. A., Tucker, C. M., Steger, C. E., Nolin, A., Reid, R., Hopping, K. A., ... & Yager, K. (2019). An integrated community and ecosystem-based approach to disaster risk reduction in mountain systems. *Environmental Science & Policy*, 94, 143-152. https://doi.org/10.1016/j.envsci.2018.12.034

Koley, S. (2020). A review of AI and machine learning based smart city frameworks. *Sustainable Cities and Society*, 53, 101938.

Konapala, G., Mruthyunjaya, T., & Gomathinayagam, P. (2020). Impacts of climate change on agriculture: A review. *Current Climate Change Reports*, 6(2), 47-54.

Kurdyś-Kujawska, A., Strzelecka, A., & Zawadzka, D. (2021). The impact of crop diversification on the economic efficiency of small farms in Poland. *Agriculture*, 11 (3), 250. https://doi.org/10.3390/agriculture11030250

Li, C., Fan, L., Ma, X., Wang, Y., & Ren, Y. (2021). An overview of climate change impacts and adaptation strategies in agriculture worldwide. *Science of the Total Environment*, 762, 143055.

Li, J., Li, Y., Jia, X., Li, Z., Yan, M., & Li, M. (2021). An overview of climate change impacts and adaptation strategies in agriculture: A review. *Agricultural and Forest Meteorology*, 306, 108438.

McManus, J. S., Dickman, A. J., Gaynor, D., Smuts, B. H., & Macdonald, D. W. (2015). Dead or alive? Comparing costs and benefits of lethal and non lethal human wildlife conflict mitigation on livestock farms. *Oryx*, 49(4), 687-695. https://doi.org/10.1017/S0030605313001610

Micu, M. M., Dinu, T. A., Fintineru, G., Tudor, V. C., Stoian, E., Dumitru, E. A., ... & Iorga, A. (2022). Climate change - between "myth and truth" in Romanian Farmers' perception. *Sustainability*, 14(14), 8689. https://doi.org/10.3390/su14148689

Mijiddorj, T. N., Alexander, J. S., Samelius, G., Mishra, C., & Boldgiv, B. (2020). Traditional livelihoods under a changing climate: herder perceptions of climate change and its consequences in South Gobi, Mongolia. *Climatic Change*, 162(3), 1065-1079. https://DOI:10.1007/s10584-020-02851-x

Moore, D. T. (2010). Forms and issues in experiential learning. *New directions for teaching and learning*, *2010*(124), 3-13. https://doi.org/10.1002/tl.415

Mueller, V., C. Gray and K. Kosec, (2014): Heat stress increases long-term human migration in rural Pakistan. *Nat. Clim. Change*, 4, 182–185, https://doi:10.1038/nclimate2103.

Nizami, A. and J. Ali. (2017). Climate change and women's place-based vulnerabilities–a case study from Pakistani highlands, *Climate and Development* 9(7): 662–670

Paudel, S., Sujakhu, N. M., Maharjan, S., Shrestha, S., & Shrestha, M. (2020). Smallholder farmers' adaptation strategies to climate change and determinants of their adaptation decisions in the Gandaki River Basin, Nepal. *Climate and Development*, 12(8), 739-749. https://doi.org/10.1186/s40066-017-0100-1

Pokhrel, Y., Karki, R., Yadav, B. K., Malla, R., & Koirala, M. (2021). Climate Change in Nepal: A comprehensive analysis of temperature and precipitation trends, variability, and extremes from 1971 to 2020. *Theoretical and Applied Climatology*, 144(1-2), 143-159. https://link.springer.com/article/10.1007/s10584-019-02418-5

Rai, S. C., Ghimire, S., & Shrestha, S. (2022). Impacts of climate change on agriculture and adaptation strategies in Nepal: a review. *Environmental Science and Pollution Research*, 29(6), 5456-5476.

Rai, S., Dahal, B., & Anup, K. C. (2022). Climate change perceptions and adaptations by indigenous Chepang community of Dhading, Nepal. *Geo Journal*, *87*(6), 5327-5342.

Rai, S., Dahal, B., & Anup, K. C. (2022). Climate change perceptions and adaptations by indigenous Chepang community of Dhading, Nepal. *Geo Journal*, 87, 5327-5342. https://doi.org/10.1007/s10708-022-10577-9

Rasul, G. and A. Hussain, (2015): Sustainable food security in the mountains of Pakistan: towards a policy framework. *Ecol. Food Nutr.*, 54(6), 625–643, https://doi:10.1080/03670244.2015.1052426

Rasul, G., et al., (2014): Towards a Framework for Achieving Food Security in the Mountains of Pakistan. International Centre for Integrated Mountain Development, Kathmandu, Nepal, ISBN 978-9291153305. 22 pp. Accessed online 2nd March 2024 https://www.cabidigitallibrary.org/doi/pdf/10.5555/20163181484

Ruiz, P., Athanasiadis, I. N., Cabello, V., & Tarquis, A. M. (2020). An overview of machine learning in water resource management: Challenges and opportunities. Water, 12(7), 1865.https://doi.org/10.3390/w12071865

Saeed, U., Arshad, M., Hayat, S., Morelli, T. L., & Nawaz, M. A. (2022). Analysis of provisioning ecosystem services and perceptions of climate change for indigenous communities in the Western Himalayan Gurez Valley, Pakistan. *Ecosystem Services*, *56*, 101453. https://doi.org/10.1016/j.ecoser.2022.101453

Snow Leopard Network (2014). Snow Leopard Survival Strategy. Revised 2014 Version Snow Leopard Network, *Seattle, Washington, USA*, 1-145. Accessed online 2nd March 2024 https://snowleopardconservancy.org/wpcontent/uploads/2014/10/Snow_Leopard_Survival_Strategy_2014.1-reduced-size.pdf

Stäubli, A., et al., (2018). Analysis of weather- and climate-related disasters in mountain regions using different disaster databases. In: *Climate Change, Extreme Events and Disaster Risk Reduction* [Mal, S., R. Singh and C. Huggel(eds.)]. Springer, Cham, Switzerland, pp. 17–41. ISBN 978-3319564692. https://doi.org/10.1007/978-3-319-56469-2_2

Sujakhu, N. M. (2019). An Ethnobotanical Approach to Study the Relation between Community Vulnerability and Climate Change in the Himalayas (Doctoral dissertation).

Tabari, H. (2020). Climate change impacts on agriculture and adaptation strategies in Iran: A review. *Journal of Environmental Management*, 262, 110355. http://dx.doi.org/10.1016/S2095-3119(17)61794-5

Talbert, L., Leslie, S. C., & Black, S. A. (2020). Use of predator controls to address human wildlife conflict. *Int J Avian & Wildlife Biol*, 5(1), 9-13. http://dx.doi.org/10.15406/ijawb.2020.05.00167

Thornton, P. K., & Scheer, S. J. (2012). Collaboratively addressing complexity: Climate change adaptation in Western Nepal. *Mountain Research and Development*, 32(4), 435-444.

Ugarte, C. S., Moreira-Arce, D., Simonetti, J. A., Valenzuela, C. M., Acuña, E., Ortega, A., ... & Morales-Salinas, L. (2019). Ecological attributes of carnivore-livestock conflict. *Frontiers in Ecology and Evolution*, 7, 433. https://doi.org/10.3389/fevo.2019.00433

Ullah, I., Ali, W., Ali, A., Khan, A., & Jan, M. T. (2020). Impact of Climate Change on Maize Productivity in Khyber Pakhtunkhwa, Pakistan. *Journal of Agriculture and Environmental Sciences*, 9(2), 45-51. http://dx.doi.org/10.17582/journal.sja/2019/35.2.594.601

UNDP (2016). Before the Flood. Islamabad: United Nations Development Programme (UNDP).

Utts, J. (2014). Seeing Through Statistics ([edition unavailable]). Cengage Learning EMEA. Retrieved from https://www.perlego.com/book/830003/seeing-through-statistics-pdf (Original work published 2014)

Van Meijl, H., Van Rheenen, T., Tabeau, A., & Eickhout, B. (2018). The impact of the Paris Agreement in limiting global warming to 2 C above pre-industrial levels. *Global Environmental Change*, 48, 142-153. http://dx.doi.org/10.54691/bcpbm.v34i.3188

Wang, C., B. Gao, Z. Weng and Y. Tian, (2020). Primary causes of total hamlet abandonment for different types of hamlets in remote mountain areas of China. A case study of Shouning country, Fujian province. *Land Use Policy*, 95, 104627, https://doi:10.1016/j.landusepol.2020.104627

Xie, S., Ding, W., Ye, W., Ma, Q., Li, X., Wu, X., & Hou, Y. (2022). Agro pastoralists' perception of climate change and adaptation in the Qilian Mountains of northwest China. *Scientific Reports*, 12, 12689. https://doi.org/10.1038/s41598-022-17040-2

Zafar, M. I., Ahmad, B., Khan, M. A., & Tariq, A. (2018). Climate change scenarios and possible adaptation measures, Chitral and DIK districts of KPK, Pakistan. *Environmental Science and Pollution Research*, 25(35), 35111-35122. http://dx.doi.org/10.13140/RG.2.1.3123.7849

Zomer, R.J., et al., (2014b) Environmental stratification to model climate change impacts on biodiversity and rubber production in Xishuangbanna, Yunnan, China. *Biol. Conserv.*, 170, 264–273, https://doi:10.1016/j.biocon.2013.11.028

Żukowska, G., Myszura, M., Baran, S., Wesołowska, S., Pawłowska, M., & Dobrowolski, Ł. (2016). Agriculture vs. Alleviating the climate change. *Problemy Ekorozwoju*, 11(2), 67-74. Accessed online 2nd March 2022 https://ekorozwoj.pollub.pl/no22/j.pdf

Zylstra, P.J., (2018). Flammability dynamics in the Australian Alps. *Austral. Ecol.*, 43(5), 578–591, https://doi:10.1111/aec.12594

APPENDIX 5.1: SURVEY ON HUMAN RESPONSES TO CLIMATE CHANGE, AND SUBSEQUENT IMPACTS ON BIODIVERSITY IN DISTRICT CHITRAL, HINDUKUSH RANGE, PAKISTAN

	Interviewer's name	
	Translator's name	
	Name of village, UC, Tehsil, District	
	Questionnaire date	
	Time started	
	Time ended	
	GPS Location	

A.	**BACKGROUND INFORMATION**	
A1.	Respondent's Role *(e.g. farmer, park ranger, village leader, etc.)*	
A2.	Main livelihood(s) in village *(e.g. farming, livestock, business, govt job, private job, porter, tour operator etc.)*	
A3.	What is your monthly income? *(Enter range: 5K-10K, 10K-15K, 15K-20K, >20K)*	
A4.	Respondent's name	
A5.	Respondent's Education *(e.g. primary, matric, higher secondary, undergraduate, postgraduate, PhD)*	
A6.	Household size *(No. of males and females)*	
A7.	Number of people employed in the household	
A8.	Since how many years have you lived in this area? *(Enter range: less than 1 year, 1-5 years, 6-10 years, >10 years)*	
A9.	What is your age? *(Enter range: 18-35, 36-53, 54-70, >71)*	
A10.	Contact Number *(in case to fill any missing information later on)*	

B.	**CHANGES in WEATHER and CLIMATE** *In this section we are trying to learn about the most significant changes in weather and climate that have occurred over the last few years. It is not necessary to find out about all the changes that have occurred, just those the interviewee mentions as most significant.*	
B1.	Are you concerned about the changes in weather and climate?	Concerned Extremely concerned Not at all

	What are the biggest changes in weather you have observed over the past 10-20 years? *Engage the interviewee in conversation about different aspects of the weather and, if you are not certain of their answer, then ask them to clarify. e.g. After a chat about rainfall, "so, do you think rainfall is staying the same or increasing or decreasing? What about timing?"*	
B2.	*Please place a tick/check mark next to the changes in weather, climate and extreme events that the interviewee has mentioned. Check all that apply.*	
	Temperature	Hotter Cooler Stayed the same More variable Don't know
	Rainfall	More Less Stayed the same More variable Don't know
	Timing of rainy season	Earlier Later Stayed the same More variable Don't know
	Seasonal pattern of rainfall	Less rainfall in summer No. of rainy days decreased/increased Heavy rainfall in winter No. of rainy days decreased/increased
	Seasonal pattern of snowfall	No snowfall in early winter Less snowfall in mid-winter Heavy snowfall in late winter
	Changes in onset pattern of seasons	Earlier/late Spring Earlier/late Summer Earlier/late Winter Earlier/late Autumn
	Changes in duration of seasons	Shorter/longer Spring Shorter/longer Summer Shorter/longer Winter Shorter/longer Autumn
	Changes in summer temperature	Slightly warmed Significantly warmed Slightly cooled Significantly cooled
	Changes in winter temperature	Slightly warmed Significantly warmed Slightly cooled Significantly cooled
	Drought	More frequent Less frequent More variable Stayed the same Don't know
	Flooding	More frequent Less frequent More variable Stayed the same Don't know
	Changes in wind pattern	More Fewer More variable Stayed the same Don't know
	Changes in Landslides/Erosion	More Fewer More variable Stayed the same Don't know

