SNOW LEOPARD
STATUS IN BHUTAN

National Snow Leopard Survey Report

2022-2023

Department of Forests and Park Services

Ministry of Energy and Natural Resources

Royal Government of Bhutan

DEDICATION

The Ministry of Energy and Natural Resources, Royal Government of Bhutan, dedicate the National Snow Leopard Survey Report to Her Royal Highness the Princess.

We pray for the good health and long life of our beloved Gyalsem and offer our deepest gratitude to His Majesty The King and Her Majesty The Gyaltsuen for this timeless gift.


Snow leopard habitats in JDNP
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Snow leopard habitats in Paro
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2022-2023

Nature Conservation Division
Department of Forests and Park Services
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Report prepared by:

1. Letro, Nature Conservation Division
2. Tashi Dhendup, Nature Conservation Division
3. Pema Dendup, Jigme Dorji National Park
4. Ugyen Penjor (PhD), Fauna and Flora, UK
5. Tandin, WWF Bhutan (Former National Coordinator for NSLS 2022-23)
6. Namgay Wangchuk, Nature Conservation Division
7. Sonam Wangdi, Nature Conservation Division

Data analysis:

Letro, Nature Conservation Division
Ugyen Penjor (PhD), Fauna and Flora, UK

Report reviewed by:

Dr Ian Durbach and Dr Koustubh Sharma, PAWS Initiatives, GSLEP

Field coordination and data management:

Ugyen Takchu (JKSNR), Pema Rinzin (DFO Paro), Ugyen Dorji and Sonam Lhaki Dema (DFO Thimphu), Pema Dendup (JDNP), Karma Wangdi (WCNP), Karma Chorten Dendup (JSWNP), Sangay Drukpa (BWS)

Overall Guidance:

Lobzang Dorji, Director, DoFPS

Layout and design by:

Letro, Nature Conservation Division

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Glacial mountains in JDNP
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AKRA:	Agency Key Result Areas
BFL:	Bhutan for Life
BSL:	Bhutan Snow Leopard
BWS:	Bumdeling Wildlife Sanctuary
CFO:	Chief Forestry Officer
CI:	Credible Intervals
CITES:	Convention on International Trade in Endangered Species of Wild Flora and Fauna
CMR:	Capture Mark Recapture
CTFM:	Camera Trap File Manager
DFO:	Divisional Forest Office
DoFPS:	Department of Forests and Park Services
FD:	Forest Division
GPS:	Global Positioning System
GSLEP:	Global Snow Leopard Ecosystem Protection Program
HWC:	Human-wildlife conflict
ID:	Identification
IUCN:	International Union for Conservation of Nature
JDNP:	Jigme Dorji National Park
JKSNR:	Jigme Khesar Strict Nature Reserve
JSWNP:	Jigme Singye Wangchuck National Park
KPI:	Key Performance Indicator
m.a.s.l.:	Meters above sea level
MCMC:	Markov Chain Monte Carlo
MLE	Maximum Likelihood Estimation
NCD:	Nature Conservation Division
NKRA:	National Key Result Areas
NSB:	National Statistics Bureau
NSLS:	National Snow Leopard Survey
PAs:	Protected Areas
PAWS:	Population Assessment of the World's Snow Leopards
RGoB:	Royal Government of Bhutan
SECR:	Spatially-Explicitly Capture-Recapture
SLIMS:	Snow Leopard Information Management System
WCNP:	Wangchuck Centennial National Park
WWF:	World Wildlife Fund

Snow leopard habitats in JDNP
© DoFPS

Snow leopard habitats in Paro
© Sherab Jamtsho, JKSNR

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Royal Government of Bhutan
Ministry of Energy and Natural Resources
Department of Forests and Park Services

FOREWORD

It gives me immense pleasure to write the foreword for the National Snow Leopard Survey Report 2022-23, which provide an updated status of snow leopards in the kingdom of Bhutan. The national snow leopard survey is one of the major activities undertaken by the Department of Forests and Park Services during the 12th Five-Year Plan. Snow leopards adorn the highland ecosystem of northern Bhutan and are the flagship species of our alpine landscapes.

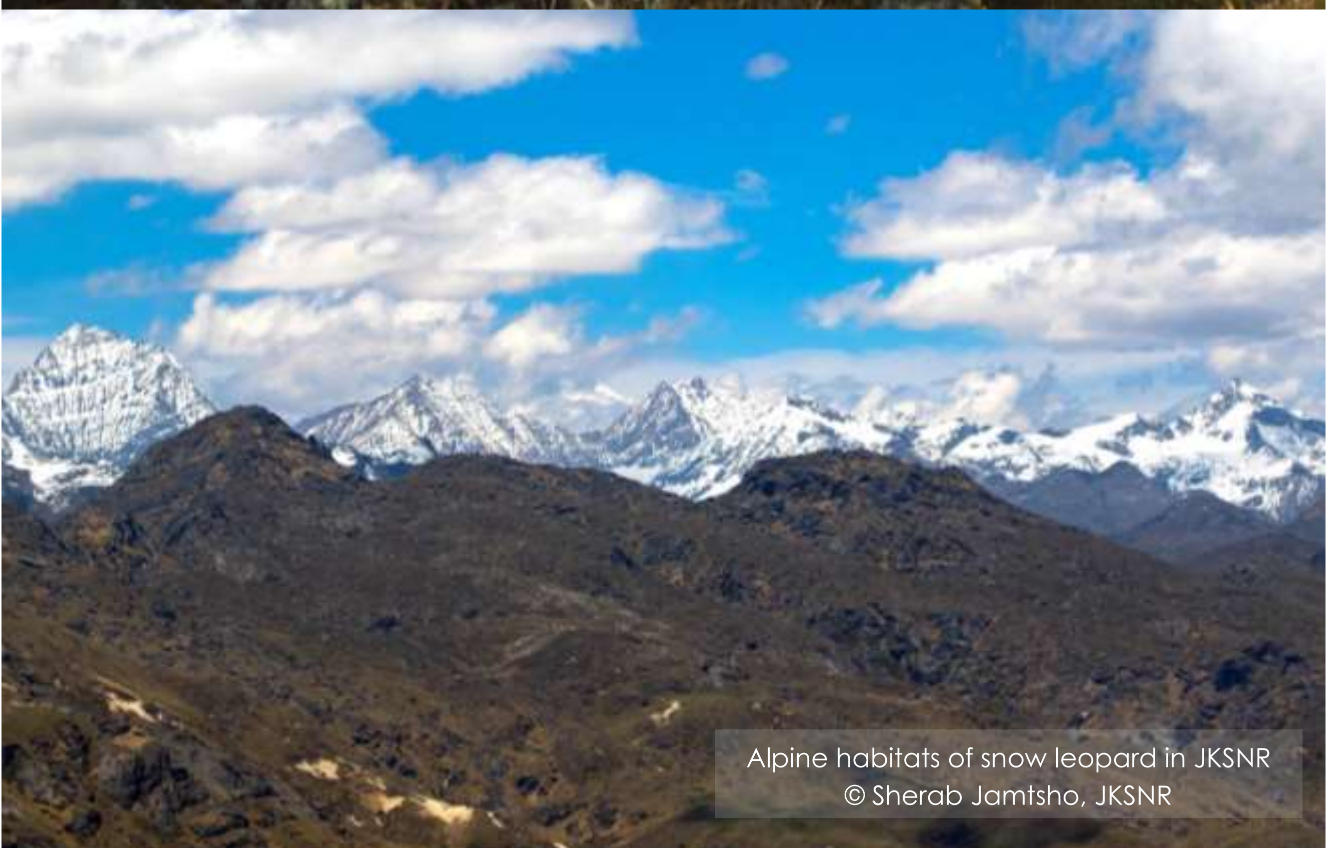
Snow leopards are threatened by habitat degradation, prey depletion, conflicts with humans, and climate change across their range. However, in Bhutan, the species continue to thrive with a healthy and viable population. This is attributed to the sound environmental policies, the overwhelming support of the Royal Government of Bhutan, conservation partners, donors, and the conservation efforts of extraordinarily dedicated team of forestry professionals, mainly the frontline rangers.

This report is an outcome of the concerted effort of our rangers over the last 10 months in setting up, monitoring, and retrieving camera traps from 310 camera stations; data management and sorting of over a million images, and analyzing the data. Since snow leopard habitats are located in some of the most remote and rugged terrains above 4500 m.a.s.l, successfully executing the fieldwork without any mishap is a great feat. More than 80 rangers have been engaged in the fieldwork. In this regard, I congratulate the Nature Conservation Division and all the field offices involved in the snow leopard survey for their dedicated efforts and the outcomes.

I hope the report will be of immense value to all working towards safeguarding and conserving our pristine natural environment in general and snow leopards in particular. Taking inspiration from this report, I hope our policymakers, conservation partners, and all relevant stakeholders will further affirm their commitment to conserving our iconic snow leopards for their long-term survival.

Thank you and Tashi Delek

Lobzang Dorji
Director



Alpine habitats of snow leopard in JKSNR
© Sherab Jamtsho, JKSNR

ACKNOWLEDGEMENT

The successful completion of the second national snow leopard survey (NSLS-2022-2023) is a collective effort of many individuals and organizations. In this regard, Nature Conservation Division would like to acknowledge everyone who has been part of our journey from the inception of the national snow leopard survey plan till the final production of this report.

Firstly, we would like to congratulate all the crew members of the national snow leopard survey for successfully completing this mammoth task of installing, monitoring and retrieving the camera traps in the most remote and rugged terrains with full dedication. We recognize the level of effort, sacrifice and commitment you put forth to collecting this invaluable data on the snow leopard in the country. We also thank all the chiefs and focal officers for their leadership and coordination at the field level.

We would like to thank the Bhutan for Life for its generous financial support of Nu. 17.8 million, without which such a resource-extensive exercise would not have been possible. We would also like to thank WWF Bhutan for their support with field gears provided for our field crew which enabled our rangers to comfortably conduct the survey. We also thank our conservation partners like Bhutan foundation, Bhutan Trust Fund for Environmental Conservation, and UNDP Bhutan for their continued support in various snow leopard conservation initiatives in the country.

We thank Dr Ian Durbach, Dr Koustubh Sharma, and Dr Justine Shanti Alexander of the PAWS initiatives under the Global Snow Leopard and Ecosystem Protection Program for their invaluable contribution in designing the survey and reviewing the report. We thank Dr Jan Janecka, Duquesne University, US, for the support in genetic analysis of the snow leopard fecal samples. We would also like to thank Mr Tandin, the former National Coordinator for NSLS 2022-2023, for his dedication and effort towards planning and initiating the survey. We thank Mr. Gem Thsering and Mr. Tandin Namgay, who were part of the planning and monitoring team. We are greatly thankful to Dr Tshering Tempa of the Bhutan Ecological Society and Dr Ugyen Penjor from Fauna and Flora, UK for their support in analyzing the data. We thank Mr Lhendup Tharchen for his feedbacks on the report.

Lastly, we would like to express our deep gratitude to everyone who contributed to the National Snow Leopard Survey 2022–2023 in one way or another. We look forward to your continued support and partnership always.

Nature Conservation Division

EXECUTIVE SUMMARY

The snow leopard (*Panthera uncia*) has a wide habitat range spanning over 2.8 million km^2 across 12 range countries in south and central Asia. The species is globally threatened, yet there isn't a robust global population estimate. The difficulty in obtaining a reliable population estimate is attributed to the secretive nature of the species, low population densities, and remoteness of the mountainous terrains that they occupy. The global snow leopard population is estimated to be between 3,920 to 7,500 individuals, though these numbers vary between different assessments.

Snow leopards, being an apex predator of the alpine landscape, represent the ecosystem's overall health. However, large carnivores such as the snow leopard are globally threatened by habitat loss and fragmentation, prey depletion, retaliation in response to livestock depredation, poaching for illegal trade, human-induced climate change and anthropogenic disturbances. This calls for conservation actions from all government agencies, non-government conservation organizations, conservationists and local communities to unite and save the species.

In Bhutan, snow leopards find a safe haven across the wide expanse of pristine alpine habitats, less inhabited by humans. The species is revered by the local communities, and it is strictly protected under forest and nature conservation laws. Bhutan started the first snow leopard survey in the 1980s, but the first robust estimate was reported only in 2016 using remote camera traps. The National Snow Leopard Survey (NSLS) 2022-2023 was conducted with the main objective of estimating the current population of snow leopards in Bhutan, including its distribution pattern. It is expected to contribute towards the global goal of assessing the global snow leopard population.

The NSLS report 2022-2023 provides an updated status of the snow leopard in Bhutan. The report is an outcome of the camera trapping survey spanning five protected areas namely Jigme Khesar Strict Nature Reserve, Jigme Dorji National Park, Wangchuck Centennial National Park, Bumdeling Wildlife Sanctuary and Jigme Singye Wangchuck National Park and two Divisional Forest Offices of Paro and Thimphu.

A total of 310 camera stations were setup across the field sites that accumulated a survey effort of 22,636 trap nights, with over 10,000 images of snow leopards captured. A careful review of 476 images identified 96 adult individuals and 10 cubs across the landscape. Bayesian-based Spatially Explicit Capture Recapture (SECR) modelling estimated 134 snow leopards, as compared to the 2016 baseline of 96 individuals. Snow leopard density was estimated at 1.34 snow leopards per 100 km^2 with possibility of higher density in western Bhutan than in central and eastern Bhutan. Habitat distribution modeling also suggests more suitable habitats in western Bhutan as compared to other regions.

DNA analysis of 184 carnivore fecal samples collected during the survey also yielded 71 positive detections for snow leopards, which yielded 22 snow leopard individuals. Through improved sampling design for fecal sample collection, non-invasive genetics can be a potential tool for snow leopard monitoring in Bhutan.

An estimated increase in snow leopard numbers from the 2016 baseline indicates that conservation efforts in the country are having a positive impact. It also re-affirms Bhutan as a stronghold for snow leopard conservation. To ensure that the species thrives in the face of emerging threats and challenges, snow leopard population needs to be monitored periodically at the national scale. Patrolling and surveillance needs to be strengthened and the degrading habitats should be managed regularly. There is also a need to enhance scientific knowledge on the species such as genetic diversity and population connectivity. The incidences of human-snow leopard conflicts need to be addressed to ensure harmonious co-existence between snow leopard and people.

CHAPTER 1
INTRODUCTION

1.1. Global status and conservation significance

Snow Leopards *(Panthera uncia)* are one of the world's most elusive felids with legendary secretiveness and camouflage (Hunter and Jackson 1997). Its range of occurrence extends from the Himalayas in the south, across the Qinghai-Tibet Plateau and the mountains of Central Asia to the mountains of southern Siberia in the north, covering an estimated area of 2.8 million km^2 (McCarthy *et al.* 2017). Snow leopards are mostly found in the higher elevations of the Himalayas and the Tibetan Plateau from 3,000 to over 5,000 m.a.s.l, but they also occur as low as 500 m in the higher latitudes of the Altai region (Snow Leopard Network 2014). Snow Leopards occur in 12 countries: Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan and Uzbekistan. Wild caprids are the principal natural prey of snow leopards, and species include blue sheep (*Pseudois nayaur*), Siberian ibex (*Capra sibirica*), Argali (*Ovis ammon),* markhor (*Capra falconeri*), etc.., depending on the locality (Lyngdoh *et al.* 2014; Thinley *et al.* 2016; Shrestha *et al.* 2018; Holt *et al.* 2018). Wild prey abundance is one of the main determinants of snow leopard abundance (Wegge *et al.* 2012; Suryawanshi *et al.* 2013).

The snow leopard is globally threatened, yet it is one of the least studied large carnivores (Snow Leopard Network 2014). While enormous progress has been made in estimating its populations at local scales, the regional and global population estimates remain ambiguous (Suryawanshi *et al.* 2021). The global snow leopard population size is estimated to be between 3,920 to 7,500 (Mccarthy and Chapron 2003; Janečka *et al.* 2008; Snow Leopard

Working Secretariat 2013), with 2,710 to 3,386 adults (McCarthy *et al.* 2017). The secretive nature of the species, low population densities, and sparse and sporadic distribution in remote mountainous terrains contribute to the difficulty in obtaining reliable populations. Moreover, the surveyed areas and sample sizes are usually small, making extrapolating the density estimates to non-surveyed areas difficult (McCarthy *et al.* 2017). However, the global population is projected to decline by at least 10% over 3 generations (22.62 years), and the species is listed under 'Vulnerable' category of the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (McCarthy *et al.* 2017). Snow leopard is also listed on the Appendix I of the Convention on International Trade in Endangered Species (CITES), therefore, trade in the animal and its body parts is strictly prohibited.

The declining population of snow leopard is due to threats which can be broadly categorized into three types; 1) decline in prey due to competition from livestock and habitat degradation (Shrestha and Wegge 2008; Aryal *et al.* 2014); 2) retaliatory killing of snow leopards as it preys on livestock (Wegge *et al.* 2012; Suryawanshi *et al.* 2013) and; 3) poaching of the animal for illegal trade in furs, bones and other body parts (McCarthy *et al.* 2017). Other emerging threats include climate change and land use change due to global warming and burgeoning infrastructure development (McCarthy *et al.* 2010; Aryal *et al.* 2016; Penjor *et al.* 2020).

The snow leopard is an iconic species and an ideal flagship for conserving the high mountain ecosystems; therefore, protecting the species has great conservation significance. Concerted efforts have been put in place by the governments of 12 range countries and global conservation organizations. Snow Leopard Information Management System (SLIMS) was developed to monitor the status and distribution of snow leopards and their prey during the 1990s. The SLIMS assesses relative snow leopard abundance through repetitive standardized sign surveys (Hunter and Jackson 1997). In 2002, the Snow Leopard Survival Strategy was developed by the Snow Leopard Trust to streamline Snow Leopard conservation efforts. In 2013 governments of the snow leopard range countries initiated the Global Snow Leopard Ecosystem Protection

"Snow leopards are Vulnerable on the IUCN Red List and the global population is projected to decline by at least 10% over 3 generations (22.62 years)" - IUCN

Program (GSLEP) to combat threats and strengthen transnational collaboration for snow leopard conservation (Snow Leopard Working Secretariat 2013). At the International Snow Leopard and Ecosystem Conservation Forum 2017 in Bishkek, the range country governments formally endorsed a plan to develop a global snow leopard population assessment initiative called Population Assessment of the World's Snow Leopards (PAWS), which aims to produce a robust estimate of the threatened cat's population status within the next 5 years (GSLEP 2017).

1.2. Snow leopard conservation in Bhutan

Bhutan is one of the 12 snow leopard range countries, and the northern alpine ecosystems of Bhutan provide a safe haven for this charismatic species. In Bhutan, the snow leopard is known by different local names, such as *gangzig*, *chenzig*, *chenggu* and *tsagay*. Its range starts from Jigme Khesar Strict Nature Reserve (JKSNR) in the west to Bumdeling Wildlife Sanctuary (BWS) to the east, with the majority of the prime habitats located in Jigme Dorji National Park (JDNP) and Wangchuck Centennial National Park (WCNP) (DoFPS 2016). Divisional Forest Office (DFO) of Paro and Thimphu are the areas outside the protected landscape where snow leopards are present. A lone snow leopard was recorded once in Jigme Singye Wangchuck National Park (JSWNP) in central Bhutan (Letro *et al.* 2021), which is essentially disconnected from the primary snow leopard habitats of northern Bhutan. The snow leopard is revered as a mountain deity by yak herders and mountain communities (NCD 2019) but is in jeopardy and conflict with humans due to predation on livestock (mostly calves) (Lham *et al.* 2021b).

Until 2016, there was limited knowledge of the population and distribution of snow leopards in Bhutan. The first snow leopard survey was initiated in the 1980s using sign and anecdotal information (Jackson *et al.* 2006). Nevertheless, the snow leopard being classified as endangered globally in the past; the species was strictly protected by the national laws since 1995 by listing under 'Schedule I' category of the forest law (RGoB 2023). Any illegal act of capturing, or killing the species is a felony of fourth degree. Most of the past conservation works on snow leopards were confined to protected areas like JDNP and WCNP. For example, Snow Leopard Information

"Snow leopard is listed under Schedule I of the Forests and Nature Conservation Act 2023, and illegal act against it is an offence of fourth degree felony"

Management System (SLIMS) training was delivered only in JDNP in 1997 and 2000 (Jackson *et al.* 2000) and snow leopard-focused camera trapping was conducted in JDNP in 2012 (Thinley *et al.* 2014) and in WCNP in 2014 (WCNP and WWF 2016).

The nationwide snow leopard survey 2015-2016 using both sign survey and camera traps for the first time, has helped the country to generate a robust population estimate of 96 (SE ± 8) individuals, with an estimated density of 1.08 (SE ± 0.09) animals per 100 km^2 (DoFPS 2016). Subsequent analysis of the data has helped ascertain the potential snow leopard habitats in the country, where Lham *et al.* (2021a) estimated 7,206 km^2 of Bhutan as suitable habitats for snow leopard: 3,647 km^2 as highly suitable, 2,681 km^2 as moderately suitable, and 878 km^2 as marginally suitable. Forty-eight per cent of the total suitable habitat consists of protected areas.

Today snow leopard conservation is one of the priorities of the Department of Forests and Park Services (DoFPS) and conservation efforts are guided by Snow Leopard Conservation Action Plan. Bhutan, as a member country to the GSLEP, is also mandated to contribute towards achieving the mission of identifying and securing at least 20 snow leopard landscapes across its range by 2020 – "Secure 20 by 2020". As such, most conservation actions and development works in the snow leopard habitats of Bhutan are linked towards securing their habitats and maintaining a viable population.

1.3. National snow leopard survey 2022-2023

The National Snow Leopard Survey (NSLS) is one of the key progress indicators under the National Key Result Areas (NKRA) and Agency Key Result Areas (AKRA) of the 12th Five Year Plan of the erstwhile Ministry of Agriculture and Forests, Royal Government of Bhutan (MoAF 2019) and the indicator requires Bhutan to maintain the 2016 baseline of 96 snow leopard individuals by the end of 12th FYP. The conservation Milestone 7 of Bhutan for Life project requires the country to maintain a stable population of snow leopards by year seven, i.e., 2024 (BFL 2015). To achieve these national objectives and to contribute towards the global goal of assessing the global snow leopard populations, the NSLS 2022-2023 undertaken.

The key scientific objectives of the NSLS 2022-2023 were to:

a. Estimate the current population of snow leopards in Bhutan,
b. Understand the distribution pattern of snow leopards across the country.

CHAPTER 2
MATERIALS AND METHODS

2.1. Study area

2.1.1. Bhutan: geographic location

Bhutan is a landlocked country between latitudes 26°N and 29°N, and longitudes 88°E and 93°E, bordered by the Tibet Autonomous Region of China to the north and Indian states of Arunachal Pradesh, Assam, West Bengal, and Sikkim to the east, south and west. The country has a geographical area of 38,394 km^{2}, and is divided into twenty administrative districts. Most of the country is characterized by mountainous terrain, with forests encompassing 69.7% of the land (FMID 2023) . More than half the country is protected through a network of protected areas in the form of National Parks, Wildlife Sanctuaries, Strict Nature Reserve, Botanical Park and Biological Corridors (Figure 1).