	Changes in Ice/permafrost melt	More Less More variable Stayed the same Don't know
	Pest attack	Slightly increased Significantly increased Slightly decreased Significantly decreased

C.	**IMPACT of CHANGES in WEATHER and CLIMATE and RESPONSES**	
C1.	Main livelihood *This section is focused on the impacts and responses to changes in weather and climate on the main livelihood of the interviewee, or the main livelihood in the area. Be sure to repeat the changes in weather they mentioned, then ask how this has impacted their livelihood.*	
C1a.	Have the seasonal changes in weather impacted your income?	Yes/No If yes: Income increased Income decreased No impact
C1b.	How have the changes in weather you mentioned impacted the main livelihood? *What are the specific impacts?* *Be sure to list the weather changes that have played a role.* *(e.g. hotter temperatures lead to decreased crop yield and more pests and disease;* *changing seasonality of rainfall changes the availability of surface water resulting in less pasture, this leads to decline/death of livestock and increase in pests and disease etc.)* *Elaborate the nature of the change with as much detail as possible. The above examples are merely indicative.*	
C1c.	How have people responded to these impacts? *(e.g. change in livestock/farming practices,* *change in location,* *water management,* *disease/pest management,* *diversifying livelihood,*	

	use of natural resources, *natural habitat encroachment,* *illegal hunting, etc.)* *Elaborate the nature of the change with as much detail as possible. The above examples are merely indicative.*	

C2.	Natural Resources (e.g., water, wood, etc.) *This section is focused on the impacts and responses to changes in weather and climate on natural resources in the area.*	
C2a.	How have the changes in weather you mentioned affected the availability of natural resources e.g. water, wood?	
	What are the specific impacts? *Be sure to list the weather changes that have played a role.* *(e.g. changed water resources,* *water quantity changed during the course of season* *water quality changing gradually* *traveling further for water,* *traveling further for firewood,* *using alternative species for fire,* *reduction in the variety and/or size of wild animals to eat,* *any animal species no longer seen,* *reduction in availability of wild fruits, etc.)* *Elaborate the nature of the change with as much detail as possible. The above examples are merely indicative.*	
C2b.	How have people responded to these impacts?	
	(e.g. natural habitat encroachment,	

	illegal hunting, *change in livelihood location,* *diversifying livelihood,* *water management, etc.)* *Elaborate the nature of the change with as much detail as possible. The above examples are merely indicative.*	
C2c.	*Have changes been observed in terms of quality and availability of grazing i.e. pastureland/rangeland*	Yes/No If yes: Quality increased Quality decreased No impact

C3.	Other impacts and responses: Are there any other impacts or responses to the changes in weather you mentioned? *This section is for noting any other general responses to changes in weather and climate that are not specific to the categories above, for example, health.*	
	e.g. new health conditions, *migration,* *borrowing,* *reliance on NGO/government support, selling assets, etc.*	
C4. *Please place a check mark next to the change in activities in response to changes in weather and climate that the interviewee has mentioned. Check all that apply*.		
	Crop practices	☐
	Livestock practices	☐
	Livelihood type	☐
	Livelihood location	☐
	Water management	☐
	Disease/Pest management	☐
	Natural resource use	☐
	Natural habitat encroachment	☐
	Land conversion	☐
	Infrastructure development	☐
	Energy source	☐
	Migration	☐
	Other (please specify)	☐

D.	**IMPACT of RESPONSES on BIODIVERSITY** *The intention here is to investigate whether any responses to changes in weather in climate are having knock-on effects on biodiversity (local wildlife and ecosystems). In some cases, this will be obvious from the impacts and responses outlined in section C, and so you will be able to fill these in yourself. In other cases, the respondent may not explicitly point to the impact of responses on biodiversity – particularly if they are negative.* *However, with your knowledge, you may be aware of the implications for certain responses, and so can further probe these. For example, if it has been mentioned that livestock are now roaming a protected area, you can specifically probe issues such as increased human-wildlife conflict, and change in wildlife populations, as a result.*	
D1.	Which responses potentially have negative impacts on biodiversity? *(e.g. Increased competition with other people and with wildlife for resources such as water , food and land leads to an increase in human-wildlife conflict,* *Responses leading to increased wildlife mortality* *Wildlife moving to/ away from communities* *Responses leading to changes in water supply* *shifting livelihood location leads to increased land degradation/* *encroachment,* *Responses leading to other impacts on local environment and ecosystems etc.)*	*Which response? How?*

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

CHAPTER 6

Conclusion, Future Implications and Recommendations

6 CONCLUSION, FUTURE IMPLICATIONS AND RECOMMENDATIONS

6.1 CONCLUSION

This research employed predictive modelling to determine the current and future habitat range for snow leopards in the Himalayan region. Our analysis revealed that the findings are consistent with the existing literature on the decline of suitable habitat by 2070. The distribution of snow leopards is mainly affected by the annual mean temperature. Moreover, we found that the ecosystem services valuation underscores the indigenous communities' significant dependence on ecosystem services.

This study also emphasizes the vulnerability of mountain communities, as climate change impacts threaten their livelihoods. Notably, ecosystem services valuation is the first exploration of community perspectives and understandings of this concept in these landscapes. It can serve as a blueprint for future research in similar areas throughout Pakistan.

Finally, this study reinforces that mountain regions can play a vital role in promoting community livelihoods and well-being through ecosystem services provision. Implementing climate adaptation strategies would safeguard the unique biodiversity and livelihoods of millions of people living in Pakistan's majestic Himalaya-Karakoram-Hindu Kush Mountain ranges.

6.2 FUTURE IMPLICATIONS

Expanding the scope of snow leopard research is crucial, particularly in areas such as the snow leopard's spatial ecology, the impact of climate change on their populations, the interactions between humans, domestic and wild animals, and the effects of infrastructure development on their habitat and behaviour. In addition, due to the substantial interface between people and snow leopards, it is essential to integrate human dimensions into conservation research.

An evidence-based conservation approach for snow leopards should be a priority for conservation organizations and governments of snow leopard range countries. However, conservation challenges for the region's snow leopards and other species will arise from habitat loss and increasing human activities.

The ecosystem services valuation findings and indigenous communities' perceptions of climate change may help determine the most critical areas for snow leopard habitat in the future and adjust their current range accordingly. Protecting and restoring the fragile alpine habitat will benefit snow leopards and other related species. Therefore, there is a need to study the sustainable use of ecosystem services and implement comprehensive and urgent climate adaptation initiatives by both local communities and the government to secure living conditions at risk from the impacts of climate change, avoiding future climate shocks and natural hazards. Mechanisms for indigenous communities to adopt viable adaptation measures are also necessary.

6.3 RECOMMENDATIONS

1. Governments of the snow leopard range countries need to expand on protected areas coverage, and such expansion should include climate refugia identified in this study for the snow leopard in Pakistan (northern Gilgit), India (northwest Kargil and Doda) and Nepal (eastern Karnali, northern Dhaualagri, northern Gandaki, and northern Bagmati). The respective wildlife departments need to increase staff in these areas to control the poaching of snow leopards.
2. Transboundary conservation needs to promote connectivity of the snow leopard population within the greater Himalayan countries (Pakistan, India, and Nepal).
3. Monitoring and research efforts need to be strengthened to better understand the impacts of climate change on snow leopard populations and their habitat and to inform adaptive management strategies.
4. Increase public awareness of the importance of snow leopards and their habitat and promote action to mitigate the impacts of climate change on these endangered species.
5. Ensure sustainable use of ecosystem services and their recognition in the regulatory systems.
6. Develop a robust database of ecosystem services in the region that includes spatial data and socio-economic data to facilitate informed decision-making.
7. Incorporate non-monetary values, such as cultural and spiritual values, into the ecosystem services valuation process to provide a comprehensive understanding of ecosystems' benefits.
8. Develop climate-resilient livelihood strategies tailored to the mountain communities' needs. These include diversifying income sources, promoting sustainable agriculture practices, developing alternative livelihood opportunities, access to markets, and strengthening infrastructure.
9. Promote sustainable land management and land use practices, including agroforestry, soil conservation, watershed management, and rotational grazing, to

reduce vulnerabilities and pressure on natural resources, promote ecosystem resilience, and address the impact of climate change on mountain communities.

10. Develop early warning systems to alert mountain communities and authorities about climate change-induced disasters, such as floods and landslides, to improve local decision-making by establishing weather monitoring stations, mobile-based weather alerts, and community-based climate information centres.
11. Human-wildlife conflict is a significant threat to large carnivores, including snow leopards in Pakistan. Preventing financial loss and educating communities on conservation could promote coexistence between humans and predators.
12. In the challenging terrain of the Hindu-Kush Karakoram Himalayas (HKH), better law enforcement, oversight, and applying penalties would help prevent forest fires. There is a need to shift towards incentive-based policies. The government introduced subsidies for farmers who adopt mechanical alternatives to stubble burning in India. In 2019, the Supreme Court mandated that northern states provide Indian Rupees (IRs) 2,400 per acre to farmers who refrained from burning stubble (BBC, 2020).
13. Promoting forest fire education and awareness initiatives is crucial through a collective effort from local communities. Additionally, planting tree species with low flammability, serving as green firebreaks, can slow or prevent fire spread and offer biodiversity benefits.
14. Mechanical flail mowers and livestock grazing can significantly reduce fuel load on the forest floor and mitigate wildfire risks.
15. In the future, it's essential to effectively implement pre-fire and post-fire management plans to minimize the impacts of forest fires. Countries should also prioritize and integrate forest fire mitigation into national and provincial-level adaptation plans. Governments must allocate funds for forest fire management and mitigation.
16. Communities must adopt a Forest Fire Management Strategy at the local level to address forest fires effectively. It should consider factors like vulnerability,

topography, gradient, and proximity to settlements. Community leaders and local firefighting teams should execute pre-fire and firefighting activities at the community level.

17. Communities can even establish rainwater harvesting ponds in the forest, serving as reservoirs for extinguishing wildfires. Therefore, the development of a local-level forest fire management strategy is critical.

Climate Change Vulnerability and Ecosystem Services of Snow Leopard Habitat in Pakistan

Research Publication of Chapter 3 of This Thesis

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Full Length Article

Analysis of provisioning ecosystem services and perceptions of climate change for indigenous communities in the Western Himalayan Gurez Valley, Pakistan

Uzma Saeed [a,b], Muhammad Arshad [c], Shakeel Hayat [d], Toni Lyn Morelli [e], Muhammad Ali Nawaz [f,*]

[a] Department of Zoology, Quaid I Azam University, Islamabad 45320, Pakistan
[b] Snow Leopard Trust, 4649 Sunnyside Ave N, Suite 325, Seattle, WA 98103, USA
[c] Himalayan Wildlife Foundation, F-8/1, Islamabad, Pakistan
[d] Institute of Management Sciences, 1-A, Sector E-5, Phase VII, Hayatabad, Peshawar, Pakistan
[e] U.S. Geological Survey, Northeast Climate Adaptation Science Center, Amherst, MA, USA
[f] Department of Biological and Environmental Sciences, Qatar University, Doha, Qatar

ARTICLE INFO

Keywords:
Economic valuation
Provisioning ecosystem services
Climate change
Focus group discussion
Gurez Valley
Western Himalayas

ABSTRACT

Climate change is a significant threat to people living in mountainous regions. It is essential to understand how montane communities currently depend especially on the provisioning ecosystem services (ES) and the ways in which climate change will impact these services, so that people can develop relevant adaptation strategies. The ES in the Gurez Valley, in the Western Himalayas of Pakistan, provide a unique opportunity to explore these questions. This understudied area is increasingly exposed not only to climate change but also to the over-exploitation of resources. Hence, this study aimed to (a) identify and value provisioning ES in the region; (b) delineate indigenous communities' reliance on ES based on valuation; and (c) measure the perceptions of indigenous communities of the impact of climate change on the ES in Gurez Valley. Semi-structured interviews and focus group discussions were used to classify the provisioning ES by using the 'Common International Classification on Ecosystem Services' (CICES) table and applying the 'Total Economic Valuation (TEV)' Framework. Results indicate that the indigenous communities are highly dependent on ES, worth 6730 ± 520 USD/Household (HH)/yr, and perceive climate change as a looming threat to water, crops, and rearing livestock ESS in the Gurez Valley. The total economic value of the provisioning ES is 3.1 times higher than a household's average income. Medicinal plant collection is a significant source of revenue in the Valley for some households, i.e., worth 766 ± 134.8 USD/HH/yr. The benefits of the sustainable use of ES and of climate change adaptation and mitigation, are culturally, economically, and ecologically substantial for the Western Himalayans.