Located in the eastern Himalayas, Bhutan is part of the Himalayan biodiversity hotspot (Myers *et al.* 2000), a biogeographic region where exceptional concentrations of endemic species are undergoing critical loss of habitat. There is also an extreme variability in elevational

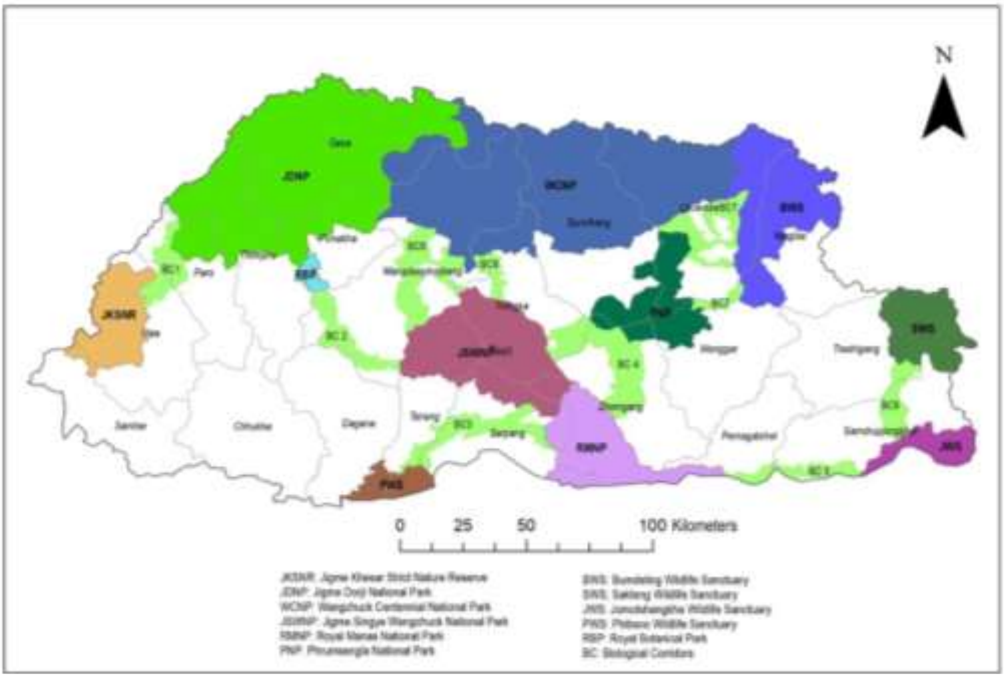


Figure 1: Administrative map of Bhutan with the protected area network.

gradient with southern foothills going as low as 90 m.a.s.l to the highest peak, Gangkhar Puensum, at 7,570 m.a.s.l in the north, making an abrupt rise in elevation within a short aerial distance of less than 170 kms. The annual temperature ranges between 15°C and 30°C, with annual precipitation between 300 millimeters and 7800 millimeters across Bhutan (NSB 2021). These factors create enabling conditions for different ecosystems to thrive with great diversity of wild fauna and flora, making Bhutan a biologically diverse country.

2.1.2. Species diversity

Over 11,200 species have been recorded in Bhutan (NBC 2019). Many of these organisms fall under the threatened category of the IUCN "Red List of Threatened Species" and are of global conservation significance. Approximately 200 mammals are expected in Bhutan (Wangchuk et al. 2004), and 27 of the recorded mammals are globally threatened. Some of the threatened species include the Royal Bengal tiger (*Panthera tigris tigris*), common leopard (*Panthera pardus*), Asian elephant (*Elephas maximus*), snow leopard (*Panthera uncia*), red panda (*Ailurus fulgens*), golden langur (*Trachypithecus geei*), Asiatic black bear (*Ursus thibetanus*), and the one-horned rhinoceros (*Rhinoceros unicornis*). Bhutan takin (*Budorcas taxicolor whitei*), which is also globally threatened, is the national animal of Bhutan. The critically endangered Chinese pangolin (*Manis pentadactyla*) and pygmy hog (*Sus

Blue sheep *Pseudois nayaur*

National animal Bhutan takin *Budorcas taxicolor whitei* *salvanius*) are also reported in the country. Bhutan is also the hotspot of wild felids (Tempa *et al.* 2013), with tigers and snow leopards co-existing together in one landscape (Dendup and Lham 2023).

2.1.3. *Survey area and population demography*

Snow leopards in Bhutan are confined to the alpine mountains of Northern Bhutan, and the National Snow Leopard Survey 2022-2023 encompassed ~10,000 km^2 focusing primarily on potential snow leopard habitats within protected areas JKSNR, JDNP, WCNP, and BWS. Amongst the Forest Divisions, the survey was conducted in potential snow leopard habitats of DFO Paro and Thimphu. The survey also covered the alpine landscape of JSWNP in central Bhutan, which is geographically isolated from the northern snow leopard landscape (NCD 2022).

With a total human population of 763,249 and a mean population density of 19.89 people per km^2, Bhutan is one of the least densely populated countries in Asia (NSB, 2022). About 62% of the country's population are rural people who depend on agriculture, animal husbandry, and forests as major sources of livelihood (RGoB 2017). Communities residing in the snow leopard habitats are traditionally nomadic pastoralist rearing yaks and frequently interacts with snow leopard, occasionally coming in conflict due to livestock depredation. Nevertheless, there is no official record of retaliatory killing of snow leopards by yak herders in Bhutan (Thinley *et al.* 2014). However, social surveys have shown that people are becoming intolerant when livestock depredation incidences increase, leading to

Yak herders camp in an alpine landscape
© Letro, NCD

changes in peoples' traditional lifestyle with many people abandoning the practices of nomadic herding (Wangchuk and Wangdi 2015; Jamtsho and Katel 2019). In recent times, the upland people's income is largely supplemented by the sale of medicinal plants and fungi, such as the highly-priced and sought-after medicinal fungus Yartsa Guenbub (*Ophiocordyceps sinensis*), the collection of which was legalized in 2004 (Wangchuk et al. 2015). Nevertheless, the collection season of medicinal plants in summer poses risk of disturbance to snow leopard and blue sheep habitats, and their ecology.

2.2. Population survey design

Camera trap surveys have become a method of choice for estimating and monitoring the population of snow leopards across its range (Jackson *et al.* 2006; McCarthy *et al.* 2010). Bhutan's national snow leopard survey of 2016 was also conducted using camera traps (DoFPS 2016). The NSLS of 2022-2023 was also planned to be executed using remote camera traps as the primary method. However, scat sampling for non-invasive genetic analysis was also incorporated to test the potentials of this tool for monitoring snow leopards. In order to decide on the camera trap locations, the potential snow leopard habitats in the elevation range of 3400 to 5200 m.a.s.l were first mapped, and the inaccessible areas within this potential habitat range were identified and excluded from the sampling area. The inaccessibility of the area is either due to geopolitical reasons or because of the difficult terrain. The potential and accessible snow leopard habitats were then divided into high-density areas and low-density areas based on the snow leopard density map generated from camera trapping during the 2016 snow leopard survey (DoFPS 2016; Lham *et al.* 2021a).

Across the accessible potential habitats, the nationally adopted 4x4 km biodiversity monitoring grids were divided into 2x2 km grid cells and were overlaid using QGIS. The grid cell size for this survey was reduced to 2x2 km from 4x4 km employed in the last snow leopard survey of 2016. This simplifies fieldwork (since cameras are placed in the best location within each grid cell) and increases the expected number of photographic recaptures at multiple locations, which are important for the spatially explicit capture-recapture (SECR) model. Reducing the grid size does not

"Camera trapping is a state-of-the-art approach to monitor rare and elusive species, such as the snow leopard"

compromise comparability with the 2016 survey or bias results, because SECR models are continuous in space and use exact distances e.g., between camera locations, regardless of grid cell size. The only potential effect is improved precision in density estimates arising from greater numbers of recaptures on different camera. The potential snow leopard habitat was then used as a mask layer to generate locations of camera stations in SECR study design simulation (Durbach *et al.* 2021). The simulation was performed in the SECR design app to identify grid cells to establish camera stations. For the simulation, a total of 303 camera trap stations (detectors) and a density of 1 per $100km^2$, lambda0 (baseline encounter rate) of 0.8, and sigma (movement parameter) of 3000 m were specified. The sigma values are lower than the 8000 m observed in the previous survey in Bhutan to reduce the distance between camera traps and increase recaptures. The result from the simulation exercise was then used to carryout ground-truthing by each field office to verify and assess the actual accessibility of grids. A few grids that were either inaccessible or located in very low probable areas were shifted to nearby potential snow leopard habitat locations. A total of 310 grids of 2x2 km were finalized for stationing camera traps.

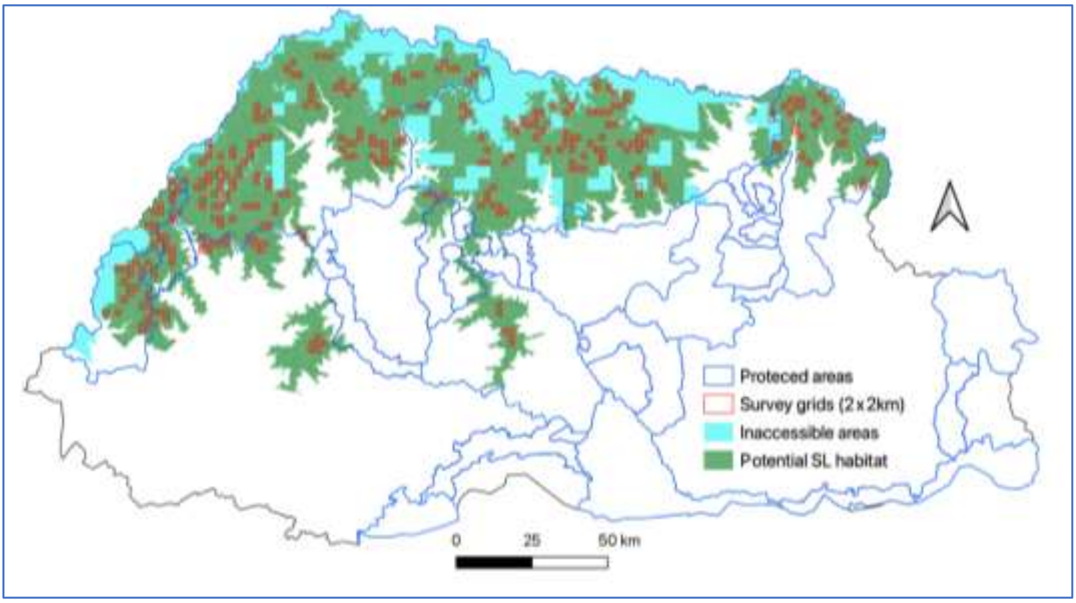


Figure 2: Map showing 310 survey grids across the survey area.

Table 1: Number of grids assigned to each field office for stationing camera traps in the survey area.

Survey area	Number of grids
Jigme Khesar Strict Nature Reserve	31
Divisional Forest Office Paro	29
Divisional Forest Office Thimphu	14
Jigme Dorji National Park	111
Wangchuck Centennial National Park	87
Bumdeling Wildlife Sanctuary	32
Jigme Singye Wangchuck National Park	6
Total	**310**

2.3. Training of the field surveyors

Once the sampling grids were finalized, the field staff from the snow leopard range offices were trained to conduct the fieldwork. The fieldwork comprises installation, monitoring and retrieval of the camera traps, and the identification and collection of snow leopard fecal samples.

A total of 24 teams consisting of three members in each team were formed to implement the NSLS 2022-2023. The allotment of the team for each field division was based on the number of camera trap stations that needed to be installed, which directly correlates to the extent and distribution of the survey area. The training was provided to standardize survey techniques based on the field manual for National Snow Leopard Survey (2022-2023) developed by NCD (NCD 2022). In addition to the technical components of the survey, such as camera trapping and scat collection, significant attention was devoted to prioritizing health and safety during the field survey. This was especially crucial due to the remote and high-altitude terrains, most of which lacked cellular network coverage and were far from the nearest human settlement.

Rangers during a training session

2.4. Camera trap field survey and monitoring

At each camera station, two Reconyx® (HyperFire) camera traps in "medium-high passive infrared (PIR) sensitivity" mode, with a photo burst of

5 photos per trigger were set up on either side of the trail on which a snow leopard was likely to pass. Two cameras were setup 30-50 cm above the ground and pointed at 45° to 90° to capture the flanks, hind (tail) or front (face and forelimbs) portions of adult snow leopards, for easy identification of the individuals. The placement of camera stations inside the selected grid cell was left to the survey team to decide. Nonetheless, camera traps were installed in areas where snow leopards were expected to frequent such as the ridge lines, valley bottoms, caves, overhung rock faces, etc.

To prevent the concentration of cameras at a location, the minimum distance between two camera stations was set at one kilometer. A specific camera number was assigned to each camera trap, and location data including geo-coordinates, habitat type, and signs of prey, were recorded through epicollect5 forms.

Jackson *et al.* (2005) reported the deployment of camera traps for 35 days based on the cumulative capture curves. However, a greater number of days (45-50 days) is recommended to ensure adequate recaptures. DoFPS (2016) recommended more than 100 days of camera trap deployment in the field based on the availability of funds. For the NSLS 2022-2023, camera traps were initially planned for a duration of 90 days deployment, but due to the nature of field accessibility and camera functionality, a uniform 90 days could not be maintained.

The camera trap deployment began soon after the training, and the first camera was stationed on 4th August 2022 in JDNP and was completed by 8th September 2022 in WCNP. Camera retrieval started on 4th November 2022

Porterage during the camera trap survey
© Karma Wangdi, WCNP

in WCNP, and except for a few camera traps that became inaccessible due to snow, the last camera was retrieved on 29th December 2022 from DFO Thimphu. The total time duration of deployment across the entire study area was 148 days.

The timeframe for camera trapping was maintained considering the following reasons;

- The timing lies between the peak monsoon and peak winter seasons, which is most favourable for conducting field surveys.
- During the peak summer and winter, incessant rainfall and heavy snowfalls make the terrain unfavourable for fieldwork.

While efforts were made to monitor camera traps once after 45 days of installation, monitoring could not be carried out in a few isolated and distant locations. Monitoring of camera stations started on 1st October 2022 and was completed on 10th November 2022. During the monitoring period, memory cards were changed, batteries were replaced, disoriented cameras were repositioned, non-functional cameras were replaced, camera lenses were cleaned, and obstructing objects between the camera lens and animal paths were removed. For the stations where camera traps were lost, new cameras were set up to record the data for the remaining survey period.

2.5. Scat collection

Putative snow leopard scats were collected during the installation, monitoring and retrieval of camera traps. Scats were collected along the trails and at the camera traps sites. Once sighted, a small piece, usually from the lower part and the tip, was collected and stored in a plastic vial containing silica. Contamination was minimized during scat collection using new gloves and twigs for each fresh scat. Information, including date of collection, geo-referenced locations, and conditions of the scats, among

A fresh snow leopard dropping
© Letro, NCD

others, were also recorded. The samples were stored in a deep freezer (-4C) before transferring to a lab for analysis. Once at the lab, the samples were transferred to 70% ethanol for long-term storage and to inactivate potential viruses, parasites, and bacteria.

2.6. Camera trap data management

Data processing and management are critical steps in camera trapping studies. Each camera trap yields a vast amount of photographic data, which needs to be processed and labelled before any formal analysis can be undertaken. Traditionally, processing camera trap data has been performed manually by entering data into a spreadsheet. This is time-consuming, prone to human error, and data management may be inconsistent. After the retrieval of the memory cards from the camera, images have to be retrieved and stored securely. Secondly, files need to be organized and labelled. Third, and often most time-consuming, is image content identification and information management, which is also called image interpretation or annotation and extraction of metadata in the form of .csv (comma-separated value) files from images. This whole process is called "data management".

The preliminary image sorting and data management were done by respective field offices based on the training delivered before the start of the survey. Camera Trap File Management (CTFM) tool was used to sort the images and extract metadata of the images in a csv file. A data management workshop was organized to further refine the sorted data and to identify the individual snow leopards following a uniform standard protocol across different field divisions. Large carnivores such

Camera trapping and monitoring

as the tiger, common leopard and snow leopard are naturally marked with distinct pelage patterns on the flanks, limbs, rumps, thighs, and tail (dorsal side), making identifying unique individuals possible. Using these markers, individuals were identified to avoid double counting of the same individual to obtain reliable estimates of capture probabilities and population abundance (Karanth 1995; Jackson *et al.* 2005). The presence or absence of the scrotum was used to determine sex, as male snow leopard have noticeable testicular protrusions. Snow leopards were divided into two age groups based on their level of independence from their mothers; adults and cubs, with cubs being always recorded with their mother.

Most of the cameras didn't take pictures as desired; hence, a combination of images from the tail, forehead, thighs, and limbs was used for the unique characterization of individuals. The identified individuals were thoroughly compared with the rest of the individuals to avoid double counting. Each individual was assigned a primary feature (the most clear and distinct body part with a unique rosette or spot pattern) and a secondary feature (an additional body part with a somewhat distinct rosette or spot pattern and other features such as a number of accompanying individuals; Appendix 1).

Besides the unique markers on the individuals, attributes such as time, date and location of the capture were also used to differentiate between the individuals. In isolated grids, capturing two or three individuals in an image led us to identify two or three distinct individuals. Images not assigned primary and secondary features were discarded and treated as non-capture. Based on the frequency of images captured during different times of the day, activity pattern of snow leopards was computed through nonparametric kernel density estimation using 'overlap' package (Meredith and Ridout 2021) in R.

A capture history was built using the date stamp on the images and the location IDs (camera station codes). Each day was considered a single occasion, and multiple captures of an individual in a single trap location during the same sampling occasion were treated as one capture incident (DoFPS 2023).

2.7. Data analysis

2.7.1. Spatially-Explicit Capture Recapture (SECR) modelling

There are two model-based approaches to estimating animal abundance and density from capture-recapture studies; the likelihood estimate (Borchers and Efford 2008) and the Bayesian framework for inference (Royle and Young 2008). These models are known as Spatially-Explicit Capture-Recapture (SECR or SCR) models (Efford 2004; Borchers and Efford 2008; Royle and Young 2008; Royle *et al.* 2009), and they explicitly account for the spatial variation in abundance by deriving from the estimated location of all individual activity centres across the available habitat. The area calculation in the SECR method is also spatially explicit without relying on the archaic method of estimating area based on the movement distance of individuals, which is often prone to errors. SECR models how an animal's distance from a detection device which affects the likelihood that an individual in a population will be captured.

While there are advantages and drawbacks to both methods, for the NSLS 2022-2023, the Bayesian approach using data augmentation (Royle and Young 2008; Royle *et al.* 2009) was used to estimate the number and density of snow leopards considering the following advantages;

- Bayesian inference allows the direct use of probability to characterize information about unknown model parameters;
- Posterior inferences can be made which are valid to any sample size which is crucial for ecological studies of rare and elusive animals, such as snow leopard, where sample sizes are often very small (Royle *et al.* 2013);
- The Bayesian approach to analysis that makes use of data augmentation to estimate the density of animal in the study area (Royle and Kéry 2007) allows for inclusion of animals that were not captured during our survey;
- This was also the method used during the snow leopard survey of 2016 and the same method was selected to ensure comparability of the results.

Taking into account the data lost due to camera theft, dysfunctional camera, and delayed re-installations,


Rangers recording data after installing the camera trap

"Bayesian inference allows the direct use of probability to characterize information about unknown model parameters"

the actual active operational days for each camera was during the study period was taken into account during the analysis. A single-season (i.e., demographically closed) spatially explicit SECR hierarchical model with two hierarchical levels was built: 1) a point process ecological model that describes the spatial distribution of individuals (density that is the main ecological process of primary interest) and, 2) an observation model accounting for imperfect detection and variability in snow leopard detectability that described the observation of individuals in camera traps (Royle *et al.* 2009).

The SECR model estimates the following three main parameters: 1) the baseline detection probability p_o, which describes the detection probability at a camera station located at an animal's activity centre s_i – a latent variable representing the expected location about which an individual is expected to use space during the sampling period, 2) the spatial variance (scale) parameter of the detection function sigma (σ), and 3) the number *N* of snow leopard activity centres within the available habitat *S* (i.e., the detector grid with a buffer of some distance), which can also be used to derive density *D*. Additionally, the SECR models can also accommodate the covariate effect on density and detection parameters, hence can also estimate the effects (regression coefficients) of spatial and individual covariates in detection probability and density.

To model the probability *p* of detecting an individual *i* at camera station *j* as a decreasing function of the distance *d* between the camera trap and the individual's activity centre *s*, the half-normal detection function was used. By convention, detection probability can be expressed as

$$p_{ij} = p_{0_{ij}} \exp\left(-\frac{d_{ij}^2}{2\sigma^2}\right)$$

The detection function is assumed to reflect individual space use and can directly be linked with the home range concept (Royle et al., 2014). Data-augmentation approach was used to include individuals that may be present but were not exposed to sampling. The detection of an individual is conditional on the individual state z_i (=1 if an individual *i* is a member of the population *N*, 0 otherwise) and is governed by the inclusion probability ψ such that $z_i \sim Bernoulli(\psi)$. The population size can then be derived by summing the z_i values,

$$N = \Sigma_{i=1}^{M} z_i$$

where *M* is the data-augmented population size (Royle et al., 2007) and represents the maximum number of snow leopards in the habitat *S*.

The ecological model describes the number and distribution of all snow leopards present in the population (i.e., observed and augmented (undetected) individuals). In the data augmentation approach, the superpopulation size *M* was chosen at 200, sufficiently larger than *N* (=96). Given relatively high photographic captures of snow leopards during the survey, an augmentation factor of 2 was chosen to facilitate the analysis by Markov Chain Monte Carlo (MCMC).

The sex model p_o(sex). σ(sex) was implemented to estimate variation in the probability of capture (*p0*) (when the distance between activity centre and camera trap is zero) and ranging scale parameter (σ) separately for male and female. The models were fitted in JAGS (Just Another Gibbs Sampler) program (Plummer 2003) using MCMC algorithm in R (R Development Core 2023), using the "jagsUI" package (Kellner 2018). A uniform prior distribution on population size and the distribution of activity centre was used. The superpopulation (*M*) and population size (*N*) are related by parameter ψ. ψ is the probability that an individual on the list of size M is a member of the population of size N that was exposed to sampling by the trap array (Royle and Young 2008). The models were run using three parallel chains of 10,000 iterations each, discarding the first 2000 iterations as burn-in and thinning at the rate of 10. The model convergence was assessed by visually inspecting trace plots and histograms for each parameter and ensuring that the Gelman-Rubin statistics (R-hat) values were <1.1.

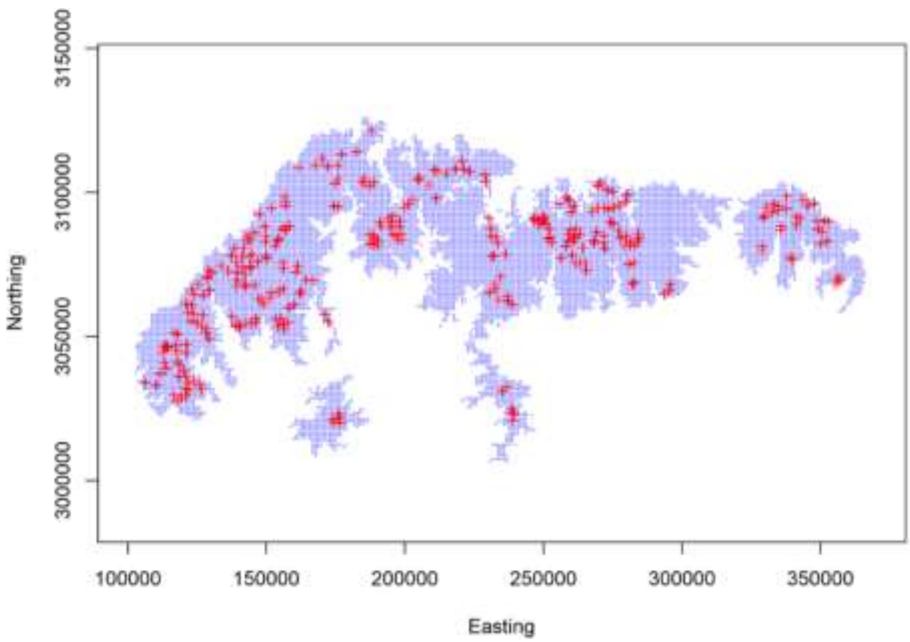


Figure 3: Space mask (20 km buffer with 1km spacing) on an irregular study area.

The model convergence was assessed by visually inspecting trace plots and histograms for each parameter, and ensuring that the Gelman-Rubin statistics (R-hat) values were <1.1. The mean, median, and 95% credibility intervals from these converged samples for the model parameters were computed. These models are computationally expensive so multiple covariate models could not be run during this analysis using the Bayesian framework. For instance, model with sex covariate took ~9 hours to run 100 iterations. So, adding more parameters such as covariate or goodness-of-fit considerably increases the computation time. However, we used maximum-likelihood (MLE) approach to perform model selection and estimated density for comparability (Appendix I). but we report results from the Bayesian framework. The posterior predictive density of the animal location was produced based on the bivariate-normal model of animal movement. The values of the pixels are the expected number of animals in the pixel at a given moment in time.

2.7.2. *Habitat suitability modelling*

- **Species occurrence points**

Species occurrence points for snow leopard comprised of camera trap locations that captured the snow leopard during the NSLS 2022-2023 and location of snow leopard scats which resulted in positive identification of snow leopard during its genetic analysis, collected during the survey. A total of 215 occurrence points were obtained (144 camera stations and 71 scat collection sites), which were rarified to assign only one record per km^2 to reduce spatial autocorrelation. A total of 192 occurrence points were retained for MaxEnt modelling.

- **Variables used for the MaxEnt model**

Different predictor variables were used for modelling snow leopard distribution and habitat suitability in Bhutan. Topographic variables such as elevation and slope were derived from the 12.5 m resolution Digital Elevation Model raster downloaded from the USSS (USGS 2018). Land use and land cover variable representing the different forest types and land use types of Bhutan was obtained from the Department of Forests and Park Services (FRMD 2017). Climatic variables were downloaded from the WorldClim data hub (Fick and Hijmans 2017)and from the 19 bioclim variables available, two were used (total annual precipitation and annual mean temperature) as they were found to have more influence in similar studies (Rashid *et al.* 2021). Variables exhibiting anthropogenic influences such as the human settlement and roads were obtained from National Statistics Bureau (NSB 2005; NSB 2022)and raster file with Euclidean distance were processed in ArcGIS 10.8.1 for these two variables. The format of the predictor variables was changed from raster to ASCII format in Arc GIS 10.8.1 (ESRI 2020).

- **Maxent modelling**

MaxEnt software version 3.4.3 (Phillips *et al.* 2020) was used to execute the maximum entropy algorithm (Phillips *et al.* 2006) with 70% training and 30% test data and a logistic output format was set up as it describes the probability of snow leopard presence, with continuous habitat suitability ranging from 0 (unsuitable) to 1 (most suitable). The pixel value equals to or higher than the ten-percentile training presence threshold were considered as the suitable habitat. The model performance was assessed using AUC (Area under the Receiver Operating Curve) whereby values ≤0.5 indicate very poor fit, >0.5 indicate good fit, and equal to 1 indicate perfect fit (Fielding and Bell 1997). From the suitability map, value > 0.7 of the predicted habitats were identified as the prime habitats in the study landscape while value from 5-7 were identified as moderately suitable habitats (Kalashnikova *et al.* 2019; Rashid *et al.* 2021).

2.7.3. Occupancy modelling

A single-season, single-species occupancy model was used to estimate the probability of occupancy of snow leopards across the entire suitable habitat in Bhutan. Unlike the presence-only model, the occupancy model accounts for detection heterogeneity (i.e., acknowledges detection is imperfect; MacKenzie et al., 2017) and hence produces a true distribution of species by accounting for biases associated with observation error (Kery and Royle, 2016). Occupancy is defined as the probability that a species will occupy a random site (in this survey 2 x 2 km grid) at any given period. It is preferred to interpret occupancy as the probability of site 'use' because the change in occupancy status due to the movement of snow leopards is random during the survey (MacKenzie et al., 2017). The detection/non-detection data coded as binary (1 for detection and 0 for non-detection) was used during analysis.

Occupancy was modelled as a function of site covariates and detection probability as a function of survey covariates. Site covariates were selected based on the ecology of snow leopards and existing literature. Five site covariates were chosen that were deemed to affect snow leopard site use: percentage of landscape with rocky outcrop (including scree and moraines), terrain roughness, elevation (linear and quadratic effect), slope and topographic ruggedness index (TRI). Detection probability was modelled as a function of effort (to account for the unequal number of sampling efforts). A set of biologically relevant models of snow leopard site use was then built. All continuous covariates were standardized to mean 0 and 1 standard deviation. The models were run in the Bayesian framework by providing uninformative priors (Uniform(-5, 5) for slopes and Beta(1, 1) for intercepts). JAGS called through R using the package jagsUI was used to run the models. Three chains with 80000 iterations each were ran, thinning at the rate of 5 and discarding the first 10000 samples as a burnin. The model fit was assessed using Freeman-Tukey discrepancy and computing Bayesian p-value as a summary of the posterior predictive check. Model convergence was assessed using R-hat statistics and by visually inspecting trace plots. All model parameters achieved convergence (R-hat < 1.1) and the top model adequately fitted the data (Bayesian p-value = 0.1). Spatial autocorrelation was checked using Moran's I and found no evidence of autocorrelation. So, no further action (e.g., inclusion of spatial autocovariate component or restricted spatial regression model) was needed.

The snow leopard distribution map was prepared (probability of site use map) across the potential snow leopard habitat in Bhutan. The detection-corrected snow leopard distribution was visualized at 90m pixel resolution. The predictive accuracy of the model was evaluated using AUC.

2.7.4. DNA analysis of scat samples

DNA was extracted from all samples using the Qiagen QIAamp Fast DNA Stool Mini kit using the manufacturer's protocol (Hacker *et al.* 2022). The mean DNA concentration was 18.85 ng/ul, and a 260/280 ratio was 1.81. This is a reasonable concentration from scat samples, and the 260/280 ratio indicates pure DNA. Most of the scat had intact DNA; of the samples with visible DNA on a SybrGreen stained agarose gel, 80% showed a single high-molecular weight band indicating intact DNA, whereas 20% had a smear indicating DNA degradation.

Microsatellite analysis was performed on snow leopard PCR-assay identified scat in triplicate with a panel of 7 microsatellites using the Qiagen Type-it Microsatellite PCR and 55°C annealing temperature. The primes were labelled with *FAM, NED, PET*, and *VIC* and amplified in two multiplexes: Plex 1: *PUN1157 FAM*, *PUN1262 NED, PUN834 PET*, Plex 2: *PUN100 FAM, PUN894 VIC, PUN124 NED*, and *PUN225 PET* (Janečka *et al.* 2008; Janečka *et al.* 2011; Janecka *et al.* 2017). Negative and positive controls were included in all PCR plates. PCR products were visualized on a SybrGreen stained agarose gel to verify amplification. Amplicons were diluted 1:10, then 1.5 ul was placed in 8.7 ul of Formamide with 0.3 ul of ABI 500LIZ size standard.

These plates with amplicons and 500LIZ in formamide were submitted for fragment analysis on the ABI3730 instrument. After the injections, the electropherograms for each PCR reaction were downloaded and analyzed in GeneMarker 2.6 software. The allele sizes were determined based on the peak heights and profiles. The genotypes were scored for each triplicate, and consensus genotypes were reconstructed. Sex identification was performed with PCR assay using felid-specific primers that amplified the 100-bp portion of the SRY using the Qiagen Type-it Microsatellite PCR kit. Each snow leopard scat sample with a 7-microsatellite genotype profile was tested with the SRY marker in triplicate to determine sex. The snow leopard was identified as a male if there was a 100-bp band in 2 or 3 PCR replicates. If there was no amplification, it was identified as a female. If there was amplification in 1 of 3 replicates, it was scored unknown sex. The sex for the female samples was also verified using AMELY PCR assay (Janečka *et al.* 2008; Janecka *et al.* 2014).


Snow leopard habitats in WCNP
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CHAPTER 3
RESULTS

3.1. Photographic captures

A total of 310 camera stations were deployed across potential snow leopard habitats in the country. JDNP had the highest number of stations at 111, followed by WCNP with 87 stations. JSWNP has the lowest number, with six camera stations (Figure 4). Of them, data from one camera station was completely lost due to the loss of the camera and yielded only two trap nights. Some of the cameras were retrieved earlier due to the risk of inaccessibility caused by snow cover.

Of the 310 stations, snow leopards were photo captured at 144 camera stations. JDNP had the highest number of stations with snow leopards (66), followed by WCNP (30). Only one camera station captured snow leopards in BWS, while no snow leopards were captured from JSWNP and Dagala region (six stations) under DFO Thimphu (Figure 4). The highest elevation at which the snow leopards were captured was 5090 m.a.s.l under WCNP while the lowest elevation was 3634 m.a.s.l under DFO Thimphu. Majority of the snow leopards were captured by camera stations between the elevation of 4251- 5000 m.a.s.l (Figure 5)

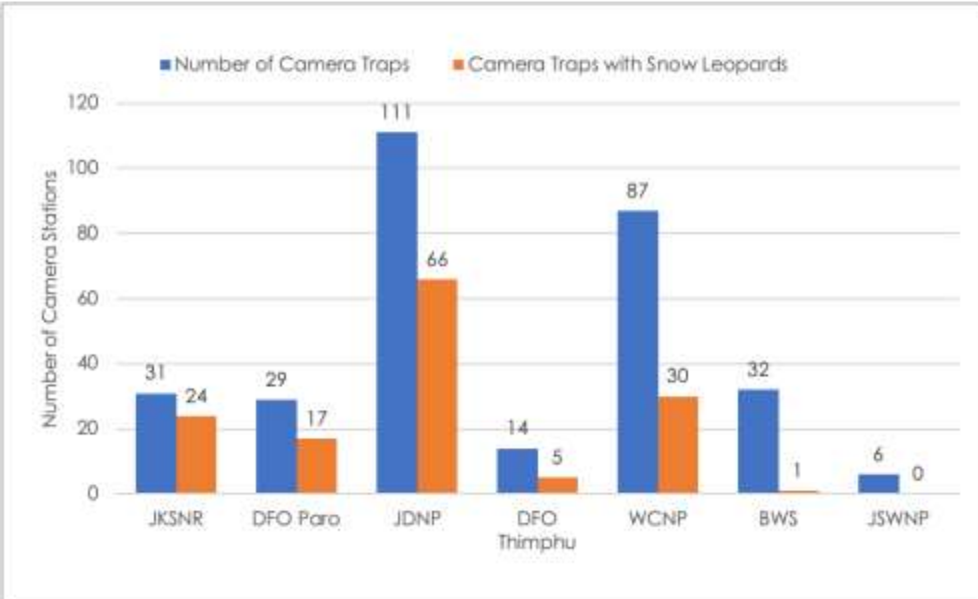


Figure 4: Total number of camera stations and number of camera stations that captured snow leopards.

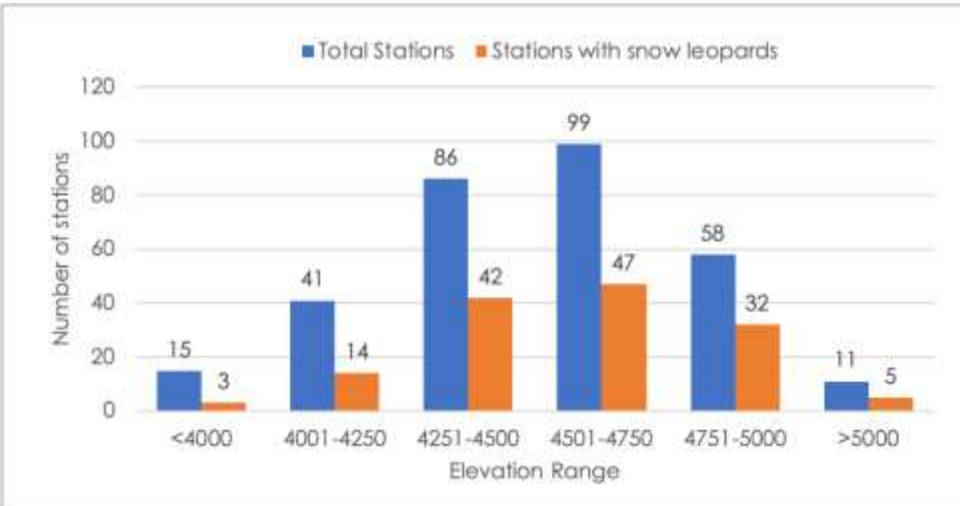


Figure 5: Graph showing the elevation range and snow leopard capture frequencies.

3.2. Snow leopard individuals

The 310 camera stations yielded a survey effort of 22,636 trap nights and captured over 10,000 images of snow leopards. We used 476 images for snow leopard individual identification and could identify 96 adult individuals, of which 45 were identified as male, and 51 as female (Table 2; Appendix II). Snow leopard images from 13 stations were not used during the abundance and density analysis due to poor quality and ambiguous identity to match the identified snow leopards.

Individual identification of snow leopard was made carefully by observing the rosette pattern on both flanks, face, limbs, torso and tails. Many images look like unique individuals, but due to a lack of multiple reference points for comparison, they were not classified as unique individuals, and, therefore, were not included in the analysis. These images include the capture of only one flank, part of the limbs, odd facial angles, or tails.

Table 2: Number of snow leopard individuals captured in each division. Recaptured snow leopard individuals in more than one field office are highlighted in bold text.

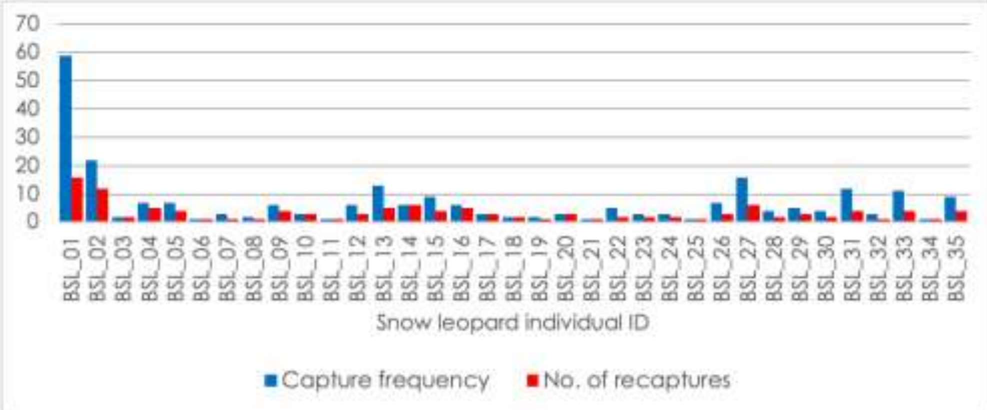
Sl. No.	Name of Field Office	No of Adult Individuals	Adult Snow leopard ID	No. of Cubs Identified
1	JKSNR	12	BSL_01-BSL_12; **BSL_05**	0
2	DFO Paro	11	BSL_13-22; **BSL_05**	2
4	DFO Thimphu	4	BSL_23-25; **BSL_27**	0
3	JDNP	53	BSL_26-78; **BSL_27**	8
5	WCNP	17	BSL_79-95	0
6	BWS	1	BSL_96	0
7	JSWNP	0		0
	Total	**96**		**10**

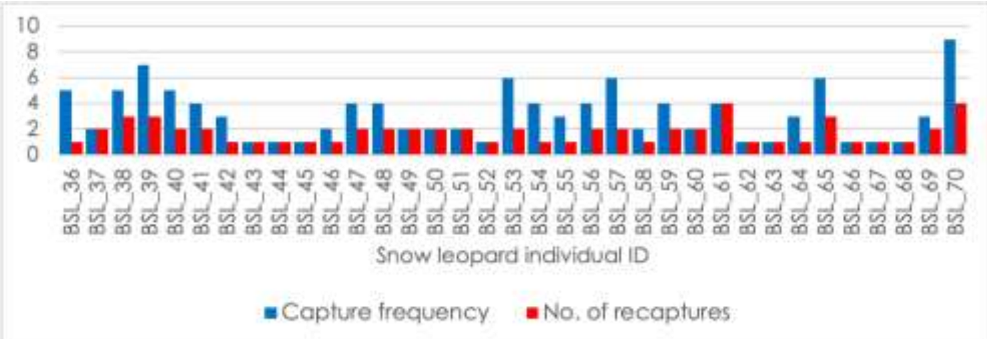
3.3. Photographic capture-recapture and activity patterns

Photographic capture-recapture patterns show that most of the identified individuals have recaptures at more than one location. Individual BSL_01 (Bhutan Snow Leopard 01) had the maximum number of recaptures at 16 camera stations under JKSNR. BSL_02 was captured at 12 different camera stations, and BSL_87 was captured at seven different camera stations. Two individuals were captured by six different stations, three individuals at five locations, 11 individuals at four locations, and 12 individuals at three locations. BSL_05 was captured by cameras in both JKSNR and DFO Paro, and BSL_27 was captured in adjoining camera stations of JDNP and DFO Thimphu.

Thirty-three individuals were captured at two different camera stations, and 32 individuals were captured at only one station. BSL_01 also had the maximum capture frequency captured at 59 different times. This was followed by BSL_02, captured 22 times, and BSL_27, captured 16 times. The majority of individuals were captured between one to 13 different times. These capture-recapture patterns show a highly localized distribution of individuals except for a few individuals that covered a vast area.

Three camera stations (JDNP_026, JDNP_051, PFD_001) captured five different snow leopard individuals each, followed by eight stations that captured four individuals, and sixteen camera stations captured three different individuals. Thirty-eight camera stations captured two different individuals, and the remaining 65 stations captured only one individual snow leopard during the survey period (Figure 6).





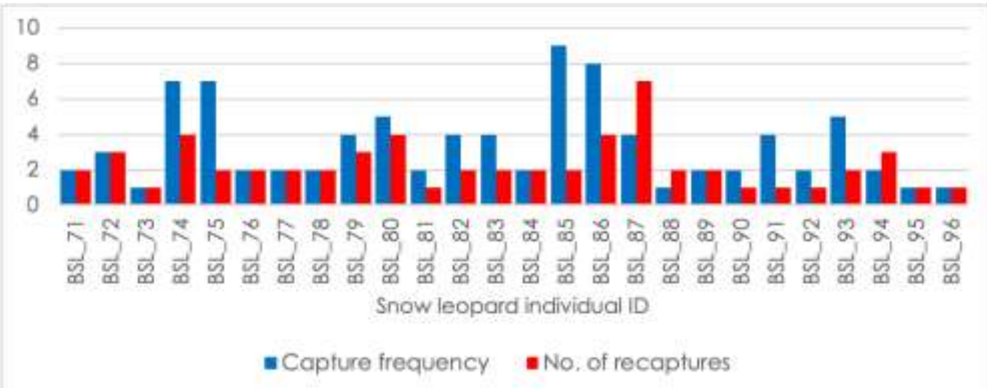


Figure 6: Record of individual snow leopard capture frequency and re-captures in different camera stations.

The activity pattern on a 24-hour time scale showed that snow leopards are mostly active at dawn and dusk with greater peak of activities in the evening hours, exhibiting a crepuscular behaviour. Activity decreases to its minimum during the mid-day, though some degree of activities were observed during all time periods of the day. Blue sheep on the other hand was most active throughout the day starting as early as 06:00 hours to 17:30 hours (Figure 7). The activity overlap between snow leopard and its prey blue sheep was also highest during the morning and evening hours (Snow leopard–blue sheep Dhat1 = 0.49).

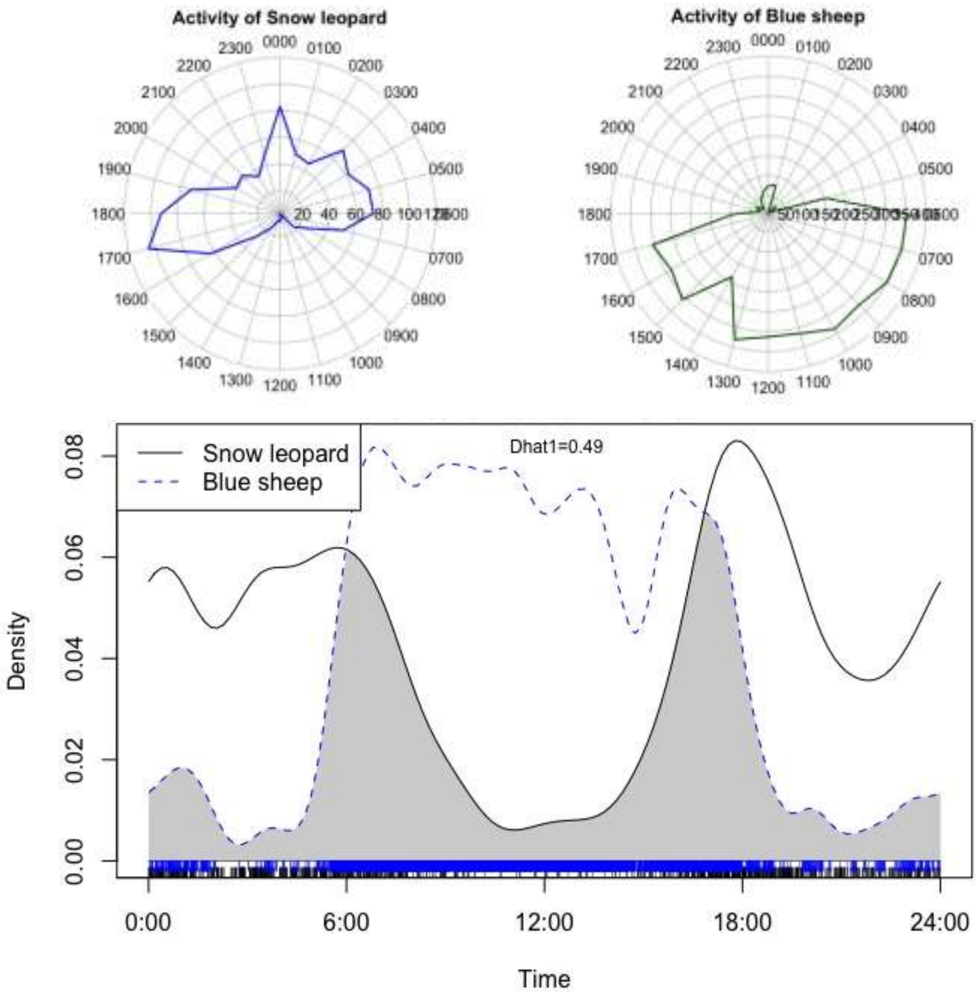


Figure 7: Temporal activity pattern of snow leopard and blue sheep.