1. Introduction

Mountains cover 22% of the global land surface but harbour more than 85% of the world's amphibian, bird, and mammal species (Rahbek et al., 2019). They are among the most endangered ecosystems on earth, being exposed and vulnerable to the impacts of climate change (FAO, 2015a). Research has shown higher rates of warming in the world's mountains (Wester et al., 2019). This climate exposure is affecting not only biodiversity, including endemic species, but also human populations. Of the approximately 13% of the global population that lives in montane ecosystems, about 90% live in the Global South, of which half live in the Asia-Pacific and one-third in China (Huddleston et al., 2003; Macchi, 2010; FAO, 2015b).

The Hindu Kush Himalayan (HKH) region is a hub of biodiversity, providing habitat for more than 35,000 species of plants, more than 200 species of animals, including the endangered snow leopard, and water to about 1.9 billion people (Xu et al., 2019). The changing climate adds an extra strain on mountain people there, many of whom are poor and are now exposed to additional survival threats and potential inequities (Gentle and Maraseni, 2012). Ecosystem services (ES) are the benefits humans obtain from ecosystems (Millennium Ecosystem Assessment, 2005) and include provisioning (e.g., goods that can be consumed such

* Corresponding author.
E-mail address: anawaz@qu.edu.qa (M. Ali Nawaz).

https://doi.org/10.1016/j.ecoser.2022.101453
Received 25 June 2021; Received in revised form 5 June 2022; Accepted 12 June 2022

as timber, minerals) and non-provisioning ES (e.g., goods or processes that are not directly consumed or can be enjoyed in situ such as carbon sequestration, soil formation, recreation, and spiritual enrichment; Maitane et al., 2018).

Mountain ES provide significant economic value, including water, crops, animal products, timber and non-timber forest products, and tourism (Egan and Mf, 2016). For example, the Himalaya, Karakoram, and Hindu Kush mountain ranges are home to about 25,000 plant species, out of which around 10,000 are of medicinal value (Pei, 1992). In the Western Himalayas of Pakistan, it is estimated that, out of the total 675 wild edible plant species, 171 species are used to cure diseases (Arora and Nayar, 1984). In the Trans-Himalayas in the Spiti Valley, local communities highly depend upon ES such as animal dung and wild plants as fertilizer and fodder for their livestock (Murali et al., 2017b). High dependence on fodder and grass in the Pyuthan District, Nepal, has been documented as well (Arun, 2004).

Climate change is threatening the ES of this region. In recent decades, the HKH region has seen substantial warming, approximately equivalent to the world average (Krishnan et al., 2019), resulting in glacial retreat, impacts on biodiversity and plant phenology, and losses of ES, including decreases in water availability and agricultural productivity (Pritchard, 2017, Bhatta et al., 2020). Even if global warming is limited to 1.5 °C, warming in the HKH region would most likely be at least 0.3 °C higher, and at least 0.7 °C higher in the northwest Himalaya and Karakoram due to their high altitude and latitude (IPCC, 2021). In addition to climate change, the secluded valleys of the Western Himalayas in Pakistan have been under increasing pressure in recent decades because of population growth, resulting in the increased harvesting of non-timber products (Awan et al., 2021).

Pastoral and agro-pastoral communities live across the range in Asia's high mountains and are reliant on the ES for their ways of life and subsistence (Murali et al. 2017a). Previous studies found that the economic benefits derived from the ES in the high-elevation Qurumbar National Park, Pakistan, contributed to 5,955 USD/Household (HH)/yr (Din et al., 2020); in Spiti Valley, India 3,622 ± 149 USD/HH/yr (Murali et al., 2017b); in Tost 150,100 ± 13,290 USD/HH/yr, in Changtang 79,303 ± 9,204 USD/HH/yr; and in Sarychat 25,544 ± 5,236 USD/HH/yr (Murali et al., 2020).

In this paper, we aimed to: (a) identify and value provisioning ES in the region; (b) delineate indigenous communities' reliance on ES; and (c) estimate whether climate change is already impacting the values of ES in the Gurez Valley in the Western Himalayas. This study is the first attempt to quantify indigenous communities' dependence on provisioning ES in the Gurez Valley and compare the values with studies conducted by Murali et al. (2017a) in similar landscapes (Spiti Valley in the Indian Trans-Himalayas, Tost Nature Reserve in Mongolia, Changtang region in Ladakh, and Sarychat region in Kyrgystan). The comparison reveals the significant impact of climate change on the provisioning values of ES.

2. Materials and methods:

2.1. Conceptual steps

To explore the above study objectives, we first conducted interviews at household level through questionnaires after selecting six communities with a sample size of 10% from each community (Fig. 1). The questionnaire was developed, based on the "International Forestry

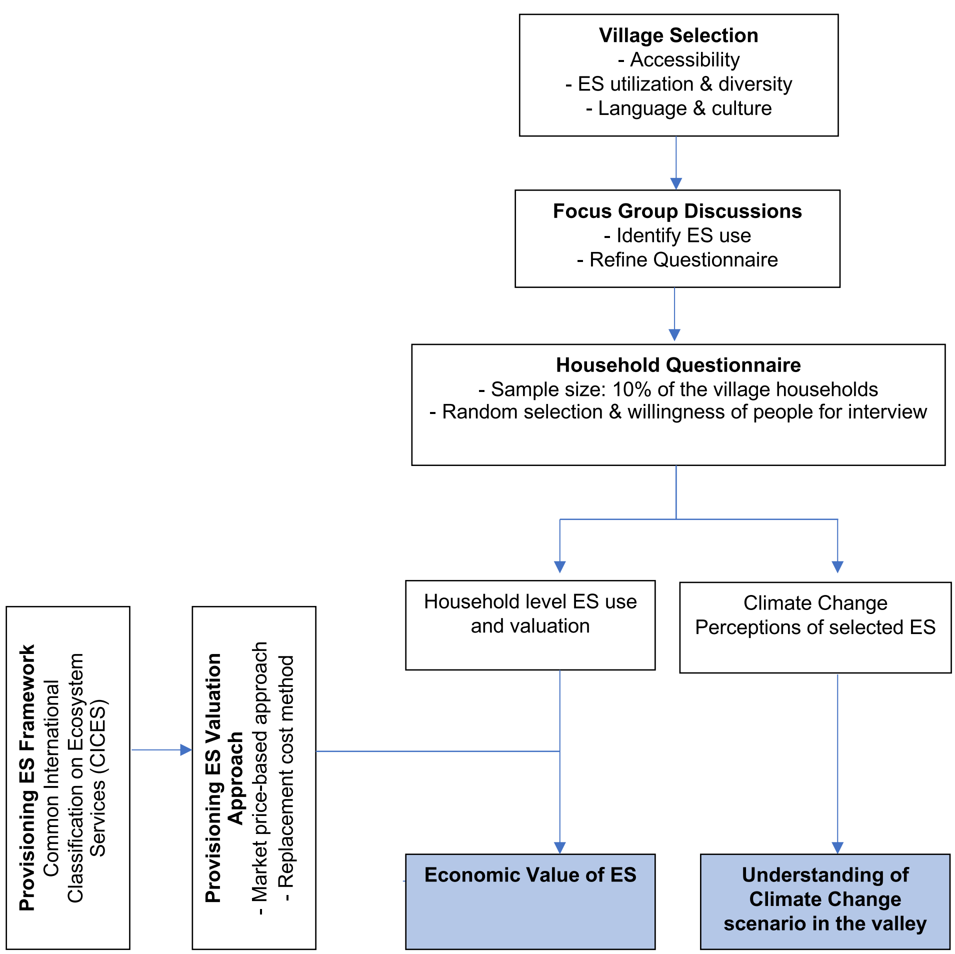


Fig. 1. Flow chart showing conceptual steps adopted to value ESS and recording perceptions of climate change in Gurez Valley.

Resources and Institutions" (IFRI) field manual (Wertime et al., 2011). forming the basis of the focus group discussion questions followed by the detailed household interview questions. One focus group discussion was conducted in each community to compile the list of ES. To value the ES described in these discussions, we relied on the 'Common International Classification on Ecosystem Services' (CICES) and the 'Total Economic Valuation' (TEV) framework, suggested by 'The Economics of Ecosystems & Biodiversity' (TEEB). ES valuation was made through the 'market price-based approach' and the 'replacement cost method' (Wyatt, 2009). The total economic value was calculated by adding up the means and standard errors for each ES. The ES that are perceived by the indigenous community members to be impacted by climate change in the Gurez Valley were assessed as well. We compared these valuations across local and regional contexts.

2.2. Study area

Pakistan's northern areas (35-37° N and 72-75° E) are characterised by glaciated crests, shallow valleys, gullies, hills, and rugged peaks (Bischof et al., 2014). They fall in the water catchment areas of the mountains of Karakorum, the Himalayas, and Hindukush. The Gurez Valley (34°41′ 34°58′ N and 74°32′ 74°53′E; 2000–6000 masl; 528.15 km^2) is situated in the Himalayan orogenic belt in northern Kashmir and southern Gilgit-Baltistan and falls under the Global Snow Leopard Ecosystem Program's (43° to 36°45′ N and 74° to 75° E) priority landscape in Pakistan (Fig. 2). This area is characterized by harsh environmental conditions and restricted agricultural suitability; hence, pastoralism is the most common livelihood strategy. The vegetation areas comprise coniferous woodland, scrub, and the alpine desert. The annual average rainfall is about 200 mm below 3000 m elevation and around 2000 mm between 3000 m and 6000 m elevation. In lower elevations, the temperature varies from 45 °C to −4°C, whereas in higher elevations it is −20 °C during winter.

The Gurez Valley was declared as Gurez National Park (also known as Musk Deer National Park) on 24th September 2007, with a total area of 528 km^2 (Qureshi et al., 2013). The unregulated grazing (not practiced on an annual rotation basis) and the removal of dry fuel wood collection (not practiced on an area assessment basis), have been reported as primary management issues in the Valley (Ahmed et al., 1998). The Gurez Valley consists of 18 villages with a total population of 25,388 individuals (Snow Leopard Foundation – Pakistan, unpublished data, 2019), mainly dependent on subsistence farming and livestock for livelihood, similar to other low productivity ecosystems (FAO, 2010). Due to the harsh ground conditions, most of the households in these villages are confined for easy access to farms, grazing areas, and forest resources in and adjacent areas of Musk Deer National Park in the Gurez Valley. Most people in the Gurez Valley are resident agro pastoralists. The crops include maize, wheat, barley, millet, fruit, and nuts as well as potatoes. Sheep, goats, donkeys, cattle, and horses are kept as livestock. Water is brought to agricultural fields by irrigation canals (some 20 km long). Other sources of revenue are gathering medicinal plants, fungi, wood harvesting and, sometimes, hunting wild animals from the woods in lower altitudes.

2.3. Data collection

2.3.1. Community description and selection

A total of six communities were selected on account of accessibility in the Valley and the willingness of people for interviews (Fig. 2). Prior conversations with our local representative team members were held to guarantee an accurate depiction of the ES use, such as crops cultivated, animals reared, and the type and amount of natural resource harvesting such as medicinal plants, forage, and fuelwood. Data were collected at the household level for a 10% sample size of each community to provide a complete picture of ES usage and perceptions of climate change in the Gurez Valley. All fieldwork was carried out during the month of June in

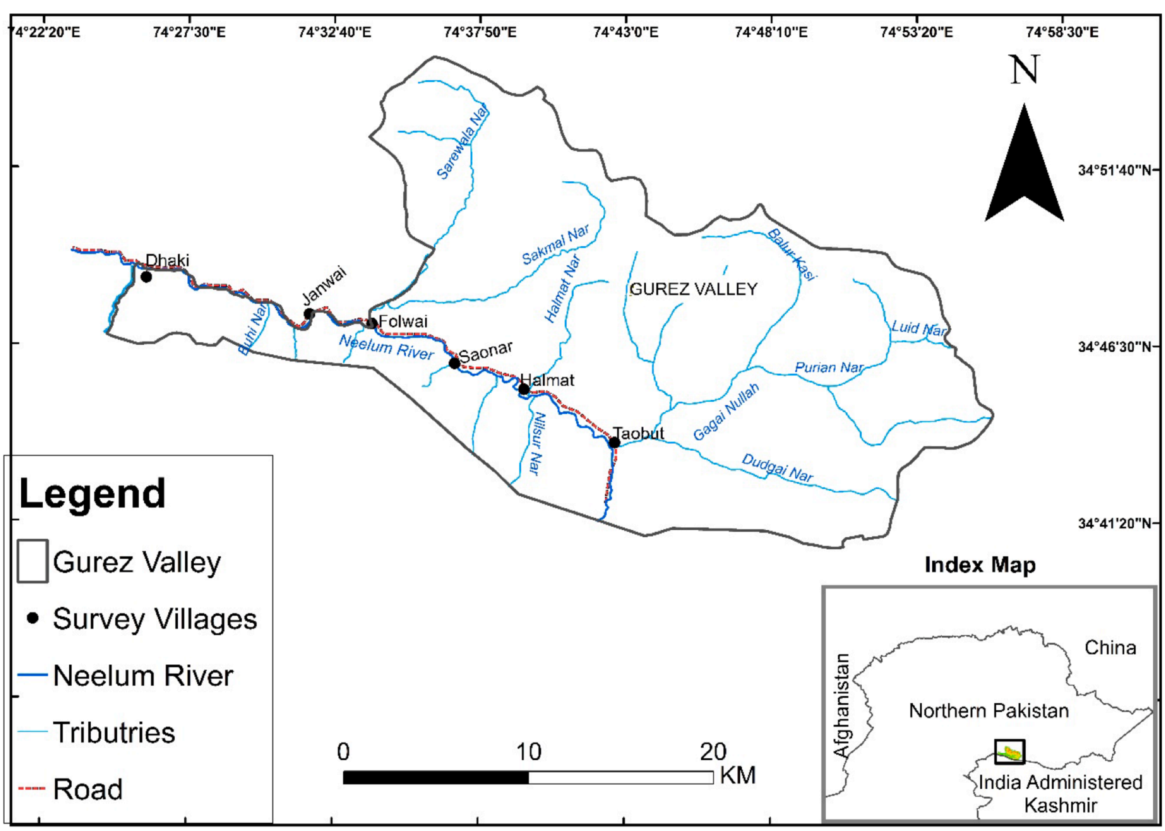


Fig. 2. Map of Gurez Valley, showing 6 survey villages.

2017.

Generally, the inhabitants of these communities conduct subsistence agriculture by cultivating maize, beans, and potatoes in fields locally known as Makki, Alo, and Lobia. For example, only one crop is grown for six months out of the year, while the rest of the year the agriculture fields remain snow covered. The inhabitants collect grass, fuelwood, and medicinal plants from the communal land and forest land located near their villages. The crops are grown mainly for household use, but some individuals sell surplus production to obtain an income. The agricultural fields surround the settlements and the border of the forest. Much of the nearby forest land is used by the community as pasture for their animals.

To obtain primary data for the study, a cumulative number of 172 interviews were conducted, including 6 focus group discussions. The number of interviews in each selected community included households from Dhakki (n = 18), Janwai (n = 13), Followi (n = 59), Saonar (n = 18), Halmat (n = 45), and Taobut (n = 19). In the sampled communities, the male to female ratio was 49% to 51%. The average household size was 7.91 people. The interviewees were adults above the age of 18 years and included both men and women of the households. The survey and participatory rural appraisal were used to gather information about the social structure, livestock, agriculture, and use of wood for fuel and building purposes. We also reported the views of community people on climate change and its consequences for ES, including impacts on crop cultivation, livestock production, and water availability.

2.3.2. Focus group discussion procedure

To determine the ES harnessed by local people at the household level in the Gurez Valley, one focus group discussion was conducted in each of the 6 communities. Following an explanation of the study's topic and objective, participants were asked to list the ES in the Gurez Valley. The questions and responses were conducted verbally, with facilitators using local vernacular to the extent feasible to ensure that participants understood what was being said. Each focus group discussion lasted no more than two hours and was moderated by a member of the study team, who were all local and fluent in the local language. The group facilitator ensured that all participants contributed to the discussion to support the group's perspective (Van Oort et al., 2015). The discussions were recorded in the questionnaire and the notebooks of the team members for later analysis. We started by talking to various key informants to get a better understanding of how ES are being used. We inquired about the quantity of agricultural products, subsistence crops harvested, livestock owned (age and gender categorization), water utilized, fodder, fuelwood, wild animal and plant products, and manure collected from the pastures (see supplementary material). The focus group discussions were centred on the compilation of the list of ES for each of the six communities. The questions are shown in Table 1.

2.3.3. Questionnaire

A questionnaire, based on the focus group discussions, was developed in accordance with the guidelines provided by the modified version of the "International Forestry Resources and Institutions" (IFRI) field manual to obtain information at household level (Wertime et al., 2011). The IFRI questionnaire has been extensively used to understand the human use of common pool resources in forest systems (Epstein 2017). The specific questions posed to each selected household in the 6 communities related to the provisioning ES in 6 communities are shown in Table 1.

We also collected information on the perceived impacts of climate change on provisioning ES by asking them if climate change had been impacting the ES, such as crop cultivation, livestock rearing, and water availability. Table 1 provides interview questions about how people think climate change will affect them.

Table 1

Detail on the focus group discussion and specific interview questions.

	Focus group discussion questions
(i)	what are the benefits provided by nature in the valley
(ii)	what are the crops grown in the village, which ones are sold, and how much is one kg of a particular crop sold for?
(iii)	Are any wild plants or animal products collected for agriculture for either fertilizing or levelling the land?
(iv)	How is the water brough from the pastures for agriculture and shared in the village?
(v)	What is used for fertilizer and how much fertilizer needed for one acre of land in a year?
(vi)	How the different livestock are herd in the village? When are they taken to the pastures? How are they fed during the winter months?
(vii)	Is the forage collected and names of the plants that are collected?
(viii)	What is the livestock used for and one kg and one liter prices of meat, fodder, livestock feed, milk respectively?
(ix)	What are the rates for selling the livestock with respective age/sex.
(x)	Are any wild plants or animal products collected and sold from pasture? (xi) What is the price of firewood if bought from the market?
	General Interview questions
(i)	What are the crops that they grow?
(ii)	How much land do they own?
(iii)	How much land do they cultivate?
(iv)	How much of crops did they harvest and sell last year?
(v)	Do they hire labour in farm?
(vi)	If so, how many and for how many days in a year and at what rate?
(vii)	Do they buy any fertilizers or pesticides?
(viii)	If so, how much do they spend on these?
(ix)	How much local fertilizer do you use?
(x)	How do they plough land?
(xi)	If they use a tractor what is the rate/hour and how many hours do they use it for?
	Specific questions – Provisioning ecosystem services (ES) obtained through livestock rearing
(i)	What are the livestock that they own?
(ii)	what is the age/sex composition?
(iii)	What is the livestock used for?
(iv)	How much milk do they get per day?
(v)	How much meat did they sell last year?
(vi)	Do they use livestock to plough land?
(vii)	If so, which one, and for how long?
(viii)	Do they buy any animal feed or fodder for your livestock?
(ix)	If so, how much do they spend on it?
	Specific questions – Provisioning ecosystem services (ES) obtained through pasture use
(i)	How much wild plants, wood and dung do they collect?
(ii)	How much time do they spend collecting these services?
(iii)	How much water does their household consume in a day?
(iv)	Where do they get water from?
(v)	Do they pay for water?
(vi)	If so, how much do they pay per month?
(vii)	Do they collect any medicinal plants from the pastures?
(viii)	What do they use it for?
(ix)	How much do they collect in a year?
	Questions on climate change perceptions
(i)	Have you experienced any changes in climate in the last five years?
(ii)	If you have noticed changes in climate, how have they impacted your crops?
(iii)	If you have noticed changes in climate, how have they impacted your livestock?
(iv)	If you have noticed changes in climate, how have they impacted your access to/sources of and water availability?

2.4. Provisioning ecosystem services identification and economic valuation

The interview responses were recorded and compared against each of the provisioning ES typology for the economic valuation. These were assigned codes and allocated to the groups of provisioning ES built upon CICES table (Haines-Young and Potschin, 2010). The TEV framework suggested by TEEB was used for calculating the economic value of provisioning ES (Kumar and Martinez-Alier, 2011).

The TEV framework is a well-organized method to delineate all the benefits that an ecosystem provides. The TEV framework is a well-known tool for economic valuations of ES because it represents value in economic or other market-based units that can be compared across ES types (Pomfret, 2014; Table 2). Using this framework, the provisioning ES is evaluated by employing direct and indirect use values that are utilised by humans. For determining the values of ES, we used market price-based and replacement cost methods. This framework has been used by earlier studies as well, those that were conducted by Murali et al. (2017a), Murali et al. (2017b), and Murali et al. (2020) in similar mountainous and arid environments. Furthermore, we also wanted to verify if the results of our study were validated with the findings of the earlier studies as well.

2.4.1. Ecosystem services valuation based on market price

The market price-based method is used to assess the value of provisioning ES. Since provisioning ES are often sold, market prices are considered to provide reliable information on value (Pomfret, 2014). This strategy was adopted for the ES with a market price in the Gurez Valley. Table 2 provides details on the economic valuation method (Kumar and Yashiro, 2014) for each ES considered under this study.

The economic values of the ES were analyzed as per the market price-based method under CICES classes for the following categories: (i) "cultivated crops" (e.g., beans and potatoes), (ii) "livestock and their outputs" (e.g., milk and meat), (iii) "fibers and other materials from plants, algae, and animals for direct use or processing" (e.g., medicinal plants) and (iv) "plant-based resources" (e.g., fuelwood). Detail on the local market prices used to value these ES, and on the formulae used to obtain the economic value of each ES is given in the supplementary material (Tables S1 & S2).

Table 2
Methods used and units of measurement for estimating the economic value of provisioning ecosystem services (ES) in Gurez Valley. The first column refers to the CICES class of provisioning ES. The second column refers to ES utilized by communities. The third column refers to the economic valuation method such as the market price-based approach and the replacement cost method. The fourth column refers to the unit prices.

Sr#	CICES Ecosystem Services Class	Provisioning Ecosystem Service	Economic Valuation Method	Unit Price
1	Cultivated crops	Beans & Potatoes	Market price-based approach	Kg/HH/yr
2	Reared animals and their outputs	Milk	Market price-based approach	L/HH/yr
		Meat	Market price-based approach	Animals/HH/yr
3	Surface water for drinking	Water for drinking	Replacement cost method	L/HH/yr
4	Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	Market price-based approach	Kg/HH/yr
5	Materials from plants, algae, and animals for agricultural use	Fodder for livestock	Replacement cost method	Kg/HH/yr
6	Surface water for non-drinking purposes	Water for livestock consumption	Replacement cost method	L/HH/yr
7	Plant-based resources	Fuelwood	Market price-based approach	Kg/HH/yr
8	Animal-based energy	Ox to plough land, donkey & horse to transport materials	Market price-based approach	Animals/HH/yr

The economic value of crops was analysed by determining the total amount of crops gathered every year and multiplying it by the market value. The value of all the external inputs, such as chemical fertilizers and the labour employed, tractor and ox physical labour costs were subtracted from the value of the crops produced to get the ES value of the crop yield. The economic value of milk was estimated by multiplying the market value of milk per litre with the number of litres per household per day multiplied by the total number of days per year. The economic value of meat was estimated by multiplying the market price of an animal per household with the number of animals sold on an annual basis. To estimate the economic value of medicinal plants, the annual collection of medicinal plants per household was multiplied with the local market prices. The economic value of the fuelwood was estimated by multiplying the annual per household consumption of the fuelwood with its local price.

2.4.2. ES valuation using the replacement cost method

The cost of replacing ES with artificial technologies is estimated by using the replacement cost approach. This strategy was utilized in Gurez Valley to replace ES that lacked a market price and might be replaced by comparable materials available for purchase. The prices chosen were those found on the local market. Table 2 provides details on the economic valuation method (Kumar and Yashiro, 2014) for each ES considered in this study.

The economic values of the ES were calculated using the replacement cost method for the following CICES classes: (i) "surface water for drinking" (e.g., for household purposes), (ii) "materials from plants, algae, and animals for agricultural use" (e.g., fodder for livestock), (iii) "surface water for non-drinking purposes" (e.g., for livestock consumption), and (v) "animal-based energy" (e.g., physical labour by ox to plough land, and donkey and horse to transport materials). The local values used to calculate each ES in the Gurez Valley, and the formulae used to get the economic value of an ES under this approach are provided in the supplementary material (Tables S1 & S2).

The value of water for daily household consumption was calculated by multiplying the known water volume multiplied by the number of people in the household and the local price of water. The local price of water was considered as the local labour charges used to bring water from the natural streams to the households. The stream water is the main source of water for Gurez communities and is free of charge (Tables S1 & S2). The value of water for livestock consumption was determined by multiplying the annual volume of water collected for livestock with the local water price (Ward and McKague, 2007). The economic value of the fodder for livestock was estimated primarily for the different livestock species individually. The amounts of fodder consumed were multiplied by the local price of fodder on an annual basis and then added up to get the value of fodder for livestock in the Valley. The animal-based energy was estimated for donkeys and horses as they are used to transport materials from the pastures to the settlement areas. The annual household cost was determined by multiplying the number of days by the local animal labour rates. The cost of ox physical labour to plough land was not considered under this category to avoid double counting because the ox physical labour to plough land was considered as external input under the crop ES economic valuation.