Blue sheep *Pseudois nayaur* captured on a camera trap

3.4. Estimates of snow leopard abundance and density

The Bayesian SECR model yielded a total estimated number of snow leopards in Bhutan at 134 individuals (SD ± 7.06). The estimated range of snow leopard abundance was between 121 and 148 individuals at 95% CI (Figure 8; Table 3). This is an increase of snow leopard population in Bhutan by 39.5% from the baseline population of 2016 where 96 (SD ± 8) individuals were estimated.

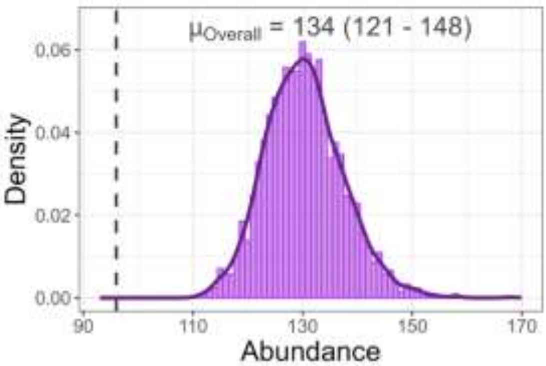


Figure 8: Histogram of overall snow leopard population abundance in Bhutan. The values in parenthesis represent a 95% credible interval. The dashed black line indicates the observed individuals (n=96).

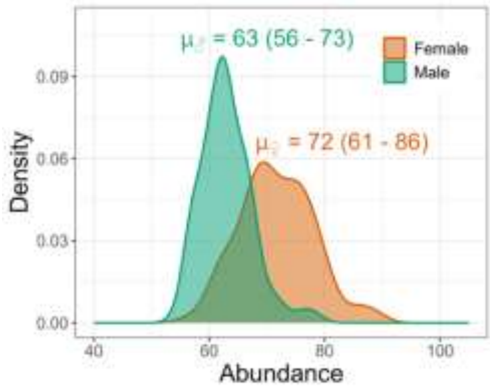


Figure 9: Sex-specific population abundance of snow leopards in Bhutan. The values in parenthesis represent a 95% credible interval.

The density estimates varied from 1.2 individuals to 1.48 individual snow leopards per 100 km^2 (at 95% CI) with a mean density estimate of 1.34 snow leopards per 100 km^2 (SD ± 0.071) (Table 3; Figure 9, 12). The posterior density map predicted higher density of animals in western Bhutan (JDNP, JKSNR, DFO Paro) as compared to similar habitats in central and eastern Bhutan. The density estimate for female was marginally higher than male (Table 3).

Table 3: Posterior parameter estimates from the Bayesian Model with 2.5%, 50% and 97.5% quantiles (95% credible intervals).

Parameters	**mean**	**sd**	**2.50%**	**50%**	**97.50%**
$p_{o_{female}}$	0.011	0.002	0.009	0.011	0.014
$p_{o_{male}}$	0.008	0.001	0.006	0.008	0.009
$p_{o_{overall}}$	0.008	0.001	0.007	0.008	0.009
σ_{female}	2.917	0.14	2.646	2.917	3.21
σ_{male}	4.773	0.174	4.454	4.759	5.114
$\sigma_{overall}$	4.161	0.127	3.921	4.157	4.414
$N_{overall}$	134.667	7.062	120.725	134	148.275
N_{male}	62.993	4.441	56	63	73.55
N_{female}	71.673	6.386	61	71	86
$D_{overall}$	1.344	0.071	1.205	1.338	1.48
D_{female}	0.716	0.064	0.589	0.709	0.829
D_{male}	0.629	0.044	0.559	0.629	0.719
Ω	0.672	0.047	0.581	0.671	0.758
p_i	0.471	0.056	0.358	0.476	0.577

p_o = baseline detection probability/encounter probability; σ – scale parameter in km; N = abundance, D = density per 100 km^2; p_i = sex-ratio of the population; Ω = data augmentation parameter

Baseline detection probability differed between sexes with higher probability for females (median and 95% CI p_o = 0.011, 0.009 – 0.014) than males (0.008, 0.006 – 0.009). The overall (without sex differentiation) baseline detection probability was similar to that of male (0.008, 0.007 – 0.009). However, the movement (or scale) parameter (σ) was opposite: significantly higher for males (4.759 km, 4.454 km – 5.114 km) than females (2.917 km, 2.646 km – 3.210 km). The overall movement parameter estimate was 4.157 km (3.921 km – 4.414 km) (Table 3).

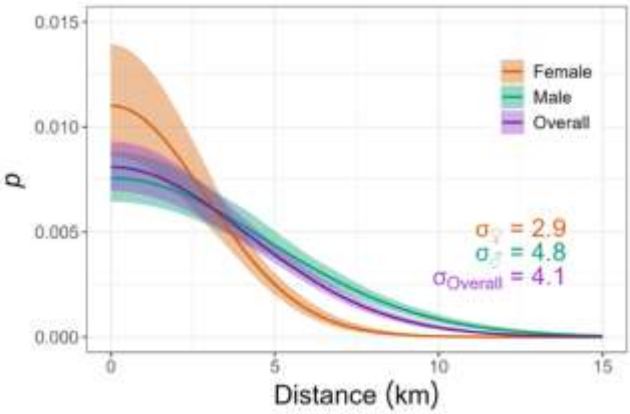


Figure 10: Baseline detection probability (p) of snow leopards in Bhutan estimated from the Bayesian spatial capture-recapture model.

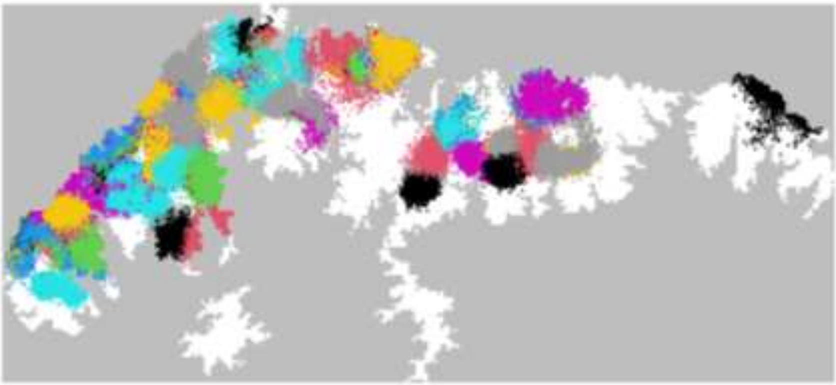


Figure 11: Posterior distribution of Activity centres of individual snow leopards (n=96) across the suitable habitat in Bhutan.

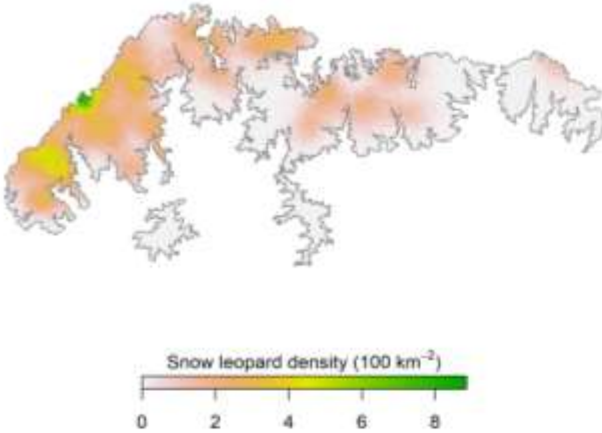


Figure 12: Map of the study area showing the posterior density estimate from the Bayesian model.

3.5. Snow leopard individuals from the scat analysis

A total of 184 putative snow leopard scats were collected from various field offices, of which 71 samples tested positive for snow leopards. Thirty-one samples were successfully genotyped (42.3%, Table 4), and consensus genotypes were used to determine the profile at each of the seven loci. The combined 7-microsatellite genotype profile had PID-unr of 0.000046 and PID-sib of 0.012. The genotype profiles were then used to identify individual snow leopards, assign unique identification numbers, and determine in which scat each snow leopard was observed.

There were 22 snow leopards observed among the 31 successfully genotyped scats, of which nine were male and 13 were female (Table 4). Nine snow leopards were observed in multiple scats, and 13 snow leopards were observed only once. One snow leopard was observed in scats from DFO Paro and JDNP, indicating that the specific sites where they were collected are close enough to be used by the same individual. For the remaining snow leopards detected in multiple scats, all of them were only observed in the same survey are

Table 4: Snow leopards identified among scat sampled in Bhutan using 7-microsatellite genotypes.

Survey Site	Total number of scats collected	PCR Assay - Uncia Scat	Uncia Scat Successfully Genotyped	% Uncia Scat Successfully Genotyped	Identified Snow Leopards (F - female, M - male)
JKSNR	53	16	7	43.8%	3 (2 F, 1 M)
DFO Paro	31	11	3	27.3%	2 (2 M)
JDNP	53	32	14	43.8%	10 (6 F, 4 M) *
DFO Thimphu	1	0	0	n.a.	0
JSWNP	0	0	0	n.a.	0
WCNP	40	11	6	54.5%	6 (4 F, 2 M)
BWS	5	1	1	100.0%	1 (1 F)
Total:	184	71	31	43.7%	13F, 9M

**One individual was common between JDNP and DFO Paro. In this table, the individual is included under JDNP*

3.6. Predicted snow leopard habitats

The variables with the highest contributions in the MaxEnt model were land use land class and annual mean temperature, and distance from road, while elevation and annual mean temperature has the highest permutation importance (Table 5).

The predictions show the relationship between snow leopard presence data and the environmental variables defined in the study area. An AUC value of 0.95 and 0.94 were obtained for training and test data respectively. With AUC value of greater than 0.8, the results exhibited high accuracy of the models as AUC value of greater than 0.80 indicates that for 80% of the time, a random selection from the positive group (sensitivity) will have a score greater than a random selection from the negative class (specificity) (Sharma et al. 2020). Hence, the results from this model can accurately predict habitat suitability for snow leopards in the study area.

Predicted map (Figure 13) shows that western Bhutan has higher habitat suitability as compared to north-central and eastern Bhutan. Certain patches of higher elevated mountain landscapes in central Bhutan and far east also exhibited potential suitable habitats for snow leopard, though no records were made during the NSLS 2022-2023.

Table 5: List of predictor variables used for modelling snow leopard habitat suitability and their contributions.

Factors	Predictor variable	Original spatial resolution	Percent contribution	Permutation importance
Topography	Elevation	12.5 x 12.5 m	4.2	60.9
	Slope	12.5 x 12.5 m	3.3	2.2
Climate	Total annual precipitation	800 x 800 m	7.2	8.6
	Annual mean temperature	801 x 800 m	21.3	14.6
Land cover	Land use types	30 x 30 m	45.1	1.8
Anthropogenic	Distance from settlement	30 x 30 m	2.5	3.8
	Distance from road	30 x 30 m	16.3	8.1

The top occupancy model contained four covariates: rocky outcrop, elevation, slope and terrain roughness (Table 6). However, only two of these had a significant influence on the snow leopard habitat use as indicated by the exclusion of zero in their 95% credible intervals (CRI). They were rocky outcrop (mean(sd); 95% CRI = 0.57(0.16); 0.27-0.91) and elevation (linear=-0.02(0.18); -0.36-0.32 and quadratic=-0.27(0.12); -0.52—0.04) (Figure 15). The overall occupancy probability was 0.51(0.04); 0.42-0.59 and the mean detection probability was 0.28(0.02); 0.24-0.31. The naïve occupancy (i.e., sites with snow leopard detections divided by a total number of sites) was 0.41 (Figure 14). The predictive model of snow leopard site use showed adequate fit (AUC = 0.68; 95% CRI = 0.64-0.71).

Table 6: Site covariates tested in occupancy modelling and values returned from top model.

	mean	sd	2.50%	50%	97.50%	overlap0	f	Rhat	n. eff
p0	0.276	0.017	0.243	0.275	0.309	FALSE	1.000	1	42000
a0	-0.968	0.085	-1.137	-0.967	-0.805	FALSE	1.000	1	42000
aEff	-0.031	0.093	-0.212	-0.031	0.152	TRUE	0.634	1	32959
psi0	0.507	0.043	0.424	0.506	0.594	FALSE	1.000	1	39050
b0	0.028	0.174	-0.306	0.024	0.379	TRUE	0.555	1	38786
bRoc	0.574	0.164	0.267	0.568	0.909	FALSE	1.000	1	42000
bElev	-0.018	0.175	-0.363	-0.018	0.322	TRUE	0.540	1	42000
bElev2	-0.267	0.123	-0.523	-0.262	-0.04	FALSE	0.990	1	42000
bSlo	-0.235	0.155	-0.543	-0.234	0.069	TRUE	0.936	1	42000
bRou	-0.192	0.171	-0.530	-0.191	0.139	TRUE	0.872	1	27465
N	140.859	4.535	133.000	140.000	151.000	FALSE	1.000	1	37004
Tobs	54.665	8.463	39.657	54.096	72.705	FALSE	1.000	1	35448
Tsim	41.699	8.117	26.994	41.299	58.714	FALSE	1.000	1	42000

Eff: Effort; Roc: Rocky outcrop; Elev: Elevation; Slo: Slope; Rou: Terrain roughness

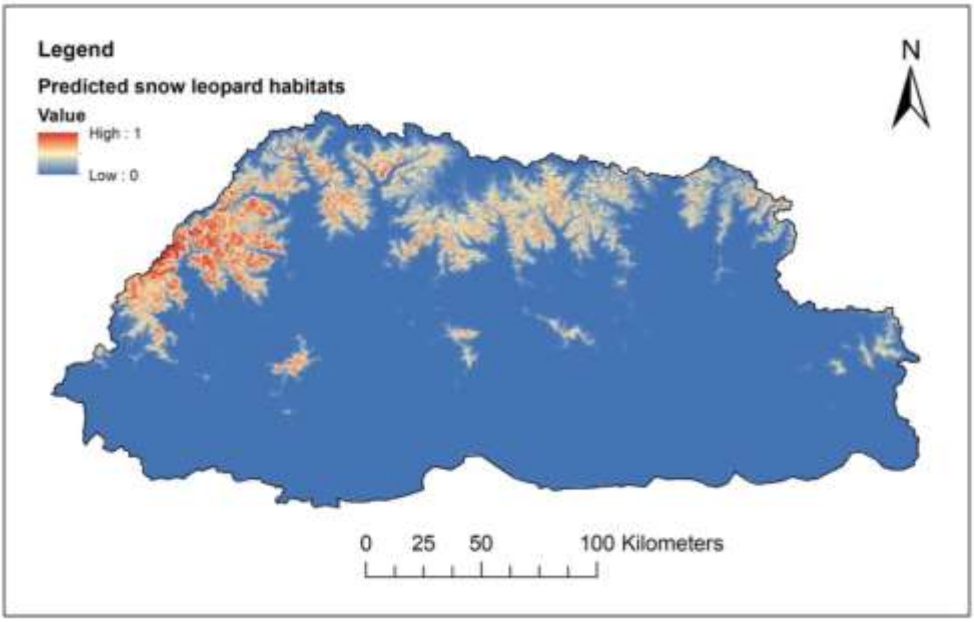


Figure 13: Habitat suitability map of snow leopard as determined by MaxEnt modelling based on current presence evidence.

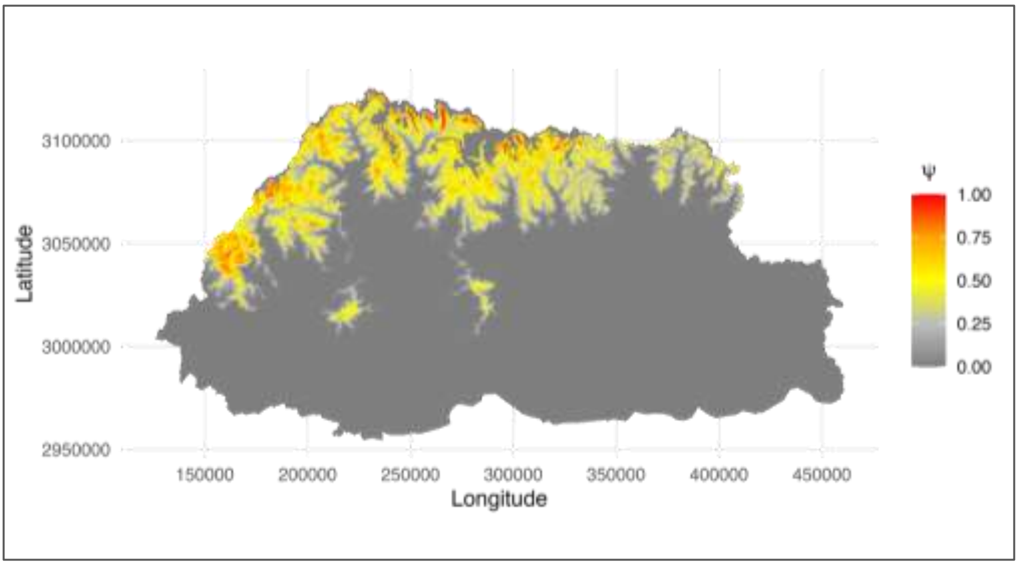


Figure 14: Snow leopard distribution (probability of site use) across the suitable habitat in Bhutan predicted by occupancy model.

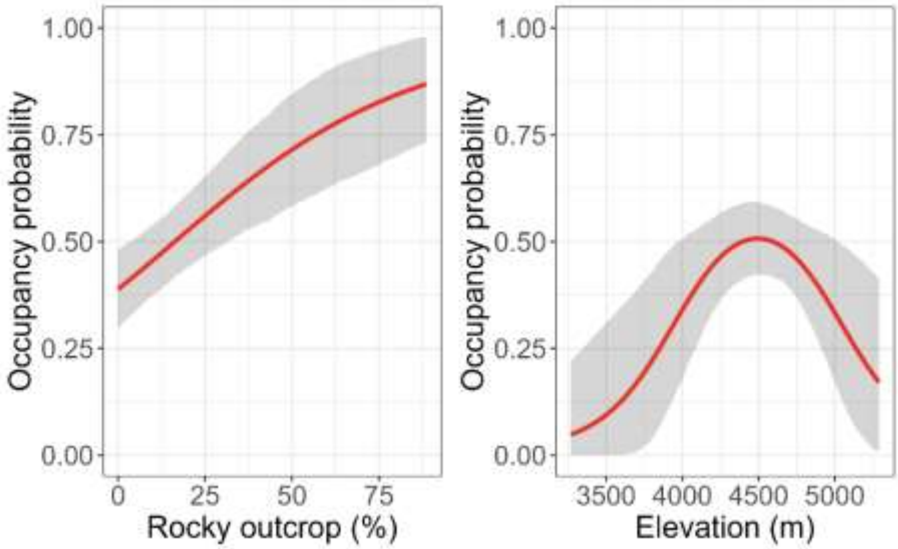


Figure 15: The snow leopard site use probability as a function of rocky outcrop and elevation. The red lines indicate the mean and grey shaded regions represent a 95% credible intervals.

3.7. Other record of mammals

During the survey period, camera traps also recorded many other species. The rare and elusive Pallas's cat (*Otocolobus manul*) was captured at two stations; one from WCNP and one from JDNP, after a gap of 10 years. Photographic captures were last reported from JDNP in 2012 (Thinley 2023). The camera traps also recorded a widespread distribution of Himalayan wolf (*Canis lupus chanco*) across the snow leopard landscape of JKSNR and Paro FD, JDNP and WCNP. The snow leopard survey also, for the first time, captured a deer species, the White-lipped deer (*Cervus albirostris)* from DFO Paro, which is a new species record for the country (Figure 16). White-lipped deer are globally threatened deer species listed under Vulnerable category of the IUCN Red List. Asian badger *(Meles leucurus)*, which was never recorded in the past in JKSNR, was also captured at a high-elevation station for the first time. Tiger and snow leopards were also captured at the same camera trap station in two locations, one each in DFO Thimphu and WCNP. A camera station under DFO Thimphu interestingly recorded the three big cats, tiger, common leopard and snow leopard at the same location.

Figure 16: Record of new deer species for the country; White-lipped Deer/Thorold's deer *(Cervus albirostris)*.

CHAPTER 4
DISCUSSION AND MANAGEMENT RECOMMENDATIONS

4.1. Bhutan: A snow leopard stronghold re-confirmed

The national snow leopard survey 2016 highlighted that Bhutan is a stronghold of snow leopards, with an estimated 96 individuals. It was for the first time that the snow leopard population in the country was declared, establishing empirical evidence that Bhutan has a healthy and viable population of snow leopards (DoFPS 2016). The NSLS 2022-2023, reporting 134 individuals, reaffirms Bhutan as a conservation stronghold for snow leopard in the Eastern Himalayas.

The snow leopard density was found higher in the western region as compared to the central and eastern regions, with a strong possibility for population connectivity. The DNA analysis of scat samples also suggested relatively higher snow leopard abundance in JDNP (N=10) than other sites (JKSNR N=3, DFO Paro N=2, WCNP N=6, BWS N=1). Nevertheless, this interpretation regarding abundance needs to be treated with caution because it does not consider sampling effort or spatial distribution of scats within the survey area. The capture of snow leopards with cubs at many locations in DFO Paro and JDNP also suggests that population is viable and breeding.

With most of the snow leopard habitats being closer to international borders, population dispersal to potential habitats across the border to India and China is high and possible. With continued conservation efforts, Bhutan can certainly be a safe haven for the snow leopards to thrive and serve as a source population in the region.

The increase in snow leopard numbers as compared to the 2016 baseline indicates that conservation efforts in the country are having a positive impact. The department has been strengthening the anti-poaching activities through patrolling, and alpine habitat management works have been continuously pursued through the support of the Bhutan for Life project. It is also important to note that survey area has been increased during this national survey by filling up gaps left during the past survey. During the 2016 survey, only 223 camera station were set up whereas 310 stations were set up during this survey.

4.2. Snow leopards in new territories

Snow leopards have expanded into new territories with records from places where the species was previously not recorded or were rare. During the last national survey in 2016, snow leopard was not recorded from BWS. A camera trap survey in the following years did record the species at few locations, and the current survey captured the species in one station. Although present, it appears that the snow leopards are rare and found in lower densities in the area. The NSLS 2022-2023 expanded the study area in DFO Thimphu including the Dagala regions and snow leopards were captured in many stations under DFO, Thimphu. Unlike in 2016 where the BWS area was excluded for density estimation, the entire surveyed areas have been accounted during the analysis this time. Movements of individuals within and among populations at larger landscapes are expected to help maintain genetic variability and population viability (Riordan *et al.* 2016). Image captures from DFO Paro and Thimphu landscape is a clear indication of the importance of securing conservation beyond protected areas and maintaining functional biological corridors that provide safe and contiguous landscape for the movement of species between our protected areas.

While snow leopard was not captured in camera traps set up in the Dagala region under DFO Thimphu and Black Mountain region of JSWNP, possibilities of snow leopard presence in these areas cannot be ruled out as Black Mountain once reported a rare capture of snow leopard (Letro *et al.* 2021) and snow leopard was captured by camera traps set for national tiger survey 2022 in the Dagala region. With evidence of snow leopards recorded in forested habitats (Bandyopadhyay

et al. 2019), and species habitat and behavior alteration in the face of climate change (Forrest *et al.* 2012; Watts *et al.* 2019; Kalashnikova *et al.* 2019), breeding snow leopards inhabiting these isolated high-altitude habitats in the future is probable. Snow leopard habitat suitability modeling also yielded potential habitats in these landscapes and high-altitude regions on Sakteng Wildlife Sanctuary in the far east.