2.5. Total economic value

The overall economic benefit was determined by assigning to each household the economic value for each provisioning ES by adding up the means and standard errors for each household service (Lindberg, 2000). The household earning values were calculated by the respondents for all their various sources of income (Cavendish, 2002) such as employment, agricultural produce, livestock products sold, and medicinal plants, and then added to determine the Gurez Valley's average income.

Table 3
Economic values of the provisioning ecosystem services (ES) in Gurez Valley, Pakistan. The first column refers to the CICES class of the ES, while the second column refers to the respective ES utilized. The third column refers to respective ES economic value in USD/HH/yr. The fourth column refers to the percentage contribution of respondents using the ES. The fifth column refers to the percentage contribution of individual ES value to the total ES value. (1 USD = 103 PKR in 2017).

CICES Class of provisioning ecosystem services	Ecosystem service	Mean ± SE (USD/HH/yr)	Proportion of respondents using ecosystem services (%)	Proportion of total value of ecosystem services (%)
Cultivated crops	Crops	65.8 ± 6.5	100	1
Reared animals and their outputs	Milk	609 ± 34.6	94.7	9
Reared animals and their outputs	Meat	98 ± 10	44.7	1.5
Surface water for drinking	Water for household purpose	11.4	100	0.2
Fibers and other materials from plants, algae and animals for direct use or processing	Medicinal plants	766 ± 134.8	33.7	11.4
Materials from plants, algae and animals for agricultural use	Fodder for livestock	4105 ± 306	100	61
Surface water for non-drinking purposes	Water for livestock consumption	18.5 ± 0.5	100	0.3
Plant-based resources	Fuelwood	1044 ± 26.7	100	15.5
Animal-based energy	Donkey & horse physical labour to transport materials	13 ± 1.7	17.4	0.2
Total Economic Value		6730 ± 520	-	

2.6. Climate change perceptions

The qualitative information gathered through the interviews on the perceived impacts of climate change on ES such as water, crop cultivation, and livestock rearing were analyzed as the percentage responses for the entire sample.

3. Results

3.1. Provisioning Ecosystem Services (ES)

The provisioning ES (Table S3) identified by the indigenous communities represented 8 of the 16 CICES classes (Haines-Young and Potschin, 2010). The most frequently used ES were 'cultivated crops' (used by 100% of the respondents), 'surface water for drinking' (used by 100% of the respondents), 'materials from plants, algae, and animals for agricultural use' i.e., 'fodder for livestock' (used by 100% of the respondents), 'surface water for non-drinking' i.e., water for livestock consumption (used by 100% of the respondents), and 'plant-based resources' i.e., fuelwood (used by 100% of the respondents) in the Gurez Valley. The other services used were 'reared animals and their outputs', e.g., milk and meat (97.7%), 'fibers and other materials from plants, algae and animals for direct use or processing', such as medicinal plants (33.7%), and 'animal-based energy', such as ox labour to plough land and donkey and horse labour to transport materials (17.4%). Fig. 4 details on each ES percentage used by the selected communities in the Gurez Valley. The Dhaki community used the most ES (82%) on average, followed by the Folowai and Taobat communities (78% each), the Saonar community (76%), the Halmat community (74%), and the Janawai community (69%).

3.2. Economic values

The most economically valued ES was 'fodder for livestock' 4105 ± 306 USD/HH/yr, which contributed around 61% of the total economic importance of ES supply. This was followed by 'horse & donkey physical labour to transport materials' 1166 ± 111 USD/HH/yr, 'fuelwood' 1044 ± 26.7 USD/HH/yr, 'medicinal plants' 766 ± 134.8 USD/HH/yr, and milk and meat all together 707 ± 44.6 USD/HH/yr (where milk = 609 ± 34.6 USD/HH/yr and meat = 98 ± 10 USD/HH/yr). The economic value of 'crops' was 65.8 ± 6.5 USD/HH/yr, water for non-drinking uses was 18.5 ± 0.5 USD/HH/yr, and water for drinking purposes was 11.4 USD/HH/yr. Water was the least economically valued service (Table 3).

In the Gurez Valley, people's main livelihood depended on local provisioning ES such as 'cultivated crops', 'reared animals and their outputs', and 'medicinal plants', whereas the other sources included employment. The gross economic value of identified provisioning services amounted to 6730 ± 520 USD/HH/yr (Fig. 3). The dependency on local ES was not captured by the economic values alone. The approximate economic support of the provisioning ES of 6730 ± 520 USD/HH/yr was 3.1 times the annual household income in the Gurez Valley. The 22.8% share of the total economic value of ES directly contributed to the household income worth 1538 USD/HH/yr (the economic support sought from the ES such as cultivated crops, livestock rearing and their outputs and the medicinal plants), whereas the remaining 77.1% share contributed to the cost's worth 6345 USD/HH/yr.

3.3. Medicinal plants

We are providing extra details on medicinal plants as an ES because they are highly valued and serve as an important source of income in the Gurez Valley. *Morchella esculenta* (price/kg = 155 USD) was the most valued medicinal fungus species, followed by *Aconitum heterophyllum* (price/kg = 68 USD), *Acacia senegal* (price/kg = 29 USD), *Picrorhiza kurroo* (price/kg = 15 USD), *Saussurea lappa* (price/kg = 10 USD), *Valeriana jatamansi* and *Viola biflora* (price/kg = 8 USD). *Berginea ciliate*, *Adiantum venustum*, and *Geranium willichianum* were not sold and had the least economic value. The local communities collected these plants for treatment of different ailments. Table 4 lists the medicinal plant species collected by the communities in the Gurez Valley along with the percentage of collection, usage, and price on an annual basis.

Medicinal plants were collected in considerable amounts by communities in Gurez Valley. *Aconitum heterophyllum* was collected in the highest quantity (1452 kg/yr), followed by *Acacia senegal* (523 kg/yr), *Picrorhiza kurroo* (424 kg/y), *Morchella esculenta* (23 kg/yr) and *Saussurea lappa* (8 kg/yr). These plants are sold in the nearby herbal markets for supplementary income. In addition, the communities utilize roots, rhizomes, leaves, flowers, and, in some cases, the whole medicinal plant to treat ailments. Ailments such as flu, cough, fever, stomach ulcers, headaches, and joint pain are treated with medicinal plants at the household level.

3.4. Climate change perceptions

In the Gurez Valley, 90.7%, out of the total respondents, reported a changing climate. 98.8%, out of the total respondents mentioned that climate change had a greater impact on 'water' ESS (because of the reduction in quantity and quality of spring water). 95.8%, out of the total respondents stated that climate change had a negative impact on the 'fodder' ES. 88.5%, out of the total respondents, revealed negative

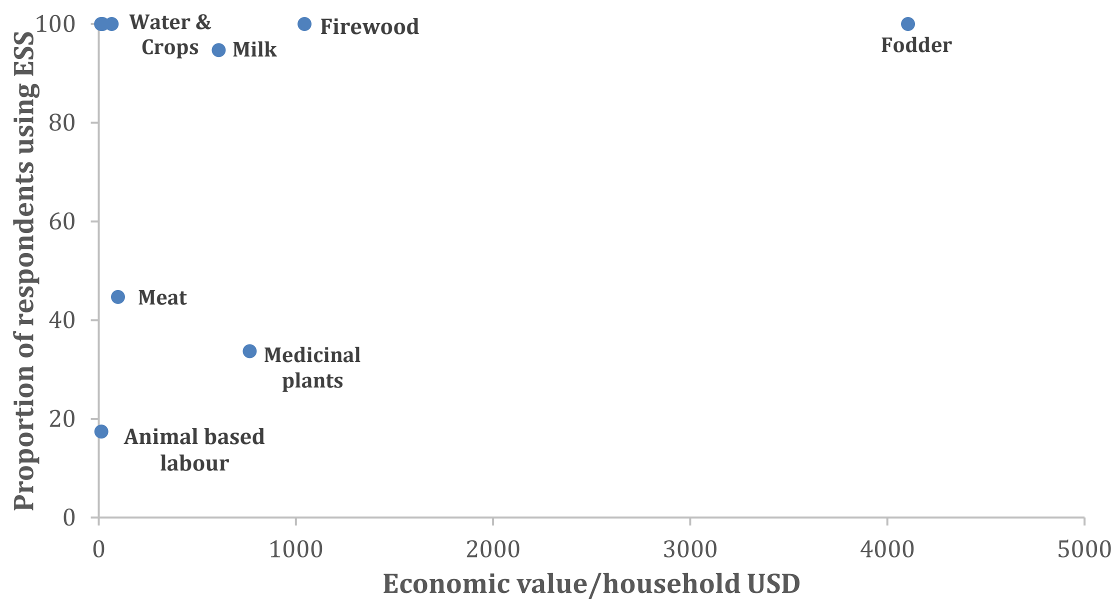


Fig. 3. Economic value of the provisioning ecosystem services and the proportion of respondents using them.

impacts of climate change on the crop yield owing to the unpredictable climatic hazards such as floods, thunderstorms, irregular rain patterns, and hot weather events in the Valley. Table 5 outlines the perceived impacts of climate change on ES in the Gurez Valley. The other perceived impacts mentioned by respondents were an increase in crop disease and pest attacks, livestock being more vulnerable to disease and reduced water availability. Only a small fraction of respondents believed that the increased crop production was due to the increased precipitation and the change in weather conditions.

4. Discussion

4.1. Provisioning ecosystem services identification

Our study revealed a range of provisioning ES identified and valued by Gurez Valley communities in the Western Himalayan part of Pakistan. The communities in this study revealed awareness and concern for provisioning ES, a similar pattern that has been found in other studies in the arid mountain regions (Murali et al., 2017a, Murali et al., 2017b, Din et al., 2020). Nearly all the respondents used the provisioning ES belonging to CICES classes (Haines-Young and Potschin, 2010), such as the cultivated crops, reared animals and their outputs, surface water for drinking, fibres and other materials from plants, surface water for non-drinking purposes, plant-based resources, and animal-based energy. We found that there was not much difference among the respondents of Gurez Valley communities with respect to the types of ES used, but rather the extent of use in terms of the proportion of people using ES and the quantity of ES used at the community level (see section 3.1). A similar trend has also been reported in the arid region of the Pamir Karakoram landscape in Pakistan for forage, fuelwood, and domestic water usage of about 90–94% (Din et al., 2020).

The Himalayas are a valuable source of different kinds of ES for local

Table 4
Annual economic values of 'medicinal plants' (mp) collection in Gurez Valley. The first column refers to the mp sold and not sold in the local markets. The second and third columns refer to the mp species collected and their taxonomic family respectively. The fourth column refers to the local names whereas the fifth and sixth columns refers to the mp parts used and their usage respectively. The seventh column refers to the quantities of the mp collected whereas the eighth column refers to percentage collection and the ninth column refers to the per kg price of mp in USD. *mp = medicinal plants, (1 USD = 103 PKR in 2017).

	Medicinal Plant	Family	Local Name	Parts Used	Local Use	Quantity (kg)	Collection (%)	Price/kg USD
Sold	*Acacia senegal*	*Fabaceae*	Trapetra	Roots	Stomach Alcer	523	16.3	29
	Aconitum heterophyllum	*Ranunculaceae*	Patris/Sarba vala	Rhizome	Cough & asthma	1452	32.5	68
Not sold	*Adiantum venustum*	*Liliaceae*	Sumbal	Whole plant	Cough	-	3.48	01
	Bergenia ciliate	*Apiaceae*	Batbhyva	Root, flowers, and leaves	Coughs and colds, asthma	-	3.48	-
	Geranium willichianum	*Geraniaceae*	Rattan Jog	Rhizome/Roots	Backache, Weakness	-	0.58	-
Sold	*Morchella esculenta*	*Morchellaceae*	Ghuchi	Plant	For energy and physical fitness	23	11.6	155
	Picrorhiza kurroo	*Scrophulariaceae*	Kohr	Root	Asthma	424	4.65	15
	Saussurea lappa	*Asteraceae*	Kuth	Rhizome	Joint pain	8	6.39	10
	Valeriana jatamansi	*Valerianaceae*	Mushk bala	Rhizome	Cough	0.3	1.74	08
	Viola biflora	*Pteridaceae*	Thandi jaree, Banafhsha	Flower/leaves	Cold & flu	0.3	1.74	08

Table 5
Perceived impacts of climate change on the provisioning ecosystem services (ES) along with their perceived nature of impact by the local communities in Gurez Valley, Pakistan. The first column refers to the ES being impacted by climate change. The second column lists the perceived impacts of climate change. The third column describes the nature of impact on the ES by climate change whereas the fourth column lists the percentage responses of the respondents.

Provisioning ecosystem services	Perceived impact of climate change	Nature of impact	% Responses
Crop production	Negative	Reduction in crop yield due to flash flooding, thunderstorms, irregular rain, and hot weather	88.5
	Negative	Increase in crop disease and pests	9.3
	Positive	Increase in crop production due to more precipitation	3.2
Livestock	Negative	Decrease in milk production due to decreased fodder	95.8
	Negative	Disease in livestock	4.2
Water	Negative	Reduction in quantity and quality of spring water	98.8
	Negative	Decrease in the water table	2.1

communities. A much higher contribution of provisioning ES was observed in this study. Many of the studies only measured the importance of non-timber forest products (NTFPs), although all the provisioning resources were not included in the other studies. Examples include a high reliance on non-timber forest product revenue, such as honey in South-West Ethiopia (Endalamaw, 2005), Cameroon (Ingram and Njikeu, 2011), and Mwinilunga in North-West Zambia (personal communication, Dan Ball, October, 2014). Likewise, Tanzanian beekeeping revenues have been estimated to be approximately USD 2.5 million (M) in annual exports (Mwakalukwa, 2016). In Sudan, gum-arabic exports produced a revenue of about USD 100 M (10% of overall exports) and USD 153,000 for gum-luban alone (CBOS, 2006 and CBOS, 2007). In Pyuthan District, Nepal, NTFPs have a greater value than wood (Arun, 2004), while wild plants in South Africa generate income of around 1200 USD/HH/yr (Shackleton et al., 2011). This survey attempted to quantify nearly all the provisioning ES identified by the respondents, and this reflected relatively higher values in our study.

4.2. Total economic value of provisioning ecosystem services

The total economic value of the provisioning ES in the Gurez Valley (6730 USD/HH/yr) was significantly higher than the economic benefits obtained in Pakistan's high-elevation Qurumbar National Park (5955 USD/HH/yr, Din et al., 2020) and India's Spiti Valley (3622 ± 149 USD/HH/yr, Murali et al., 2017a). This value was less when compared with the arid regions of Khunjerab National Park in Pakistan (8912 USD/HH/yr; Din et al. (2020); the Changtang livestock production system, India (79,303 ± 9204 USD/HH/yr); the Changtang crop production system, India, (15,083 ± 1656 USD/HH/yr); the Tost Nature Reserve, Mongolia (150,100 ± 13,290 USD/HH/yr); and Sarychat, India (25,544 ± 5236 USD/HH/yr; Murali et al., 2020).

4.3. Medicinal plants collection

Our results disclosed that medicinal plants were collected in the Gurez Valley by most of the respondents in six communities (see Fig. 4).

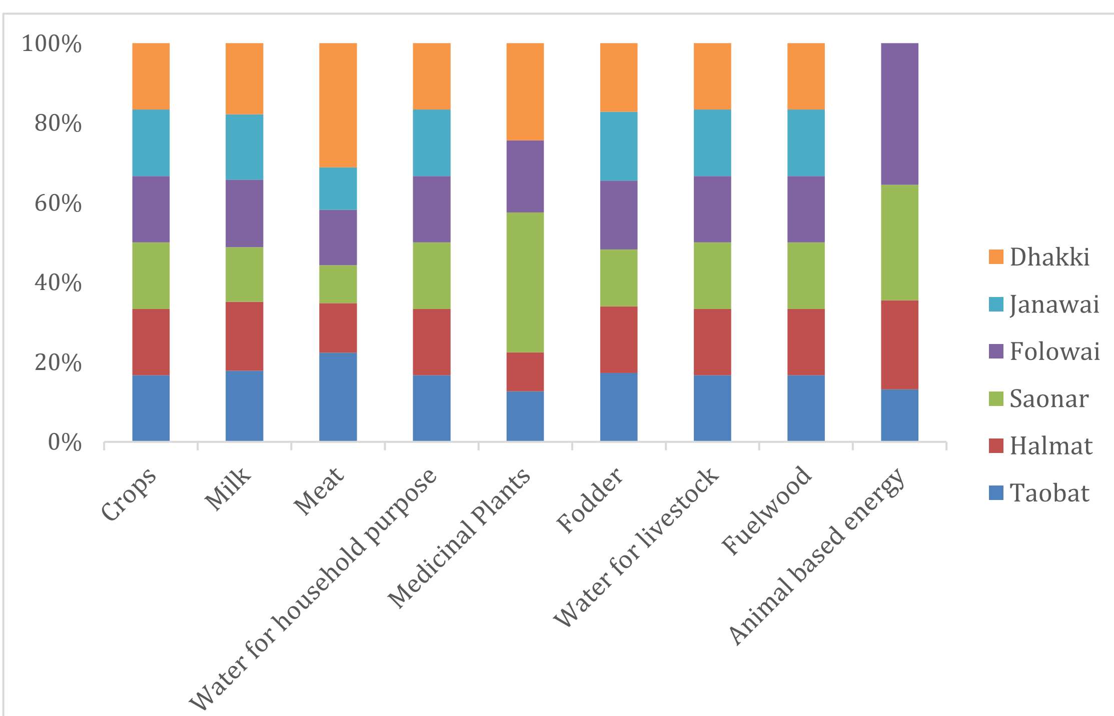


Fig. 4. Detail on the ES percentage used by each selected community in Gurez Valley.

About 70% of the Himalayan medicinal plants and animals are wild, and about 70%-80% of the population depends for their health needs on the indigenous medicines (Pie and Manandhar, 1987). The large amount of *Aconitum heterophyllum* collected (1452 kg/yr) in the Gurez Valley may indicate its unsustainable harvesting. The overharvesting of medicinal plants, especially *Morchella esculenta* (also known as morels or Black Mushroom) has been reported to highly degrade the rangelands in the Western Himalayas (Awan et al., 2020). The average household annual collection of 3–5 kg dry weight of *Morchella esculenta* has been reported to be sold at a price of 500–900 USD/kg in the Western Himalayan Neelum Valley (Shaheen et al., 2017).

4.4. Livelihood support through provisioning ecosystem services

Our study shows that provisioning ES are integral to livelihoods in the Gurez Valley. The total value of the provisioning ES was 3.1 times higher than the average household income in the Valley. This indicates that the people obtained a considerable part of the income by selling goods obtained through provisioning ES. This value was even higher in the case of Spiti Valley in the Indian Trans-Himalayas (3.6 X), in the Changtang region of the agro pastoralists in India (3.7 X), for the nomadic pastoralists (26.1 X), in the Tost Nature Reserve, Mongolia (38.7 X), and in the Sarychat region, Kyrgystan (7.4 X; Murali et al., 2020).

Our results revealed that medicinal plants contributed significantly to the household incomes in the Valley (766 ± 134.8 USD/HH/yr, 11.4% of the total annual economic value). This is contrary to the case mentioned by Murali et al. (2020) in the arid regions, where medicinal plants were least economically valued. For example, in the Spiti Valley, medicinal plants are valued at only 3.4 ± 0.3 USD/HH/yr, with a total economic value share of 0.1%; in the Tost Nature Reserve, Mongolia 6 ± 2 USD/HH/yr, 0% of the total economic value; in the Changtang region, India, ± 0 USD/HH/yr, 0% of the total economic value; for nomadic communities; and in the Sarychat region, Kyrgyzstan, 2.1 ± 0.6 USD/HH/yr, 0% of the total economic value. According to Din et al. (2020), the arid region of the Pamir-Karakoram landscape had lower economic values of medicinal plants. The Qurumber National Park had an economic value of the medicinal plants 06 USD/HH/yr with 0.03% of the total economic value, whereas the Khunjerab National Park had an economic value of the medicinal plants worth 10 USD/HH/yr, 0.1% of the total economic value.

4.5. Provisioning ecosystem services value comparison in similar landscapes

4.5.1. Fodder for livestock'

According to our findings, the highest valued ES in the Gurez Valley was 'fodder for livestock,' accounting for more than 60% (4105 ± 306 USD/HH/yr) of the total economic value. Similar trends have been documented in the arid regions of the Indian Trans-Himalayan Spiti Valley (1960 ± 208 USD/HH/yr, 49.4% of the total economic value), Tost Nature Reserve, Mongolia (145,381 ± 13027 USD/HH/yr, 96.9% of the total economic value), Changtang region, India (75,025 ± 8848 USD/HH/yr, 94.6% of the total economic value in the livestock production system), and Sarychat region, Kyrgyzstan (24,073 ± 5115 USD/HH/yr, 94.5% of the total economic value, Murali et al, 2020). Similar results of the high economic value of fodder were also reported from the Qurumber National Park and Khunjerab National Park in the arid landscape of Pamir Karakoram in Pakistan, (2436 USD/HH/yr, 59.6% of the total economic value and 1944 USD/HH/yr, 54.5% of the total economic value, respectively, Din et al., 2020).

4.5.2. Fuelwood

According to our findings, fuelwood was the second highest ES, accounting for 15.5% of total economic value in the Valley after fodder for livestock, with a total economic value of 1044 ± 26.7 USD/HH/yr. This value exceeded the economic value of fuelwood estimated by Murali et al. (2020), in the arid regions of Indian Trans-Himalayan Spiti Valley (201 ± 17 USD/HH/yr, 5.1% of the total economic value), Tost Nature Reserve, Mongolia (206 ± 16 USD/HH/yr, 0.1% of the total economic value), Changtang region, India (900 ± 151 USD/HH/yr, 1.1% of the total economic value for nomadic communities), and Sarychat region, Kyrgyzstan (169 ± 25 USD/HH/yr, 0.7% of the total economic value). The arid region of the Pamir Karakorum had lower economic values of fuelwood estimated by Din et al. (2020). The fuelwood economic values were 432 USD/HH/yr, with 11.7% of the total economic value in Qurumber National Park and 540 USD/HH/yr, with 9.9% of the total economic value, respectively). In the Western Himalayan landscape, the fuelwood collection varies from valley to valley. At lower elevations, juniper, deodar, spruce, and pine forests are available, so locals depend on them for fuelwood, while at higher elevations, shrubs are used for this purpose. In certain regions of the landscape, the annual needs of the communities exceed the cumulative annual increment of firewood (Snow Leopard Foundation-Pakistan, unpublished data, 2019).

4.5.3. Reared animals and their products

This study indicates that people derive nutritional benefits from agricultural products and livestock products such as milk, and meat. The economic value of the CICES ES category 'reared animals and their outputs' was the fourth highest after the medicinal plants at 707 ± 44.6 USD/HH/yr (milk = 609 ± 34.6 USD/HH/yr and meat = 98 ± 10 USD/HH/yr together). This value was lower in the arid region of the Trans Himalayan Spiti Valley 523 ± 46.2 USD/HH/yr, with a total economic value share of 13.2%; the Tost Nature Reserve, Mongolia 3881 ± 360 USD/HH/yr, 2.6% of the total economic value; the Changtang region, India, 929 ± 67 USD/HH/yr, 6.2% of the total economic value for nomadic communities; and the Sarychat region, Kyrgyzstan, 1182 ± 177 USD/HH/yr, 4.6% of total economic value. The economic value of cultivated crops was 65.8 ± 6.5 USD/HH/yr. Reared animals are an important part of the cultural and religious aspects of the Muslim ethnic group in the Gurez Valley, which are bought and sold during the annual religious ceremonies.

4.5.4. Water

Water was the least valued ES in the Gurez Valley with an economic value of 29.9 ± 0.5 USD/HH/yr (water for domestic usage 11.4 USD/HH/yr and water for livestock consumption 18.5 ± 0.5 USD/HH/yr combined. A similar result has been documented in the other arid mountainous regions of the Indian Trans-Himalayan Spiti Valley (35 ± 4.3 USD/HH/yr, 0.9% of the total economic value), the Tost Nature Reserve, Mongolia (533 ± 59.7 USD/HH/yr, 0.3% of the total economic value), the Changtang region, India (41.5 ± 3.1 USD/HH/yr, 0.32% of the total economic value in the livestock production system), and the Sarychat region, Kyrgyzstan (83.3 ± 11.9 USD/HH/yr, 0.35% of total economic value, Murali et al, 2020). The Qurumber National Park and Khunjerab National Park in the arid landscape of Pamir Karakoram in Pakistan had relatively higher water values (826 USD/HH/yr, 22.5% and 826 USD/HH/yr, 25.7% of the total economic value, respectively, Din et al. (2020). In the Gurez Valley, water is mainly obtained from nearby streams for household use and livestock consumption, free of charge.

4.6. Biodiversity sustainability

Biodiversity helps the sustained provisioning of ES (Loreau et al., 2001), but the relationships between biodiversity and ES are yet to be understood (Balvanera et al., 2016; De Groot et al., 2016). Although the local indigenous communities are paying a cost to conserve the biodiversity in the Gurez Valley, the economic security that these landscapes offer, remains unmeasured. Ahmad et al. (2016) reported an annual economic loss of USD 28,145 (189 USD/HH) from the loss of 276 livestock by predation in the Musk Deer National Park, in addition to the destruction of maize and potato crops by Asian black bears and brown bears, resulting in a loss of 16,330 USD/yr (110 USD/HH). Increased livestock depredation by big predators in the HKH region's highlands has been ascribed to an increase in the livestock populations (Mishra, 1997). To support the coexistence of carnivores and humans in the Musk Deer National Park, compensation and environmental education have been recommended (Mishra et al., 2003).