4.3. Non-invasive genetics: A potential tool for snow leopard monitoring in Bhutan

Non-invasive genetics is a popular alternative to camera trapping for estimating the abundance and density of wildlife populations. The data obtained from the DNA can be brought into a capture history format similar to the camera traps as required for SECR models. During the current survey, the number of samples collected were lower as it was done opportunistically while carrying out the camera trap survey. Nevertheless, the results from the analysis showed that non-invasive scat survey can be a viable option for snow leopard monitoring in Bhutan as most of the samples that genotyped successfully yielded promising results in individual identification. Several reports indicate that the method is cost-efficient and could be tested in Bhutan's context. The main limitation for Bhutan is the lack of a well-equipped lab that can do complex genetics analyses.

The current fecal sample analysis also found that more than half of the putative snow leopard scats belonged to other species. Therefore, cautionary measures should be taken ii using sign surveys for snow leopard monitoring and dietary analyses as the results show a significant misidentification of samples. The species identification must be confirmed with genetics first. Genotyping with more microsatellites will also yield more information on the genetic diversity, which is vital information for ensuring long-term population viability. This analysis is currently underway and the results should provide further insights into population structure and dispersal.

4.4. Carnivore community and rich prey

Of the 310 camera stations, 185 stations captured blue sheep, the primary prey species of the snow leopard. More than 60,000 images of blue sheep were photographed during this survey, indicating prey richness. A healthy population of prey is an important determinant for carnivore population viability (Carbone and Gittlemann 2002), abundant blue sheep means the snow leopard have access to abundant and easy wild prey, obviating the need to hunt for domestic livestock, eliminating conflict with humans and thus supporting a thriving snow leopard population. Studies across the range found that there is positive correlation between snow leopard and wild ungulate density, and this underlines the need to conserve the ungulate prey population. Its abundance and body size makes the blue sheep an ideal prey for snow leopards (Lyngdoh *et al.* 2014).

Other potential prey species captured by the camera trap are Himalayan musk deer *(Moschus chrysogaster)*, marmot *(Marmota himalayana)*, goral *(Naemorhedus goral)*, serow *(Capricornis thar)*. These species have been described as prey species besides the main prey species the blue sheep in other similar regions (Aryal *et al.* 2016; Holt *et al.* 2018; Suryawanshi *et al.* 2021; Lham *et al.* 2021b).

Intriguingly, current survey showed that there is potential habitat overlap between snow leopard and other large carnivores such as tiger and common leopard, besides its sympatric carnivores such as dhole, Himalayan wolf, and red fox. Two camera stations captured both snow leopard and tiger while one station captured snow leopard and common leopard. Earlier studies in Bhutan found strong evidence of tigers and leopards occupying sites together when prey species such as gaur was abundant (Penjor *et al.* 2022). While the current records may be occasional overlaps without much interspecific interactions, long-term overlap of habitat between these top carnivores may result in either resource exploitation and behavioral interferences (Donadio and Buskirk 2006) or co-existing through habitat separation and exploitation of different prey species (Lovari *et al.* 2013). Maintaining diverse and healthy prey population is therefore vital (Karanth *et al.* 2004; Lovari *et al.* 2013; Shrestha *et al.* 2018; Suryawanshi *et al.* 2021).

4.5. Human-snow leopard conflict

Human–wildlife conflict (HWC) is a major conservation challenge (Madden 2004) and predation of livestock by large carnivores is one of the serious issues impacting both rural livelihoods and conservation (Karanth and Sunquist 2000; Kissui 2008; Wegge *et al.* 2012). Predation of livestock by snow leopard is quite common across its range (Wegge *et al.* 2012; Suryawanshi *et al.* 2013; Alexander *et al.* 2015) and it is no exception in Bhutan. Yak *(Bos grunniens)* herding is very common in all the snow leopard habitats across the country and in recent years, people seeking government interventions for snow leopard predation were high from the highland areas of JKSNR, DFO Paro and JDNP. Increased population of snow leopard will definitely put pressure on the herding communities as snow leopard will prey on the yak calves. In the snow leopard abundant places like JKSNR, past studies accounted 78.86% of livestock kills to snow leopard (Dorji and Powrel 2022), while in WCNP in central Bhutan, predation of livestock by snow leopard was found to be 24% (Jamtsho and Katel 2019). Lham *et al.* (2021) reported that across the snow leopard landscape, yaks constituted 14% of the snow leopard prey.

4.6. Key recommendations

Bhutan is inarguably one of the important snow leopard conservation strongholds among the snow leopard range countries. Limited anthropogenic pressure, abundance of prey species, and the strong conservation policies and actions have resulted in thriving population of snow leopard in the country. In the last five years, snow leopard population has increased and with records of many snow leopards with cubs, the future is only promising. To have continued long-term viable snow leopard populations in the country, the following recommendations are proposed:

- **Conduct periodic population survey**

Successful conservation and effective management of charismatic large carnivores such as the snow leopard relies on the effectiveness of monitoring programmes (Alexander *et al.* 2016; Suryawanshi *et al.* 2021). With annual monitoring of snow leopard populations going to be more difficult due to huge cost implications and limited human resources, it is vital that periodic population surveys are conducted at least once in five years. Nevertheless, intensive monitoring of smaller areas on annual basis is recommended to have better insights into population processes.

- **Strengthen patrolling and surveillance**

While there are no reports of snow leopard poaching in the country, the prevalence of illegal market for wildlife parts in the region may prompt local people to kill snow leopards to sell their parts. Besides, snow leopards preying on domestic animals will also increase the risk of retaliatory killing by the livestock owners. Therefore, patrolling needs to be strengthened and upscaled to reduce dangers of snow leopard killing and poaching. Patrolling can also curb other illegal activities taking place in snow leopard habitats.

- **Habitat assessment and management**

Carnivores play a key role in regulating the terrestrial ecosystems, but their prevalence is also a result of complex interactions between food and habitat availability. For the snow leopard to thrive, there should be a healthy prey population, which in turn depends on good natural habitats (as shown by high probability of site use across terrain with rocky outcrops). Snow leopard being an elusive species, anthropogenic disturbances should also be minimized. Prime snow leopard habitats must be protected as core zone and critical conservation areas. Therefore, periodic assessment of alpine habitat and placing management intervention where necessary is important. Studies should be done for a better understanding of the carnivore intraguild relations to inform management and conservation actions in areas where there is a habitat overlap between snow leopards and other carnivores.

- **Habitat use and connectivity**

The possibilities of snow leopard population dispersal from high density areas to other potential habitats are high in Bhutan. In order to ascertain these dynamics, scientific studies should be continued, and snow leopard movement should be tracked through GPS collaring snow leopards or by using non-invasive genetic sampling.

- **Human-snow leopard conflict management**

As a predator that occasionally kills domestic animals, the conflict between local highlanders and snow leopards is heightening. In order to ensure positive interaction between snow leopards and the people sharing the same landscape, it is vital that livestock insurance schemes are established. Implementation of interventions, such as providing coral fencing to yak herders has proven effective in reducing snow leopards preying on yak calves. Consequently, it is essential to sustain and enhance these interventions for continued positive outcomes.

- **Community-based wildlife tourism**

An innovative intervention to reduce the impact of snow leopard predation onto highlander's livestock population would be through the introduction of community-based wildlife tourism in areas with high snow leopard density which consequently also experience high livestock predation rates. These areas are coincidentally also popular trekking destinations thereby offering high potential of success of such interventions.

- **Conservation action plan**

To effectively prioritize conservation efforts to preserve snow leopard habitats and safeguard their prey species, it is crucial to establish pragmatic conservation action plans. Given that the existing national snow leopard conservation action plan has expired, it is imperative to develop new action plans to identify conservation management requirements and secure sufficient funding for their successful implementation.

"Introduction of community-based wildlife tourism in areas with high snow leopard density in an opportunity"

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APPENDICES

Appendix I: Abundance and density estimate as obtained from Maximum Likelihood approach.

Overall population estimate

Estimate	SE	Lower CL	Upper CL	n	Area (km²)
128.5602	13.29682	105.0272	157.3661	96	9979.598

Overall density estimates per 100 km²

Estimate	SE	Lower CL	Upper CL
1.28823	0.13324	1.052419	1.576878

Sex specific estimates

Male population estimate

Estimate	SE	Lower CL	Upper CL	N	Area (km²)
61.1795	8.642293	46.44699	80.58501	45	9979.598

Density estimate per 100 km²

Estimate	SE	Lower CL	Upper CL
0.6130457	0.08659961	0.4654195	0.8074976

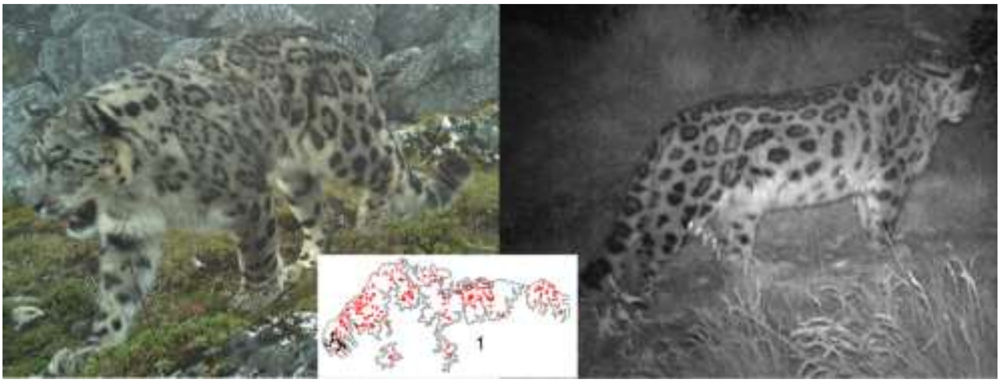
Female population estimate

Estimate	SE	Lower CL	Upper CL	n	Area (km²)
67.22891	10.27853	49.90777	90.56157	51	9979.598

Female Density estimate per 100 km²

Estimate	SE	Lower CL	Upper CL*
0.6736635	0.1029954	0.500098	0.9074671

Appendix II: Images of identified snow leopard individuals with their activity centre maps



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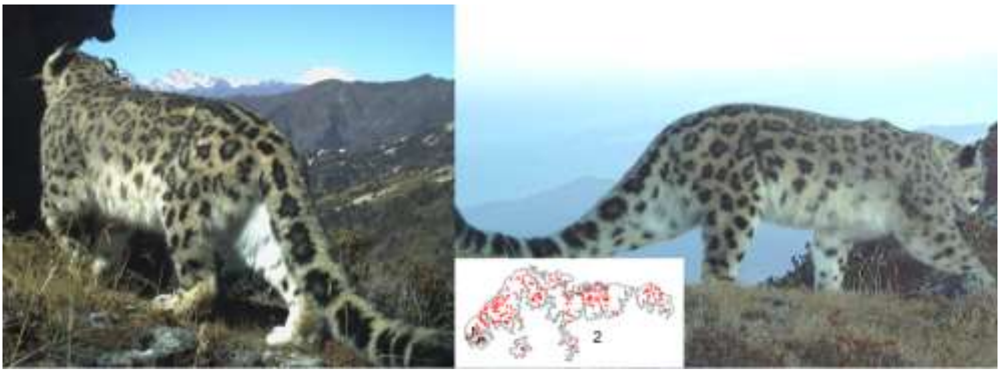

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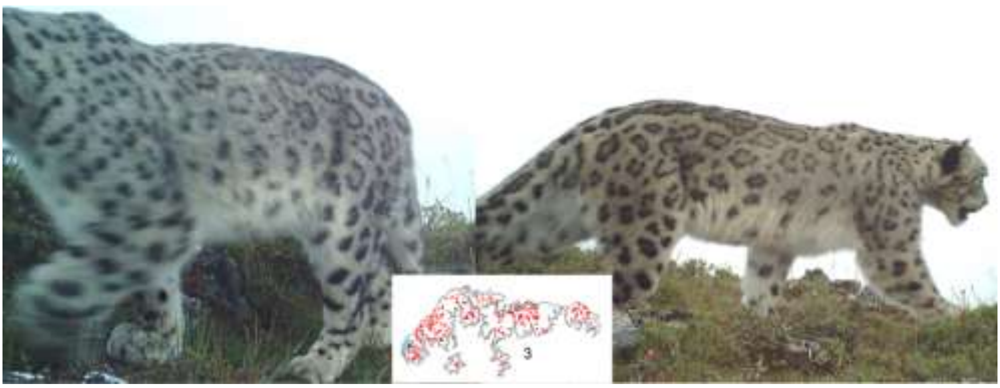

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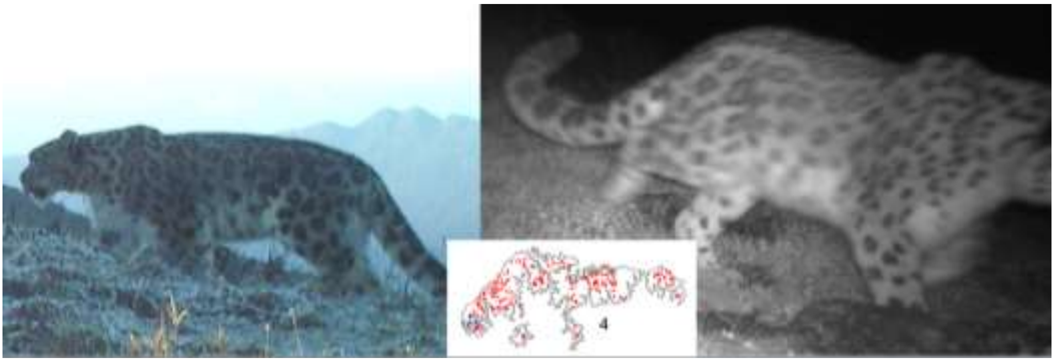

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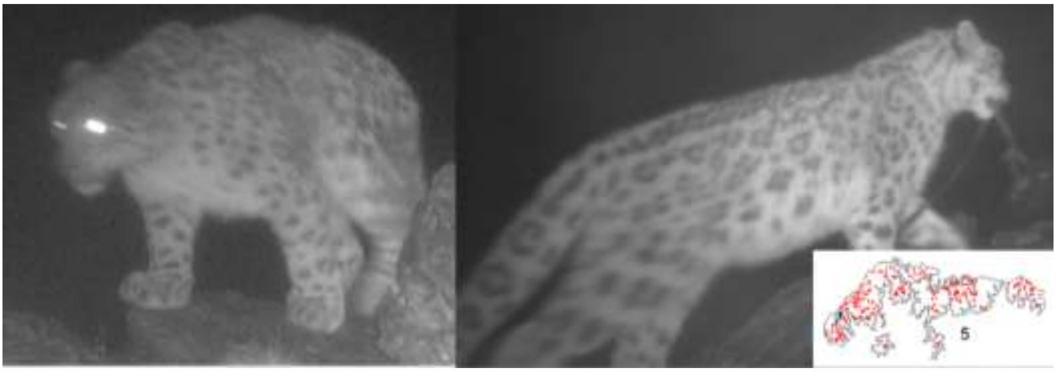

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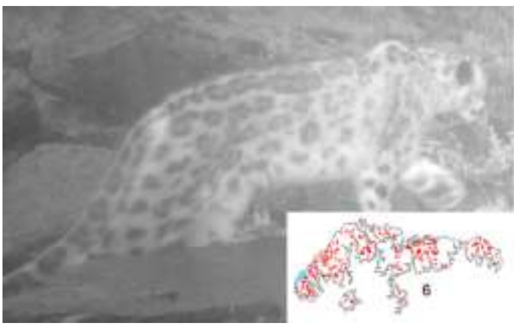

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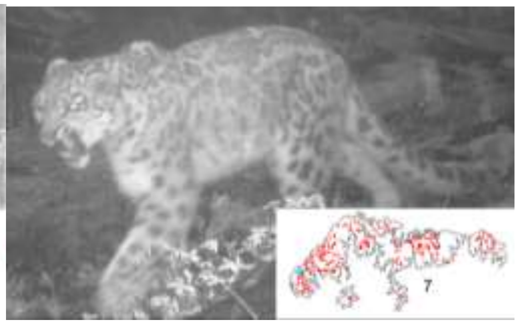

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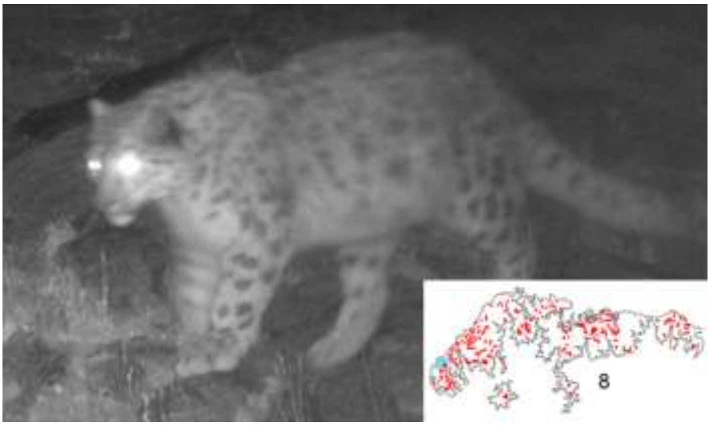

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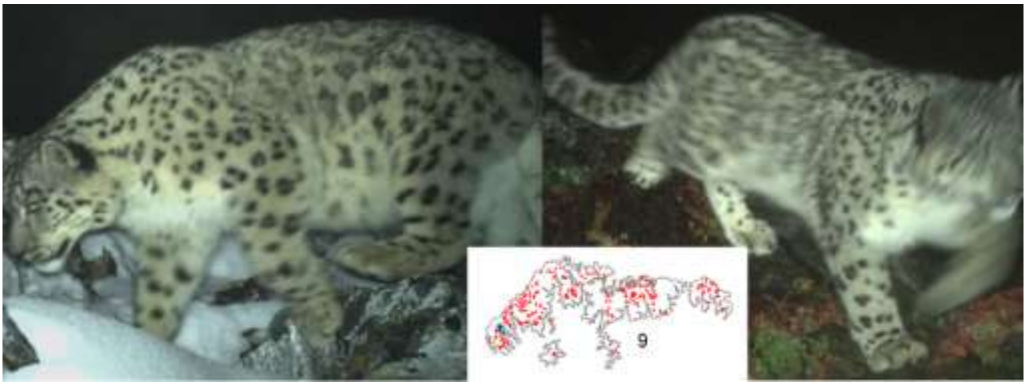

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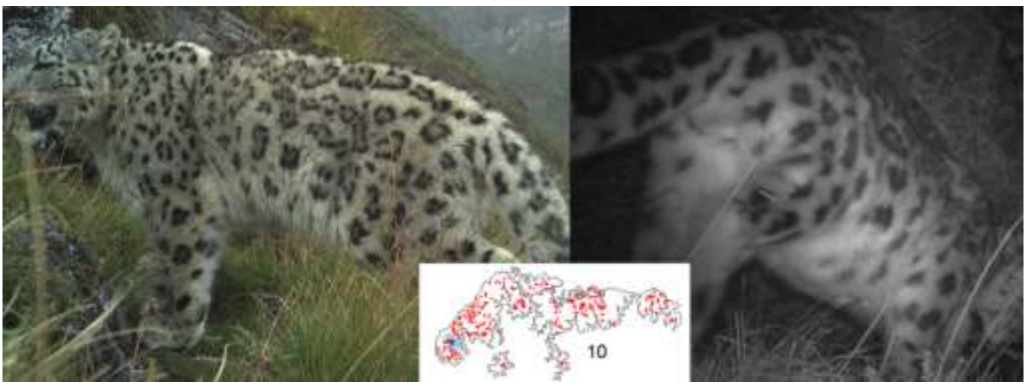

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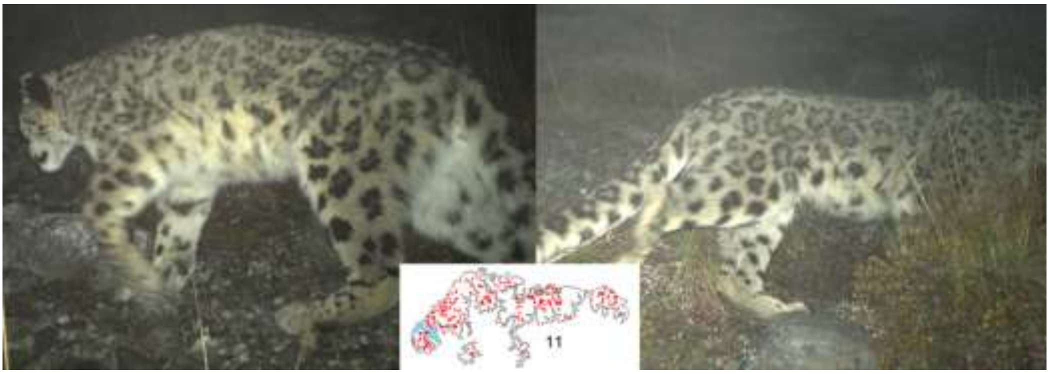

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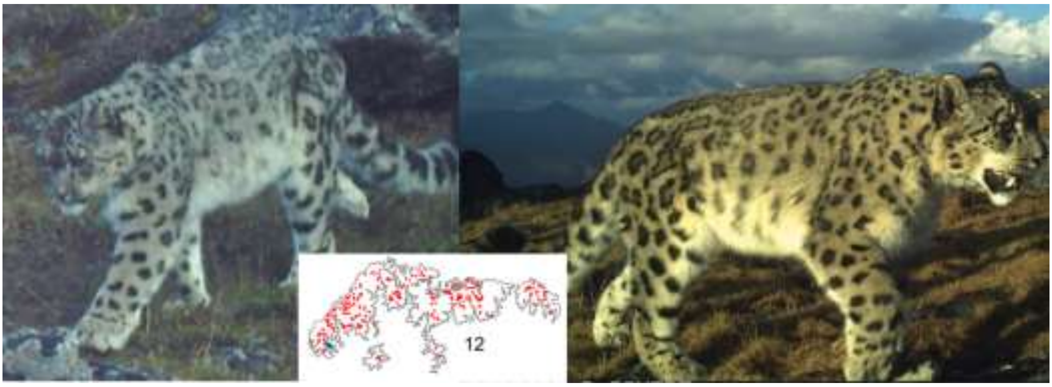

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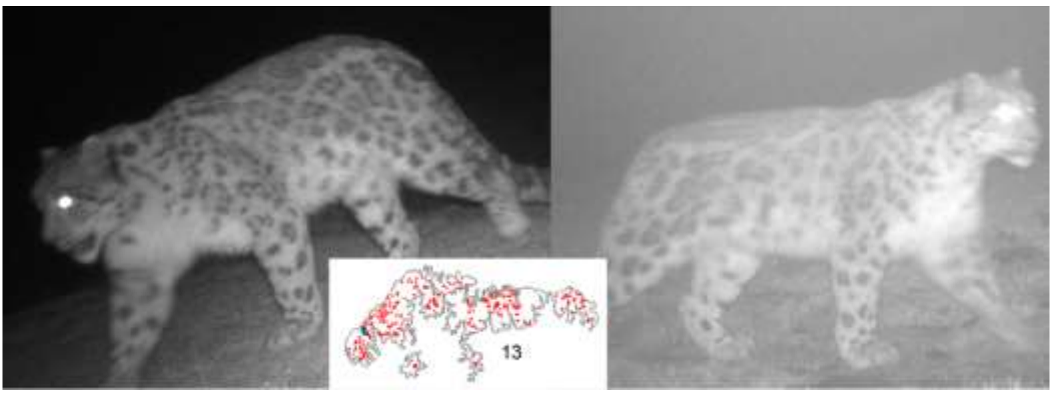