4.7. Climate change perceptions

Climate change is having an increasing and significant impact on natural resources such as pastures, agriculture areas, and water, particularly in arid mountain environments. The productivity of crops and seafood, droughts, and variable hydrological cycles have been reported to impact and endanger the sustainability of water (Nelson et al., 2013). A similar pattern of reported climate consequences has been reported from the Western Himalayan Naltar Valley and the Rakaposhi Valley in Gilgit-Baltistan, Pakistan (Bhatta et al., 2020; Azfar Hussain et al., 2019) and by the studies conducted in the Sarychat region, Kyrgystan and the Northeast of India and Bhutan as well (Tse-ring et al., 2010; Murali et al., 2017a).

In the Millennium Ecosystems Assessment, climate change has already been identified as a major factor affecting biodiversity and related products and services (Lee and Diop, 2009; Samper, 2003). Most of the respondents in the Gurez Valley reported a change in climate with decreasing river water quality and quantity. Although the HKH region has been designated as a climate change hotspot (Sharma et al., 2019), climate change impacts on ES and damage such as water-induced catastrophes are still not a key subject of the research. Several destructive floods have been caused by glacial lake outburst flooding, which have changed the Himalayan landscape while also altering the lifestyles of mountain communities. Thus, it is imperative to study future climate scenarios to provide insight into the types of agriculture that can be grown, lifestyles that can be practised, and patterns of snowfall and rain to be expected in the landscape.

4.8. Policy implications

The ES provided by the mountain ecosystem in the Gurez Valley is considered vital for local livelihoods and serves as a main support to the economic security of Gurez Valley communities (Murali et al., 2017a). The majority of people in the mountainous and arid region of the Western Himalayas are agro-pastoralists and live in villages (88%), where they practice subsistence agriculture and pastoralism. This entitlement grants them traditional rights and concessions on nearby pastures and natural areas to meet their daily fuelwood, forage, and fodder needs (Awan et al., 2020). The population of the mountain regions of Pakistan is predicted to grow from 51.47 million people in 2017 to 72.64 million people by 2030 (Sharma et al., 2019). This scenario is a serious concern for the sustainable ES provision by the Western Himalayan landscape exceeding its potential.

A bibliometric analysis of the ES research trends in the HKH region revealed only a few studies on ES in Pakistan (n = 10, 2%), which reflects the limited interest and investment in the ES discourse (Kandel et al., 2021; Martín-López et al., 2019). Pakistan devised 'National Forest Policy' (MoCC, 2017) and 'National Climate Change Policy' (MoCC, 2021), where there are no specific policy interventions to acknowledge 'ecosystem services' and hence their implementation and governance. The lack of a sufficient regulatory and policy framework in economically developing nations is seen as a major impediment for programmes aimed at ensuring the long-term management of natural resources (FAO, 2015a). Moreover, in this region, the lack of official recognition of ES, especially by policymakers, can be seen as a major barrier for the persistence of ES, including the forage to maintain pastoral lifestyles.

The government of Azad Jammu & Kashmir devised 'Climate Change Policy' (Climate Change Center, 2017), but still the establishment of an overarching framework for climate action is on the way to consider the local contexts, capacities, and vulnerabilities to be regulated and adopted by the indigenous communities. In the Gurez Valley, only 48% of the households had viable occupation options as their major source of income, putting the remaining households in the less privileged category and hence mainly reliant on the ES for their survival. This study, as well as others on comparable themes (Gerlitz et al., 2014), have underlined the complexity of adaptation and how it is tied to resource availability. Pakistan is the only one of the five South Asian states (Bangladesh, Bhutan, India, Nepal, and Pakistan) that has not seen a decline in the rate of poverty since the mid-1990s (Kumar and Yashiro, 2014). Vulnerability varies by social group, so the less privileged have fewer alternatives to cope with or adjust to the changing circumstances. Therefore, to improve mountain peoples' resistance to change, the inherent reasons for vulnerability, such as poverty, social inequity, restricted income possibilities, and political and economic marginalisation, must be addressed.

4.9. Limitations of the study

ES is an under researched topic in Pakistan's mountains. In this study, we could only focus our analysis on the provisioning ESS. We anticipate that when regulatory and cultural ES are factored in, the economic worth of ES in the Gurez Valley is likely to increase substantially. Due to the time and resource constraints, we were only able to sample six communities; nevertheless, sampling more communities might have provided a different picture of the ES used and its economic value in the Valley. Future research on this topic may concentrate on regulatory and cultural ES, as well as the trade-offs that exist between the provisioning and regulating ES.

5. Conclusions

This study highlighted the Gurez Valley communities' considerable reliance on the ES offered by the high mountain arid landscapes in Asia. Our study is the first to look at community views and identifications of ES in the Western Himalayas in Gurez Valley. It can serve as a model for future research in similar environments and ecosystems throughout Pakistan. This study, in which community members identified eight provisioning ES in the Gurez Valley, supports the idea that this and similar mountain areas promote community livelihoods and well-being through ES provision. Therefore, sustainable harvesting of the ES and official acknowledgement of ES in the regulatory systems are needed.

Further, this study underscores the Gurez Valley communities' vulnerability to climate change as a real and serious threat to their livelihoods and sustenance. The indigenous people there, regardless of their socioeconomic status, have observed a shift in the climate. Water stress is seen as being more severe than the other ES components. The reduction in the crop yields due to disease and pests, flash floods, storms, irregular rain patterns, hot weather, and disease in livestock have had adverse consequences, harming already existing food, water, and income insecurities. Certain changes, on the other hand, present possibilities as well, such as more than one farming season each year at higher elevations or favourable temperatures and more precipitation for specific crops.

Medicinal plant collection is an important source of revenue for many households in the Valley, for which coherent and sustainable harvesting policy measures are needed on an urgent basis to conserve the endangered medicinal plant species. In the HKH region, medicinal plants are one of the most common and valuable natural resources, and they play an important role in local lifestyles and economies (Kalita et al. 2014; MoAF, 2014). To come up with a sustainable plan for harvesting medicinal plants in the Gurez Valley, its important to take a close look at their current state and level of use.

Other than an evaluation of the identified ES, social, and climatic effects, our findings highlight the need to study sustainable use of ES. Comprehensive and urgent climate adaptation initiatives by local communities as well as the government are important to secure living conditions at acute risk from the consequences of climate change. Unfortunately, no such mechanism exists at present to be adopted by the indigenous communities. The participatory rural approach might help in building local climate change adaptation plans. Since the mountain indigenous communities remain politically and economically marginalised, enough resources must be allocated for the execution of current policies to enable avenues for anticipatory and targeted adaptation, as well as increased resilience among the most vulnerable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is available in the MS

Acknowledgements

We would like to thank the Global Environemntal Facility Global Environmental Facility for funding this study (Project title: Snow Leopard and ecosystem protection program, Project ID: 00095191). We appreciate the cooperation and support of the Gurez Valley indigenous communities. We also acknowledge the support of the Snow Leopard Foundation-Pakistan for fieldwork in terms of equipment and trained field staff. We are grateful to Tahir Mehmood, Shakeel Malik, Barkatullah Khan, and Muhammad Amir for helping with data collection and compilation. We are thankful to Doost Ali Nawaz, Shakeel Ahmad, and Esri for providing GIS support. We are extremely thankful to Dr. Ranjini Murali, from Snow Leopard Trust, for the guidance, support, and technical help, in executing this study, moreover providing useful comments and proofreading of the manuscript during two review stages. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US Government. This study's survey was not conducted on behalf of the USGS and, therefore, Paperwork Reduction Act considerations do not apply.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2022.101453.

References

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir. Pakistan. *European Journal of Wildlife Research* 62 (5), 565–576. https://doi.org/10.1007/s10344-016-1029-6.

Ahmed, J., Mahmood, F., Mayers, J., 1998. Changing perspectives on forest policy. International Institute for Environment and Development.

Arora, R. K., & Nayar, E. R. (1984). Wild relatives of crop plants in India. *Wild relatives of crop plants in India.*.

Arun, K.C., 2004. Extraction of NTFPs from the community forest: Analysis of benefit distribution pattern in household level. Journal of forest and Livelihood 4 (1), 38–43.

Awan, M.N., Kabir, M., Ahmad, S., Huettmann, F., 2020. The Future of biodiversity in the changing watersheds of Kashmir Himalaya, Pakistan: Conservation challenges and opportunities. In: Regmi, G.R., Huettmann, F. (Eds.), Hindu Kush-Himalaya Watersheds Downhill: Landscape Ecology and Conservation Perspectives. Springer International Publishing, Cham, pp. 113–133.

Awan, M. N., Saqib, Z., Buner, F., Lee, D. C., & Pervez, A. (2021). Using ensemble modeling to predict breeding habitat of the red-listed Western Tragopan (*Tragopan melanocephalus*) in the Western Himalayas of Pakistan. *Global Ecology and Conservation. 31*. e01864.

Azfar Hussain, S.A., Begum, S., Ali, I.H.H., 2019. Climate change perspective in mountain area: impact and adaptations in naltar Valley, western himalaya, Pakistan. Fresenius Environ Bull 28, 6683–6691.

Balvanera, P., Quijas, S., Martín-López, B., Barrios, E., Dee, L., Isbell, F., . & de Groot, R. (2016). The links between biodiversity and ecosystem services. In Routledge handbook of ecosystem services. 45-61. Routledge.

Bhatta, L.D., Udas, E., Khan, B., Ajmal, A., Amir, R., Ranabhat, S., 2020. Local knowledge based perceptions on climate change and its impacts in the Rakaposhi Valley of Gilgit-Baltistan. Pakistan, *International Journal of Climate Change Strategies and Management* 12 (2), 222–237. https://doi.org/10.1108/IJCCSM-05-2019-0024.

Bischof, R., Ali, H., Kabir, M., Hameed, S., Nawaz, M.A., 2014. Being the underdog: An elusive small carnivore uses space with prey and time without enemies. Journal of Zoology 293 (1), 40–48. https://doi.org/10.1111/jzo.12100.

Cavendish, W., 2002. Quantitative methods for estimating the economic value of resource use to rural households. In: Luckert, M.K., Campbell, B.M. (Eds.), Uncovering the Hidden Harvest Valuation Methods for Woodland and Forest Resources. Earthscan Publications, London, pp. 17–63.

CBOS, (2006). *Annual Report 2006,* Central bank of Sudan. Retrieved 14 June 2021, from https://cbos.gov.sd/en/content/annual-report-2006.

CBOS, (2007). *Annual Report 2006,* Central bank of Sudan. Retrieved 14 June 2021, https://cbos.gov.sd/en/content/annual-report-2007.

Climate Change Center (2017). AJ&K Climate Change Policy. Planning & Development Department, Azad Government of the State of Jammu & Kashmir.

De Groot, R.; Jax, K. and P. Harrison (2016): *Links between Biodiversity and Ecosystem Services. In: Potschin, M. and K. Jax (eds): OpenNESS Ecosystem Services Reference Book.* EC FP7 Grant Agreement no. 308428. Available via: http://openness-project.eu/library/reference-book.

Din, J.U., Nawaz, M.A., Norma-Rashid, Y., Ahmad, F., Hussain, K., Ali, H., Adli, D.S.H., 2020. Ecosystem Services in a Snow Leopard Landscape: A Comparative Analysis of Two High-elevation National Parks in the Karakoram-Pamir. Mountain Research and Development 40 (2), R11. https://doi.org/10.1659/MRD-JOURNAL-D-19-00047.1.

Egan, P.P., Mf., 2016. Mountain ecosystem services and climate change—a global overview of potential threats and strategies for adaptation. UNESCO, Paris.

Endalamaw, T.B., 2005. Dynamics in the management of honey production in the forest environment in Southwest Ethiopia. MSc Thesis. Wageningen University.

Epstein, G., 2017. Local rulemaking, enforcement, and compliance in state-owned forest commons. Ecological Economics 131, 312–321.

FAO. (2010). Global Forest Resources Assessment 2010: Main Reports.

FAO. (2015a). In R. Romeo, A. Vita, R. Testolin, T. Hofer, (Ed.), *Mapping the vulnerability of mountain peoples to food insecurity*. Rome. http://www.fao.org/3/a-i5175e.pdf.

FAO. (2015b). Combating Land Degradation for Food Security and Provision of Soil Ecosystem Services in Europe and Central Asia – International Year of Soils. European Commission on Agriculture, 39th Session, Budapest, Hungary.

Gentle, P., Maraseni, T.N., 2012. Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. Environmental Science & Policy 21, 24–34. https://doi.org/10.1016/j.envsci.2012.03.007.

Gerlitz, L., Conrad, O., Thomas, A., Böhner, J., 2014. Warming patterns over the Tibetan Plateau and adjacent lowlands derived from elevation-and bias–corrected ERA-Interim data. Climate research 58 (3), 235–246.