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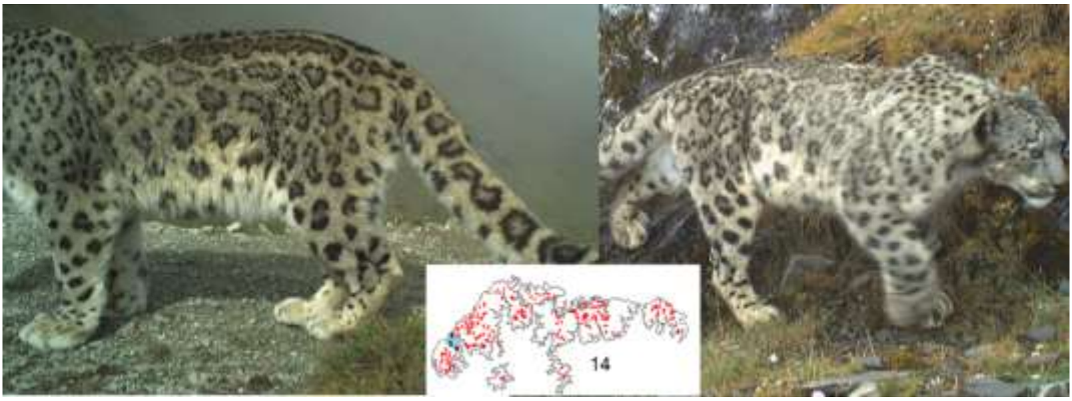

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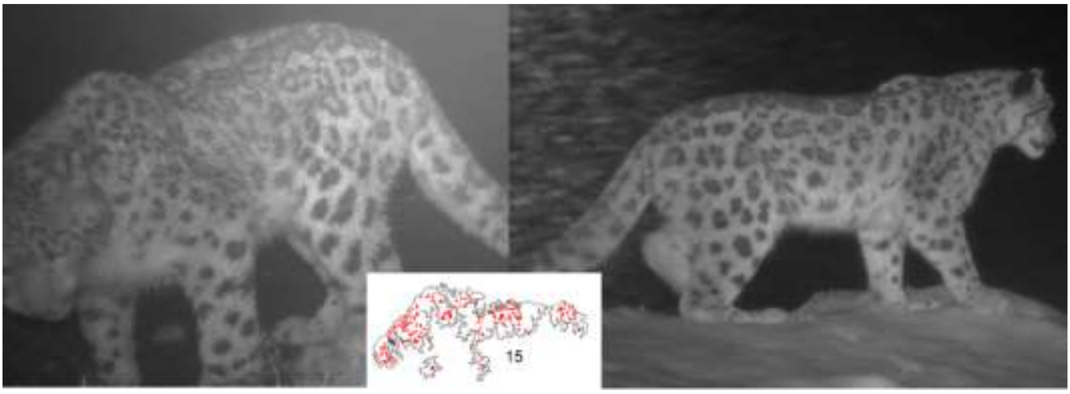

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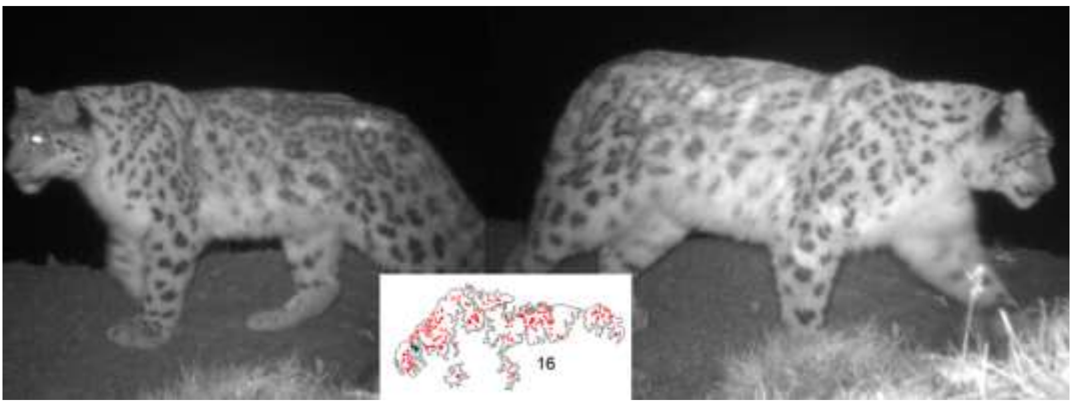

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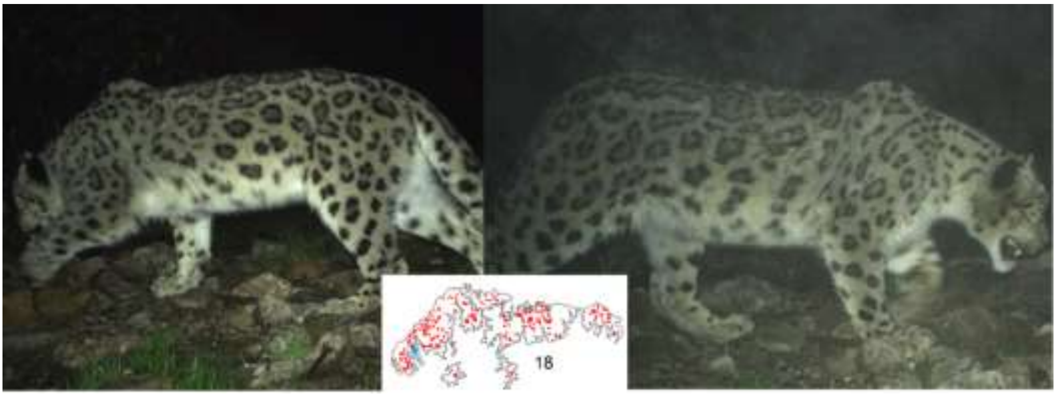

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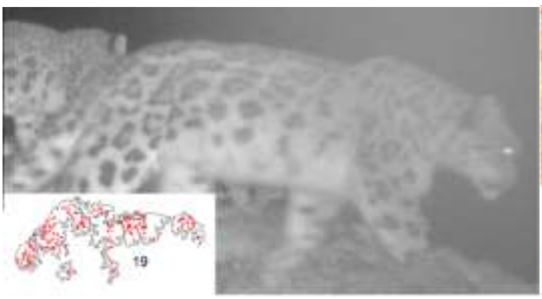

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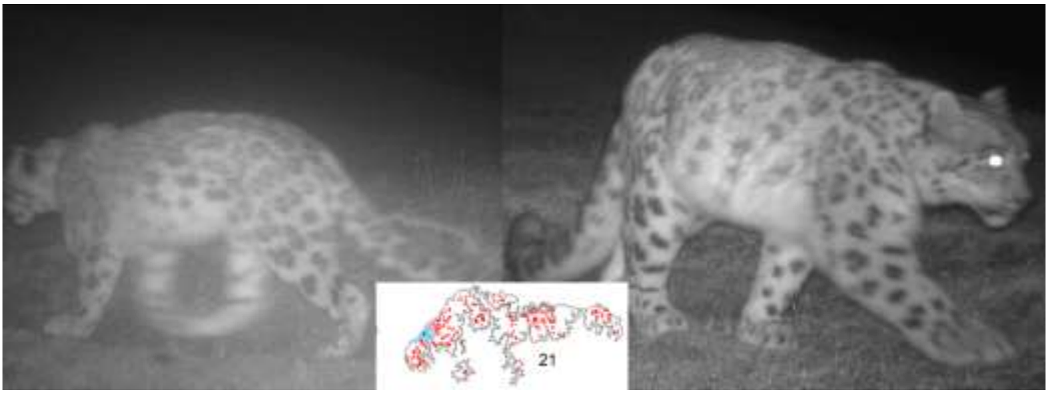

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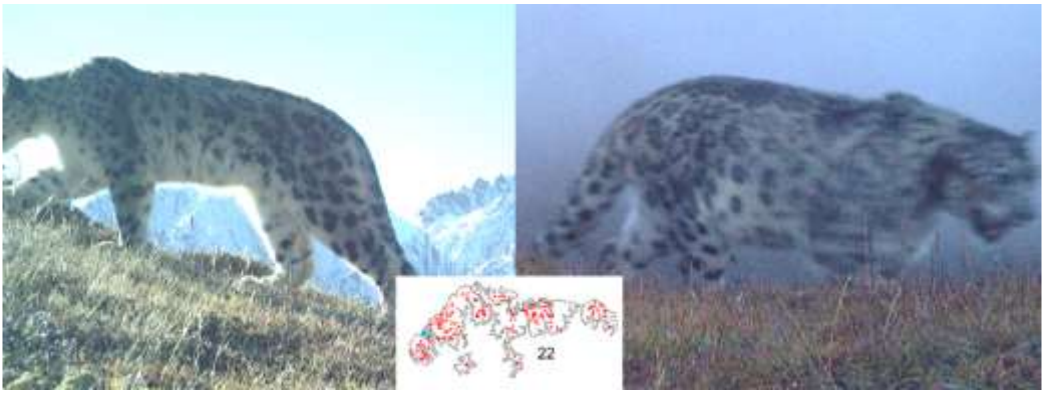

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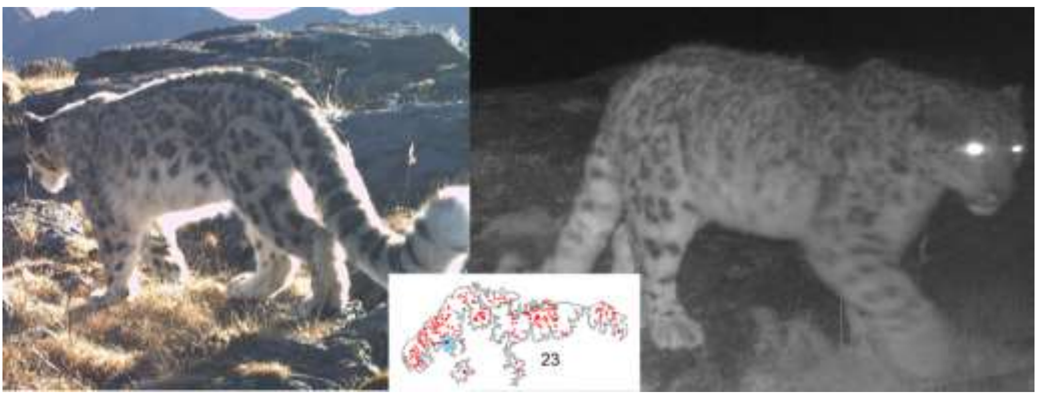

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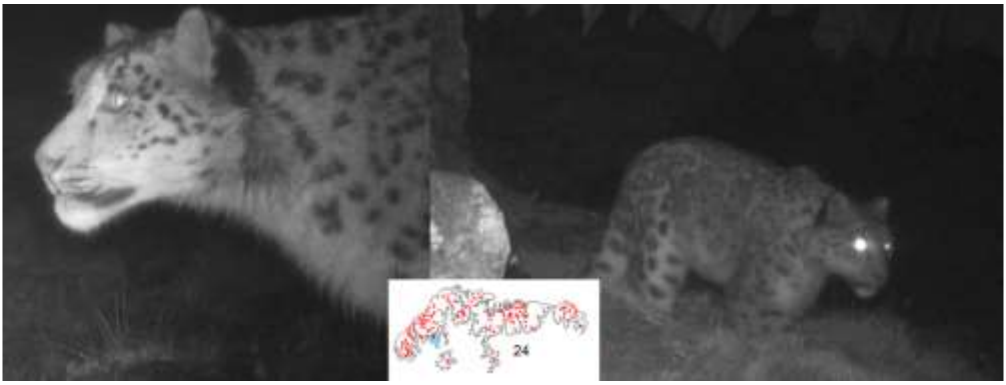

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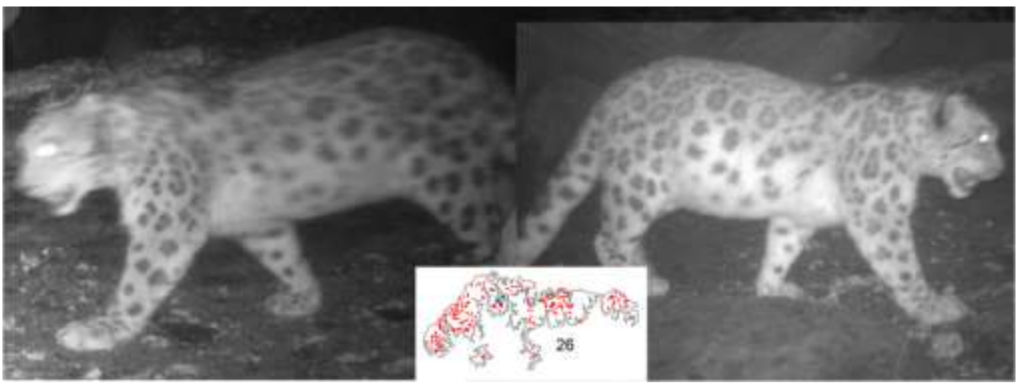

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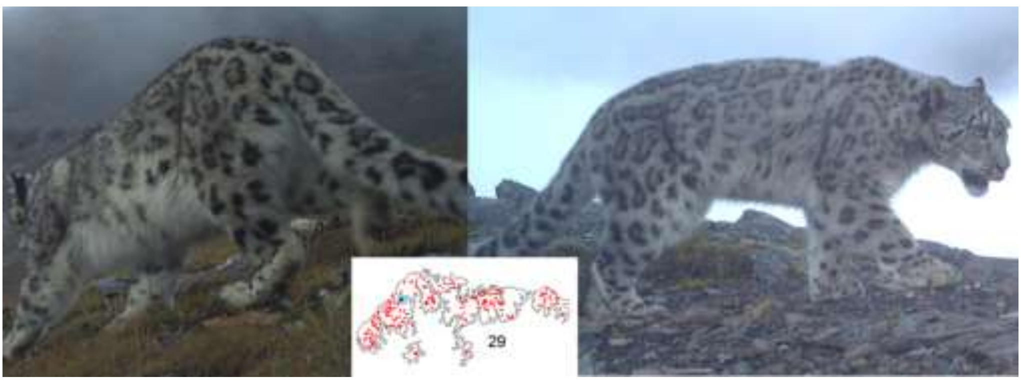
BSL_27

BSL_28



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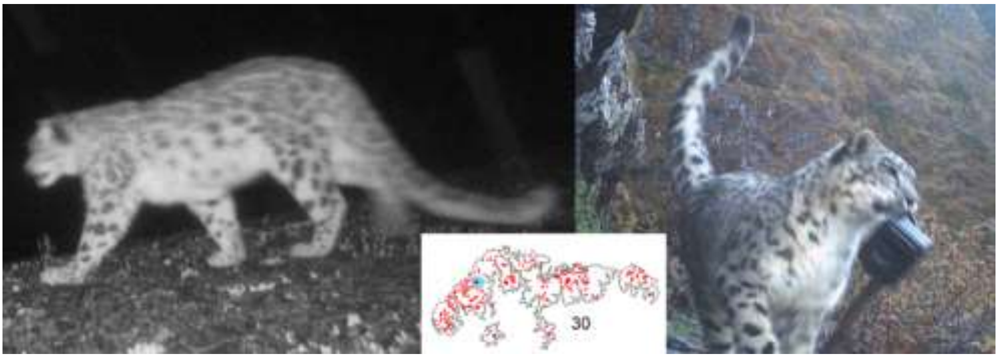

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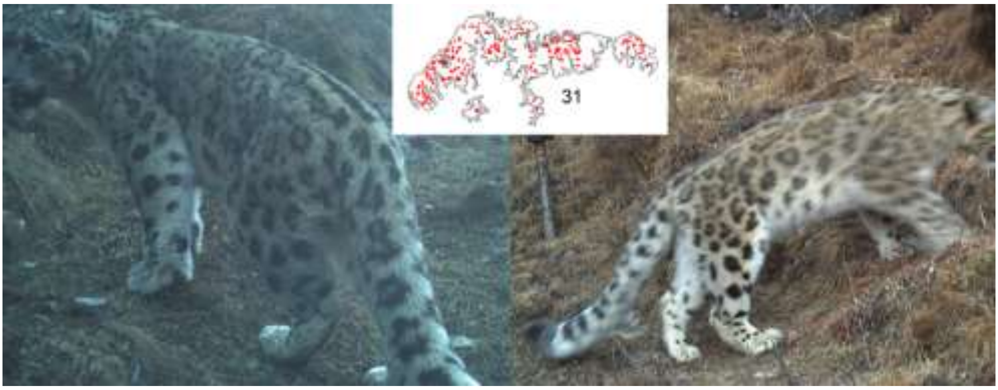

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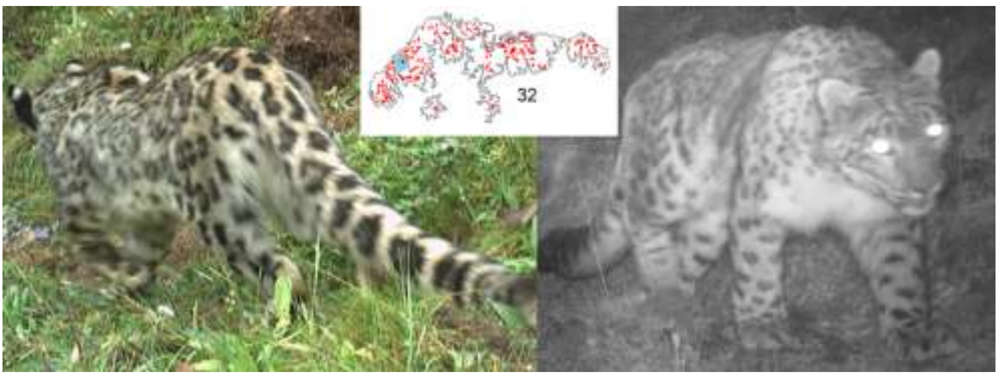

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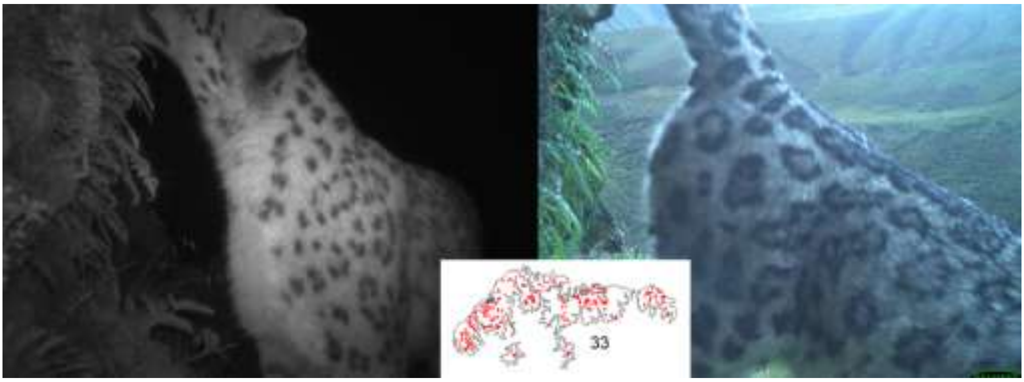

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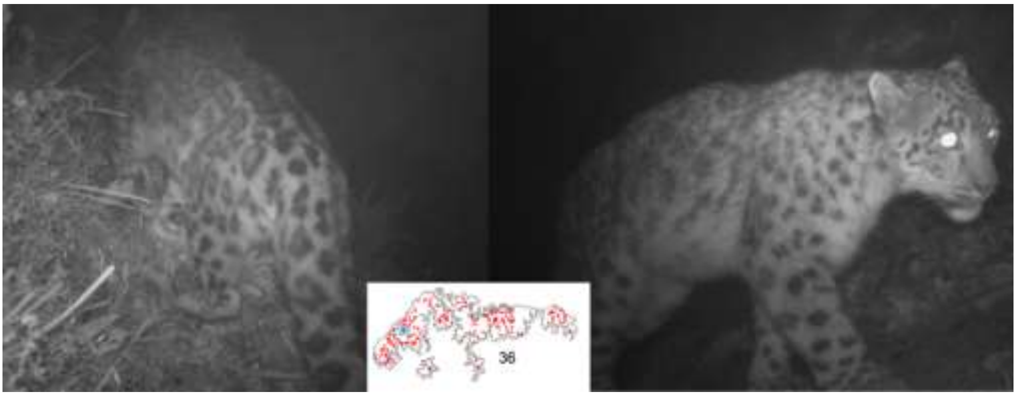

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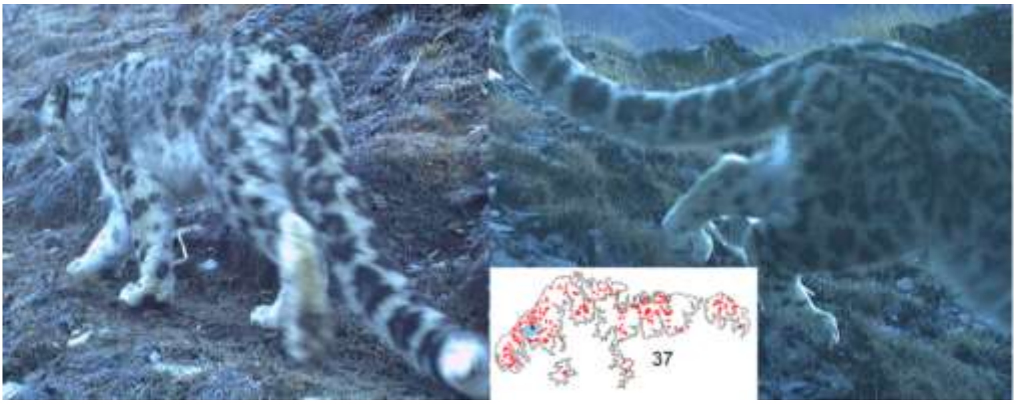

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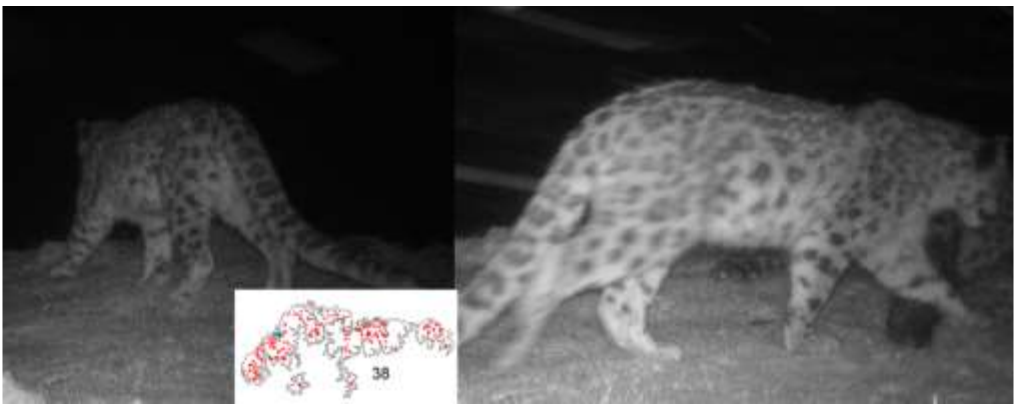