Haines-Young, R., Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being. In: Raffaelli, D.G., Frid, C.L.J. (Eds.), *Ecosystem Ecology* 110–139. Cambridge University Press. https://doi.org/10.1017/CBO9780511750458.007.

Huddleston, B., Ataman, E., de Salvo, P., Zanetti, M., Bloise, M., Bel, J., & Fe d'Ostiani, L. (2003). Towards a GIS-based analysis of mountain environments and populations. Environment and Natural Resources. Working Paper (FAO).

Ingram, V., Njikeu, J., 2011. Sweet, sticky, and sustainable social business. Ecology and Society 16 (1).

IPCC (2021). Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kalita, P., Tag, H., Sarma, H.N., Das, A.K., 2014. Evaluation of nutritional potential of five unexplored wild edible food plants from Eastern Himalayan biodiversity hotspot region (India). International Journal of Biological, Food, Veterinary Agricultural Engineering 8, 207–210.

Kandel, P., Chettri, N., Chaudhary, S., Sharma, P., Uddin, K., 2021. Ecosystem services research trends in the water tower of Asia: A bibliometric analysis from the Hindu Kush Himalaya. Ecological Indicators 121, 107–152.

Krishnan, R., et al., 2019. In: Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes. The Hindu Kush Himalaya Assessment. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_3.

Kumar, P., Yashiro M. (2014). The Marginal Poor and Their Dependence on Ecosystem Services: Evidence from South Asia and Sub-Saharan Africa. In: von Braun J., Gatzweiler F. (eds). Marginality. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7061-4_11.

Kumar, P., Martinez-Alier, J. (2011). The Economics of Ecosystem Services and Biodiversity: An International Assessment. *Economic and Political Weekly. 46* (24). 76-80. Retrieved June 17, 2021. from http://www.jstor.org/stable/23018249.

Lee, M., & Diop, S. (2009). Millennium ecosystem assessment. An Assessment of Assessments: Findings of the Group of Experts Pursuant to UNGA Resolution 60/30. 1. 361.

Lindberg, V., (2000). Uncertainties and error propagation. Manual on Uncertainties, Graphing and the Vernier Caliper, Part I. Rochester Institute of Technology, New York, USA. http://www.rit.edu/uphysics/uncertinities/Uncertinitiespart2.html#addsub.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J.P., Hector, A., Hooper, D.U., Huston, M.A., Raffaelli, D., Schmid, B., Tilman, D., Wardle, D.A., 2001. Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges. Science 294 (5543), 804–808.

Macchi, M. (2010). Mountains of the World–Ecosystem Services in a Time of Global and Climate Change: Seizing Opportunities–Meeting Challenges. International Centre for Integrated Mountain Development (ICIMOD).

Martín-López, B., Leister, I., Lorenzo Cruz, P., Palomo, I., Grêt-Regamey, A., Harrison, P. A., & Walz, A. (2019). Nature's contributions to people in mountains: a review. *PloS one*. *14*(6). e0217847.

Samper, C., 2003. The Millennium Ecosystem Assessment: science and policy for sustainable development. BioScience 53 (12), 1148–1149.

Mishra, CHARUDUTT, 1997. Livestock depredation by large carnivores in the Indian trans-Himalaya: conflict perceptions and conservation prospects. Environ Conserv 24 (4), 338–343.

Mishra, C., Allen, P., McCarthy, T., Madhusudan, M.D., Bayarjargal, A., Prins, H.H.T., 2003. The role of incentive programs in conserving the snow leopard. Conserv Biol 17, 1512–1520.

MoAF, 2014. National biodiversity strategies and action plan, Bhutan 2014. Ministry of Agriculture and Forest, Royal Government of Bhutan, Thimphu, Bhutan.

MoCC, 2017. National forest policy 2015. Ministry of Climate Change, Government of Pakistan, Islamabad, Pakistan.

MoCC, 2021. *National climate change policy* (updated version). Ministry of Climate Change, Government of Pakistan, Islamabad, Pakistan.

Murali R, Lkhagvajav P, Saeed U, Kizi VA, Zhumbai-Uulu K, Nawaz MA, Bhatnagar YV, Sharma K, Mishra C. (2017a). Valuation of ecosystem services in snow leopard landscapes of Asia. Snow Leopard Trust, Nature Conservation Foundation, Snow Leopard Conservation Foundation, Snow Leopard Foundation Kyrgyzstan, and Snow Leopard Foundation Pakistan. Report Submitted to the Global Environment Facility (GEF) funded United Nations Development Program (UNDP) project on Transboundary Cooperation for Snow Leopard and Ecosystem Conservation.

Murali, R., Ikhagvajav, P., Amankul, V., Jumabay, K., Sharma, K., Bhatnagar, Y.V., Suryawanshi, K., Mishra, C., 2020. Ecosystem service dependence in livestock and crop-based production systems in Asia's high mountains. Journal of Arid Environments 180, 104204.

Murali, R., Redpath, S., Mishra, C., 2017b. The value of ecosystem services in the high altitude Spiti Valley, Indian Trans-Himalaya. Ecosystem Services 28, 115–123. https://doi.org/10.1016/j.ecoser.2017.10.018.

Mwakalukwa, EE (2016). Beekeeping in Tanzania: Country situation paper. Presented at ApiExpo Africa. Camp Kigali, Rwanda. https://www.apitradeafrica.org/Documents/ApiExpoAfrica_2016/Tanzania_Honeybee_Industry_situation_paper.pdf Accessed 15 Jan 2018.

Nelson, E.J., Kareiva, P., Ruckelshaus, M., Arkema, K., Geller, G., Girvetz, E., Goodrich, D., Matzek, V., Pinsky, M., Reid, W., Saunders, M., Semmens, D., Tallis, H., 2013. Climate change's impact on key ecosystem services and the human well-being they support in the US. Frontiers in Ecology and the Environment 11 (9), 483–893. https://doi.org/10.1890/120312.

Pei, S. J. (1992). Mountain culture and forest resource management of Himalaya. *Himalaya Ecosystem*. 114-120. http://refhub.elsevier.com/S0140-1963(20)30108-7/sref39.

Pie, S.J., Manandhar, N.P., 1987. Sources of some local medicines in the Himalayan Regions. Himalayan Ecosystem 97–112.

Pomfret, R., 2014. The Economies of Central Asia. Princeton University Press.

Pritchard, H.D., 2017. Asia's glaciers are a regionally important buffer against drought. Nature 545 (7653), 169–174. https://doi.org/10.1038/nature22062. PMID: 28492255.

Qureshi, B.D., Anwar, M., Hussain, I., Beg, M.A., 2013. Habitat utilization of Himalayan musk deer (*Moschus chrysogaster*) in the musk deer National Park Guraiz, Azad Jammu and Kashmir, Pakistan. The Journal of Animal and Plant Science 23 (5), 1366–1369.

Rahbek, C., Borregaard, M.K., Colwell, R.K., Dalsgaard, B.O., Holt, B.G., Morueta-Holme, N., Fjeldså, J., 2019. Humboldt's enigma: What causes global patterns of mountain biodiversity? Science 365 (6458), 1108–1113.

Shackleton, C., Shackleton, S., Shanley, P., 2011. Building a holistic picture: An integrative analysis of current and future prospects for non-timber forest products in a changing world. In: Non-timber forest products in the global context. Springer, Berlin, Heidelberg, pp. 255–280.

Shaheen, H., Aziz, S., Dar, M.E.U.I., 2017. Ecosystem services and structure of western Himalayan temperate forests stands in Neelum Valley. Pakistan. *Pakistan Journal of Botany* 49 (2), 707–714.

Sharma, E., Molden, D., Rahman, A., Khatiwada, Y.R., Zhang, L., Singh, S.P., Wester, P., 2019. Introduction to the Hindu Kush Himalaya Assessment. In: The Hindu Kush Himalaya Assessment. Springer, Cham, pp. 1–16. https://doi.org/10.1007/978-3-319-92288-1_1.

Tse-ring, K., Sharma, E., Chettri, N., & Shrestha, A. B. (2010). Climate change vulnerability of mountain ecosystems in the Eastern Himalayas. International centre for integrated mountain development (ICIMOD).

Van Oort, B., Bhatta, L.D., Baral, H., Rai, R.K., Dhakal, M., Rucevska, I., Adhikari, R., 2015. Assessing community values to support mapping of ecosystem services in the Koshi river basin. Nepal. *Ecosystem Services* 13, 70–80.

Ward, D., & McKague, K. (2007). *Water requirements of livestock*. Ministry of agriculture, food, and rural affairs, Government of Canada. Retrieved 12 June 2021, from http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm.

Wertime, M.B. et al., 2011. International Forestry Resources and Institutions (IFRI) Research Program: Field Manual, Michigan, USA. Available at: http://www.ifriresearch.net/wp-content/uploads/2012/09/IFRI_Manual.pdf.

Wester, P., Mishra, A., Mukherji, A., & Shrestha, A. B. (2019). In P. Wester, A. Mishra, A. Mukherji, & A. B. Shrestha (Eds.), *The Hindu Kush Himalaya assessment—Mountains, climate change, sustainability and people*. Springer. https://doi.org/10.1007/978-3-319-92288-1_5.

Wyatt, P., 2009. Replacement cost and market value. Journal of Property Investment & Finance 27 (6), 593–602.

Xu, J., Badola, R., Chettri, N., Chaudhary, R.P., Zomer, R., Pokhrel, B., Hussain, S.A., Pradhan, S., Pradhan, R., 2019. Sustaining biodiversity and ecosystem services in the Hindu Kush Himalaya. In: The Hindu Kush Himalaya Assessment. Springer, Cham, pp. 127–165.

Turnitin Originality Report

Climate change vulnerability and ecosystem services of snow leopard habitat in Pakistan by Uzma Saeed .

From PhD (PhD DRSML)

- Processed on 30-Mar-2023 12:50 PKT
- ID: 2050797588
- Word Count: 29916

Similarity Index
17%
Similarity by Source

Internet Sources:
12%
Publications:
11%
Student Papers:
5%

Focal Person (Turnitin)
Quaid-i-Azam University
Islamabad

sources:

1 3% match (Internet from 27-Jun-2022)
https://pide.org.pk/rasta/wp-content/uploads/Food-Security_Hameed-Jamali_WP.pdf

2 2% match (Ranjini Murali, Purevjav Ikhagvajav, Venera Amankul, Kubanych Jumabay et al. "Ecosystem service dependence in livestock and crop-based production systems in Asia's high mountains", Journal of Arid Environments, 2020)
Ranjini Murali, Purevjav Ikhagvajav, Venera Amankul, Kubanych Jumabay et al. "Ecosystem service dependence in livestock and crop-based production systems in Asia's high mountains", Journal of Arid Environments, 2020

3 1% match (student papers from 08-Apr-2019)
Submitted to Manipal University on 2019-04-08

4 1% match (Internet from 09-Feb-2023)
https://www.researchgate.net/publication/345307704_Ecosystem_services_research_trends_in_the_water_tower_of_Asia_A_bibliometric

5 1% match (student papers from 01-Oct-2012)
Submitted to Leeds Metropolitan University on 2012-10-01

6 1% match (Ranjini Murali, Stephen Redpath, Charudutt Mishra. "The value of ecosystem services in the high altitude Spiti Valley, Indian Trans-Himalaya", Ecosystem Services, 2017)
Ranjini Murali, Stephen Redpath, Charudutt Mishra. "The value of ecosystem services in the high altitude Spiti Valley, Indian Trans-Himalaya", Ecosystem Services, 2017

7 < 1% match (Internet from 15-Feb-2023)
https://www.researchgate.net/publication/315767562_Ecosystem_services_and_structure_of_western_himalayan_temperate_forests

8 < 1% match (Internet from 19-Feb-2023)
https://www.researchgate.net/publication/344427308_The_way_bioclimatic_variables_are_calculated_has_impact_on_potential_distributic

9 < 1% match (Internet from 17-Feb-2023)
https://www.researchgate.net/publication/258374590_Climate_change's_impact_on_key_ecosystem_services_and_the_human_well-being_they_support_in_the_US

10 < 1% match (Internet from 28-Jan-2023)
https://www.researchgate.net/publication/320757722_The_value_of_ecosystem_services_in_the_high_altitude_Spiti_Valley_Indian_Trans Himalaya

11 < 1% match (Internet from 16-Feb-2023)
https://www.researchgate.net/publication/324679669_The_response_of_lake_area_and_vegetation_cover_variations_to_climate_change_Tibetan_Plateau_during_the_past_30years

12 < 1% match (Internet from 25-Feb-2023)
https://www.researchgate.net/publication/240918371_Mapping_and_assessment_of_ecosystems_and_their_services_An_analytical_fram

CHAIRPERSON
Department of Zoology
Quaid-i-Azam University