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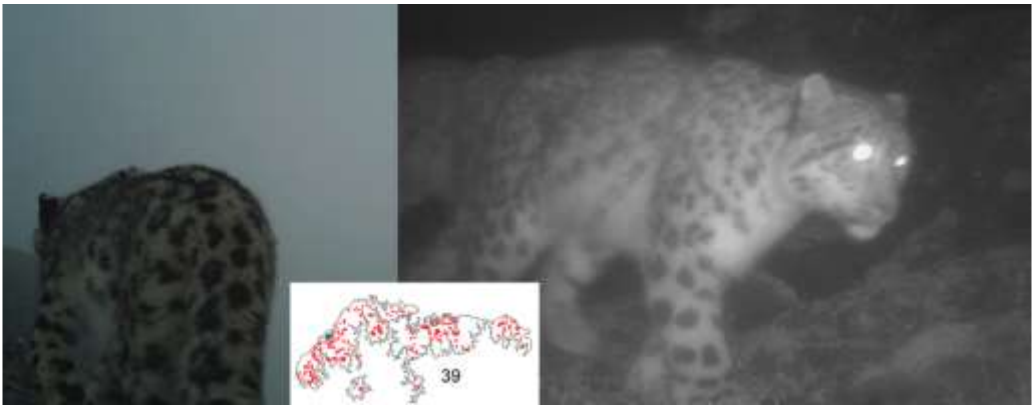

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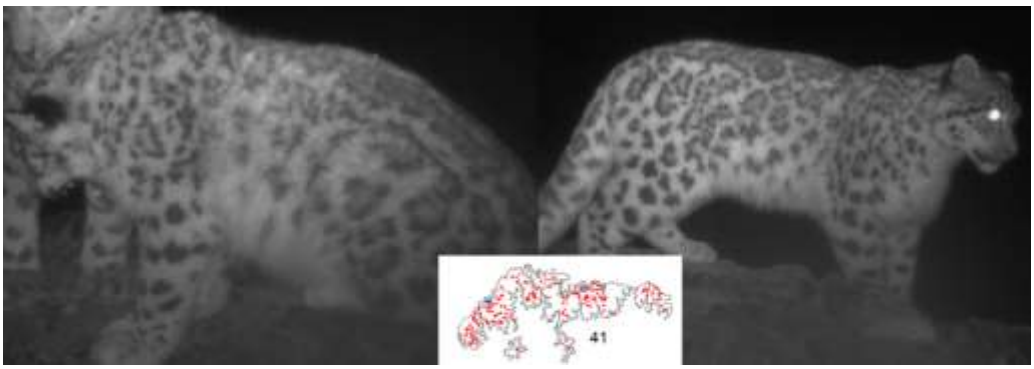

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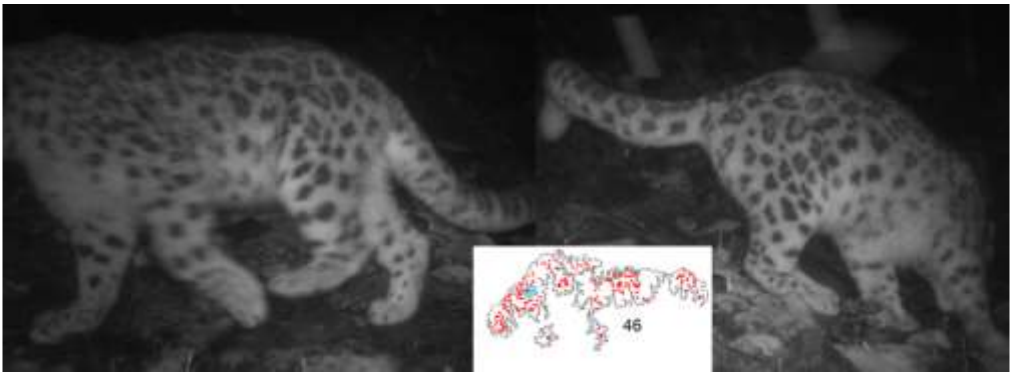

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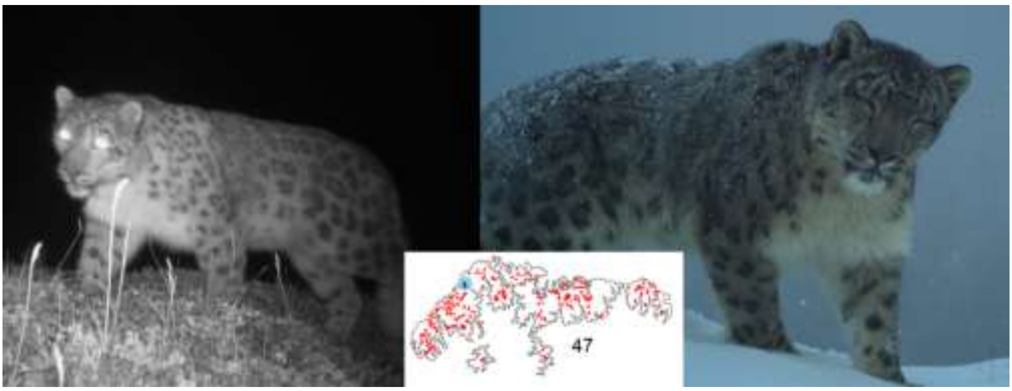

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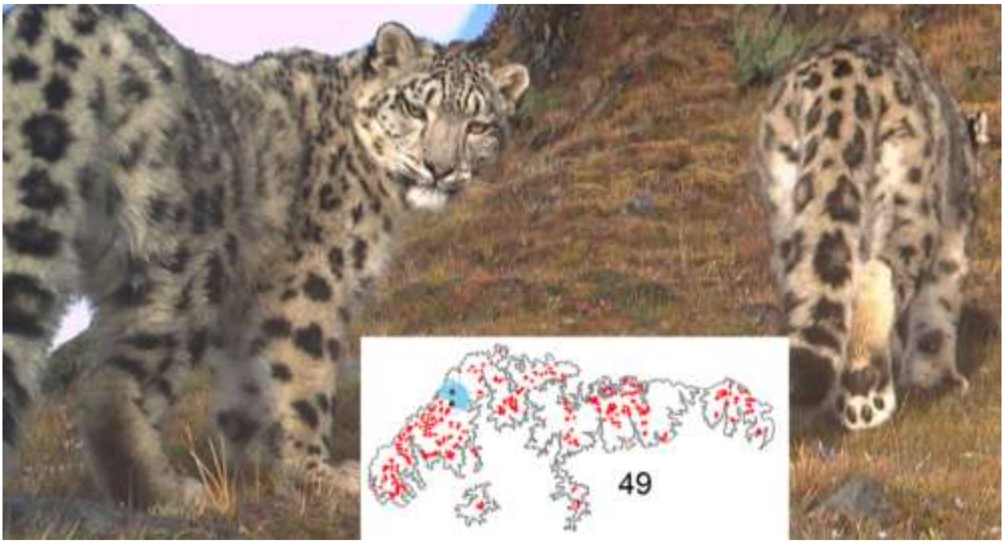

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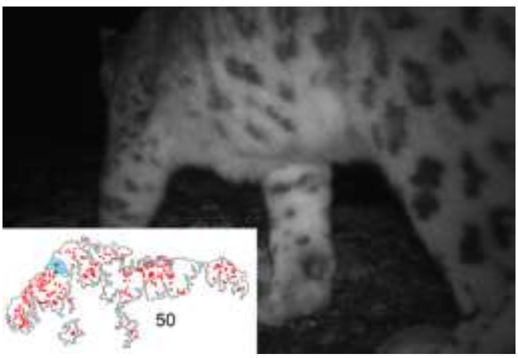

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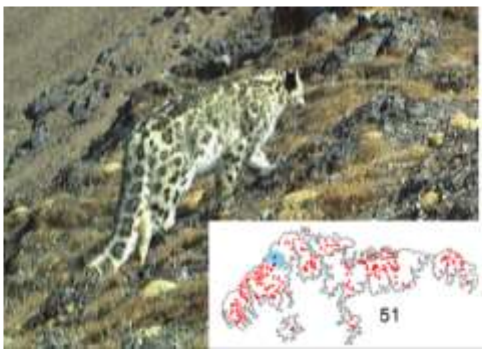

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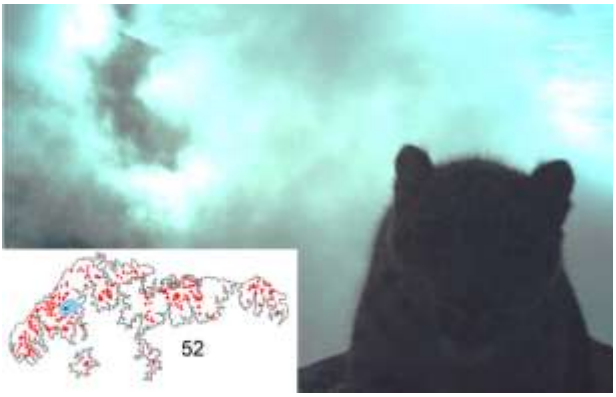

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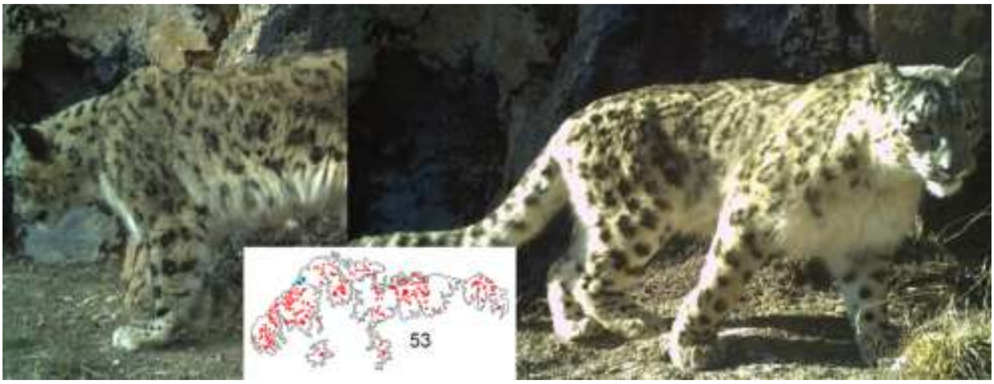

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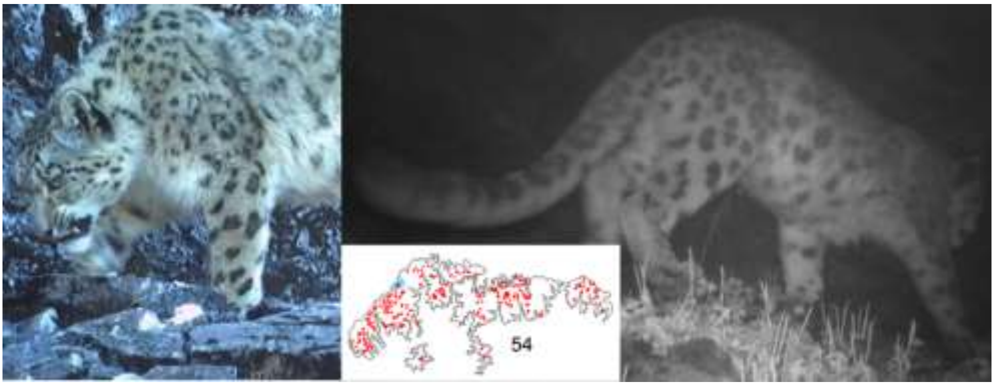

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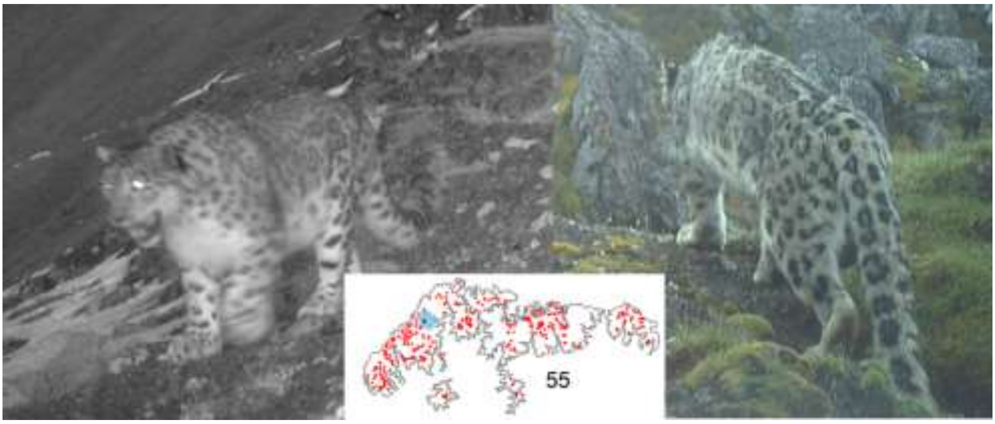

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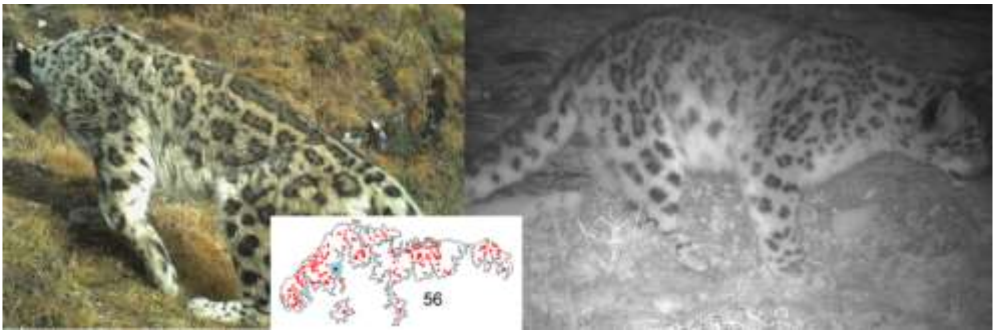

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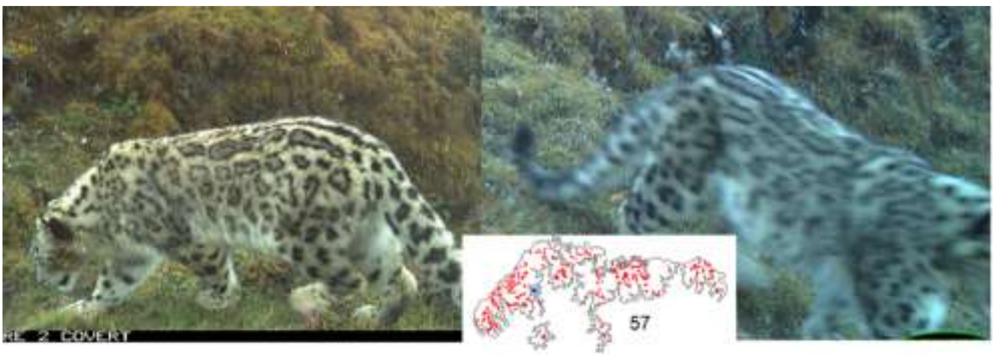

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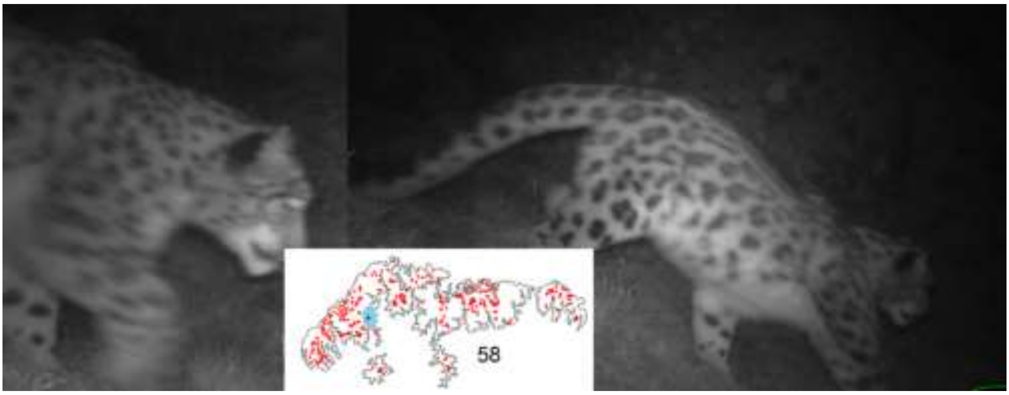

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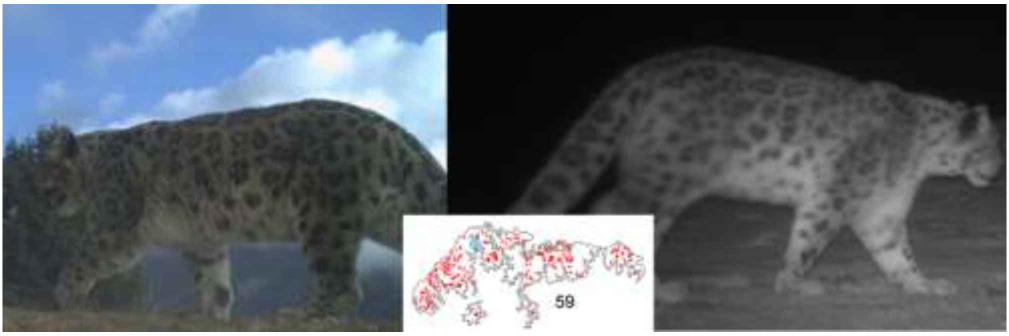

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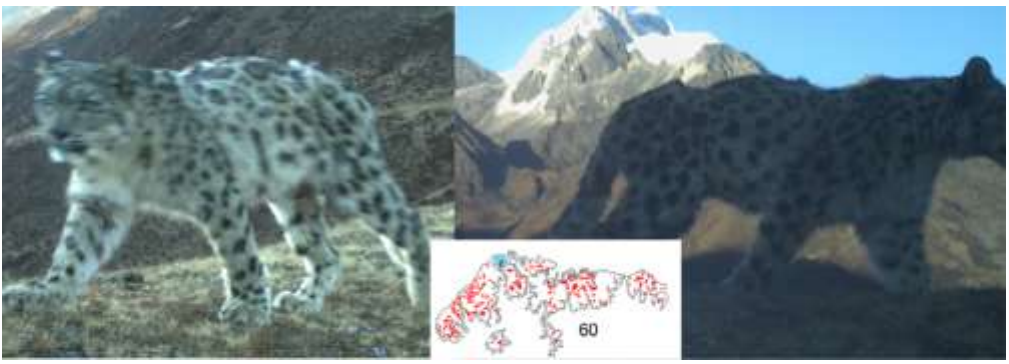

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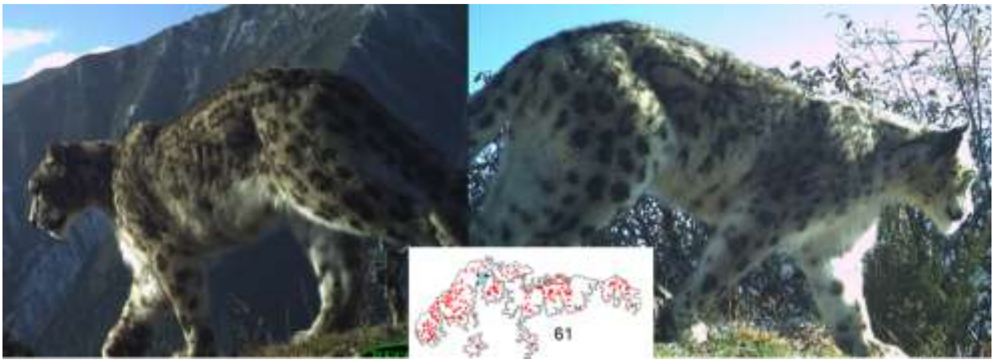

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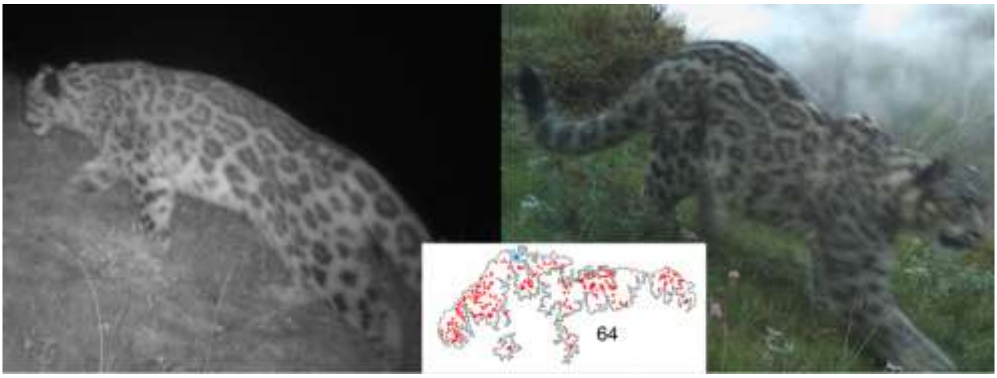
BSL_62

BSL_63



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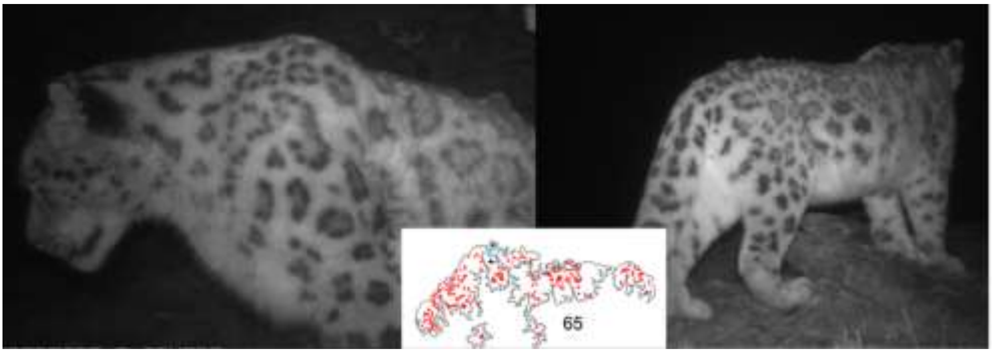

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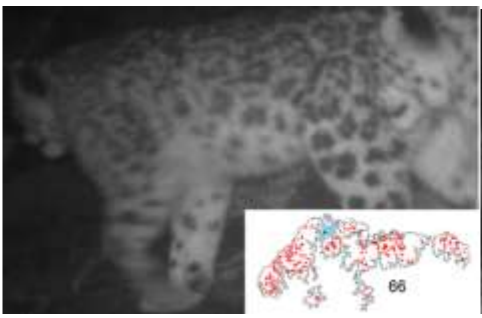

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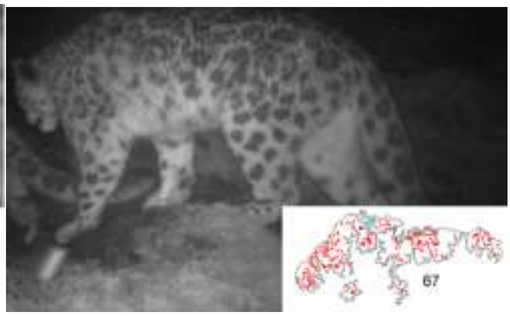

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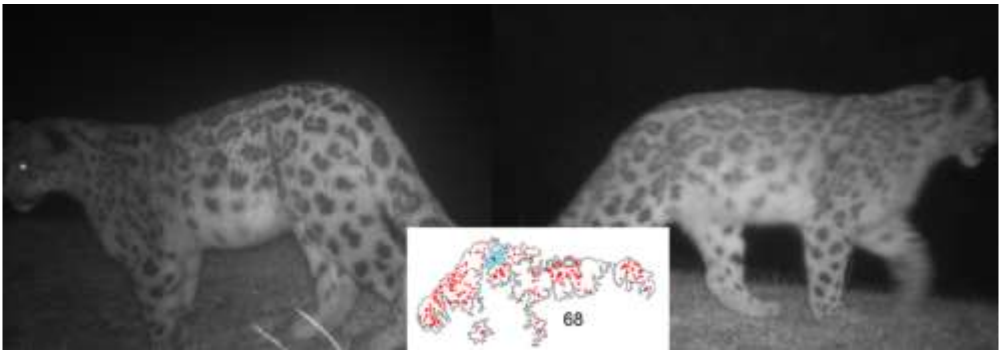

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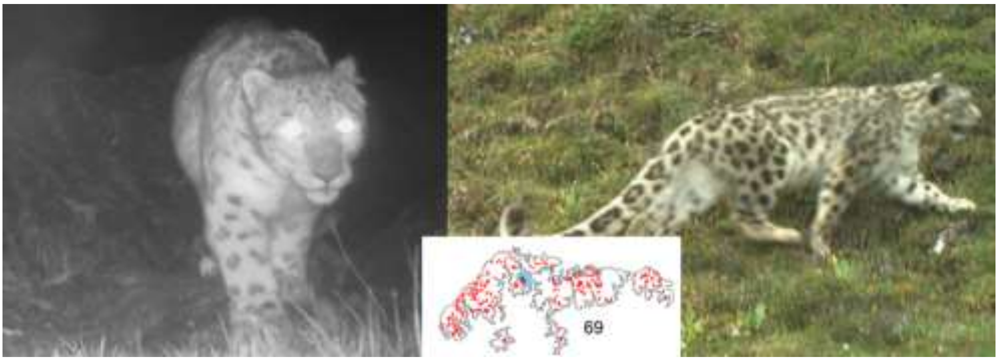

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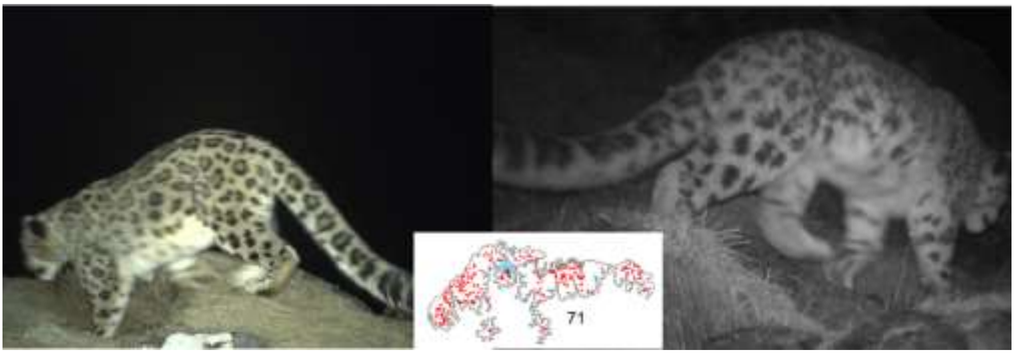
BSL_70



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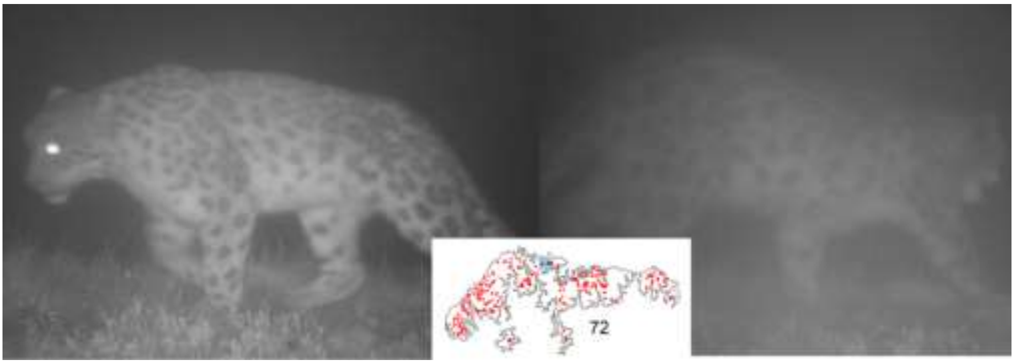

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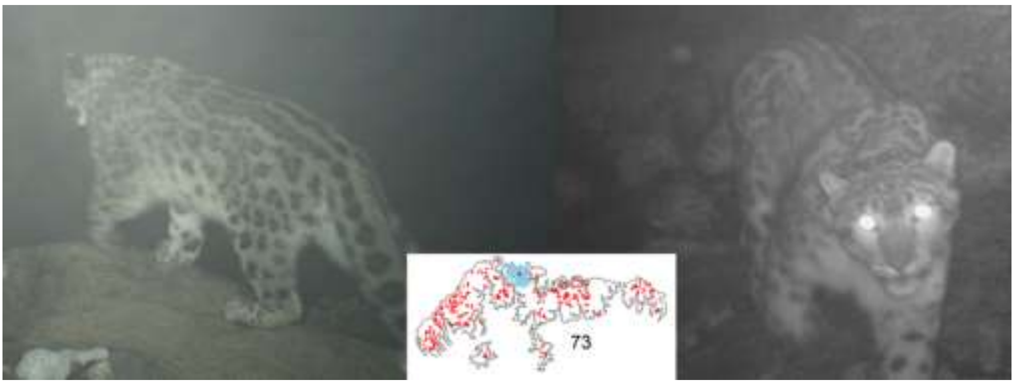

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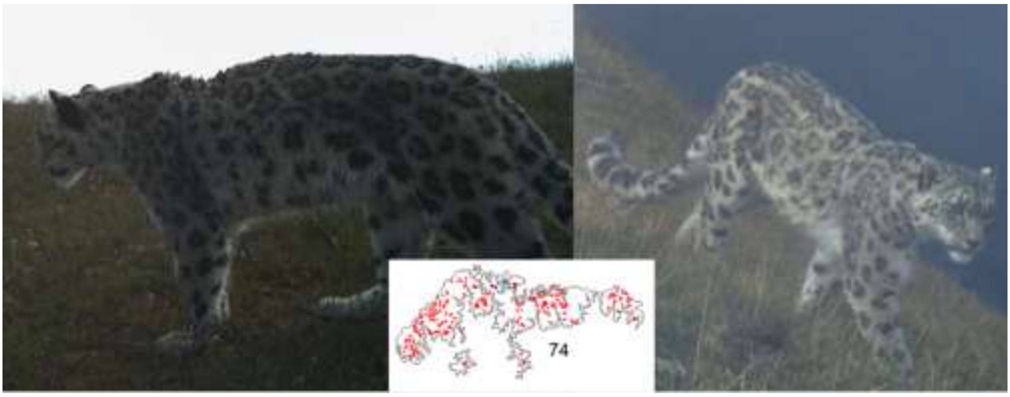

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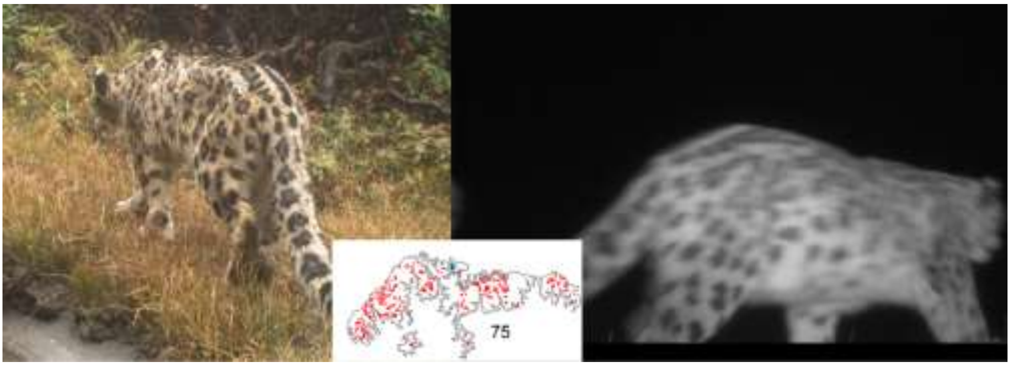

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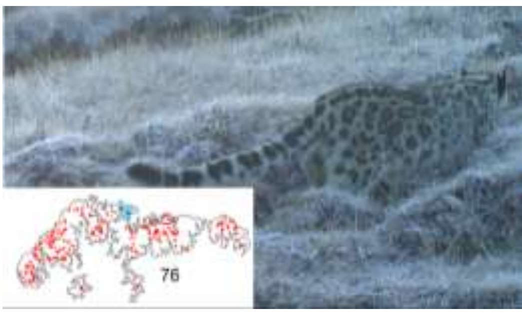

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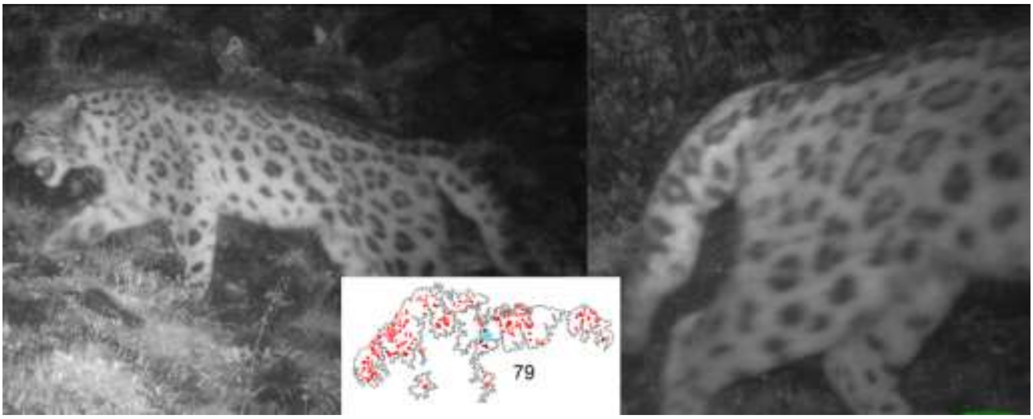
BSL_77

BSL_78



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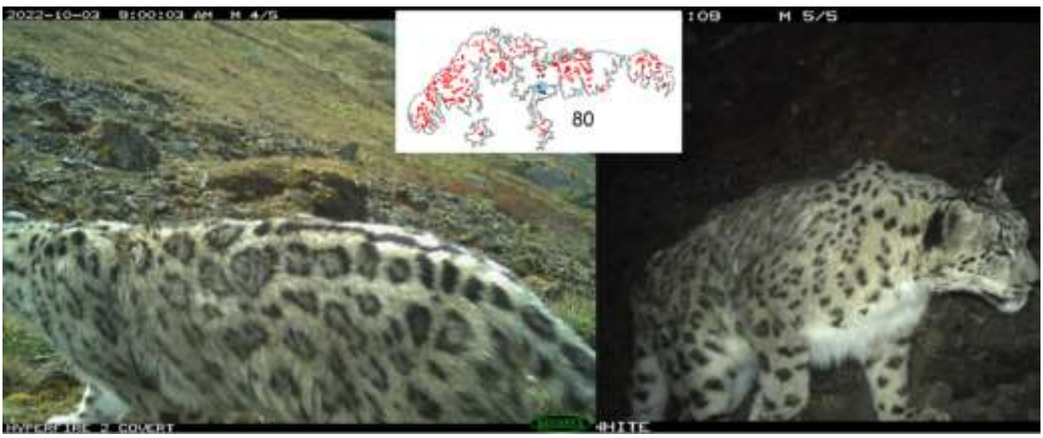

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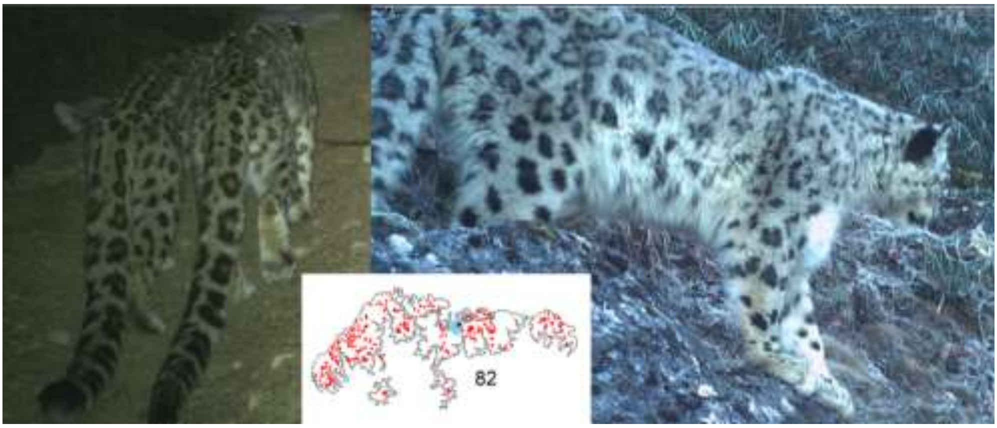

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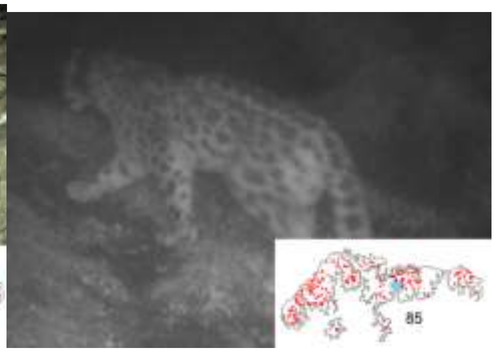
BSL_83

BSL_84



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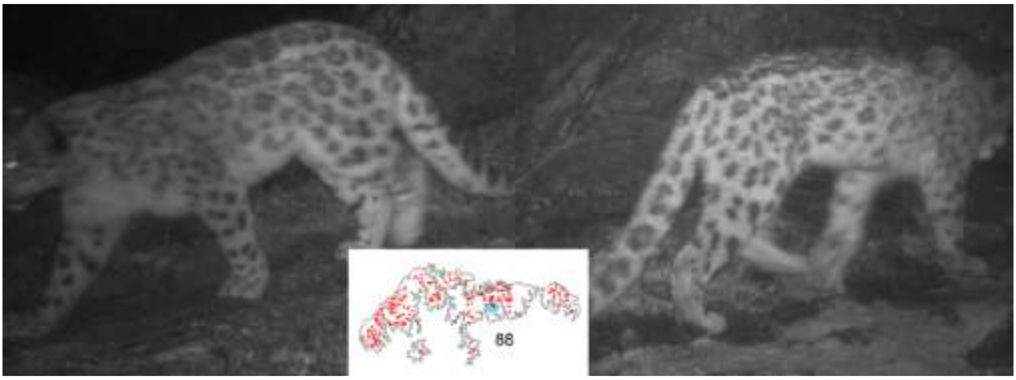
BSL_86

BSL_87



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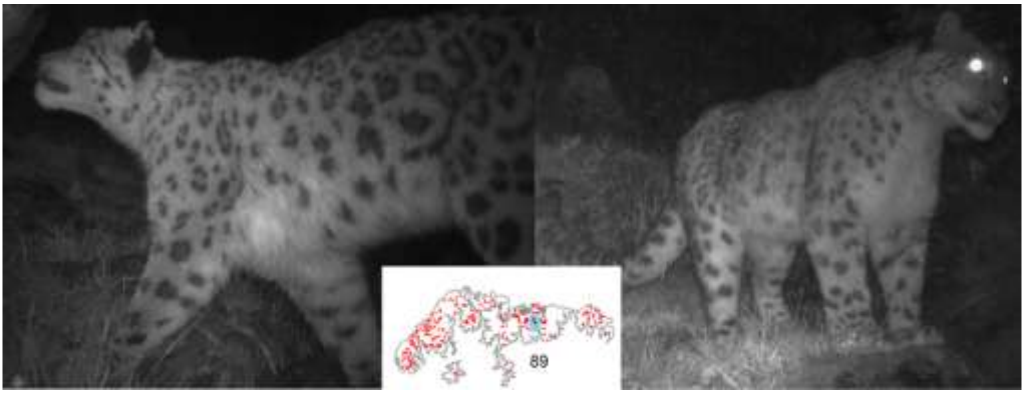

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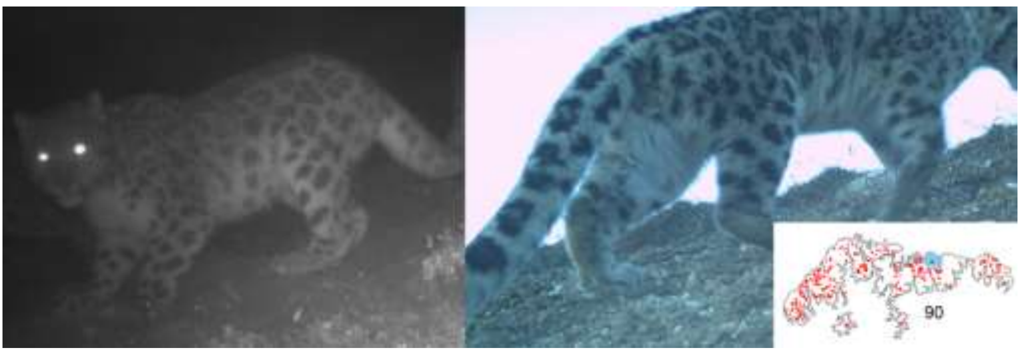

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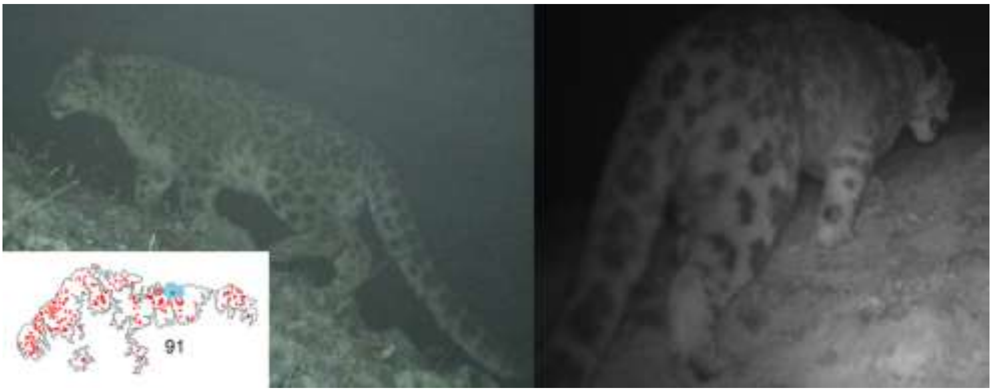

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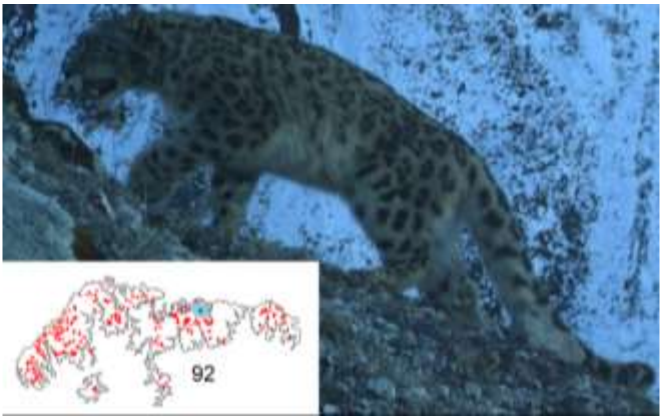

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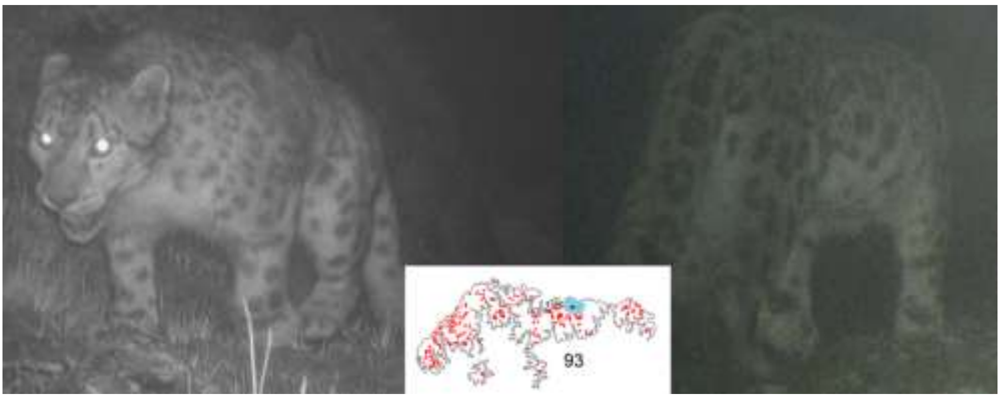

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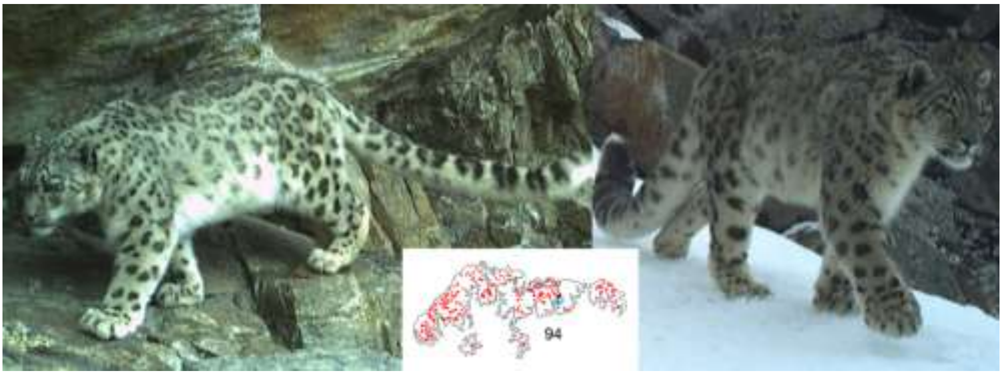

BSL_94

BSL_95

BSL_96

Appendix III: Carnivores co-occurring with snow leopard as captured during the survey

Tiger *(Panthera tigris)*

Common leopard *(Panther pardus)*

Asiatic golden cat *(Catopuma temminckii)*

Pallas's cat *(Otocolobus manul)*

Himalayan wolf (*Canis lupus chanco)*

Asiatic wild dog *(Cuon alpinus)*

Tibetan red fox *(Vulpes ferrilata)*

Yellow-throated marten *(Martes flavigula)*

Asiatic black bear *(Ursus thibetanus)*

Red panda *(Ailurus fulgens)*

Wolly flying squirrel *(Eupetaurus nivamons)*

Asian badger *(Meles leucurus)*

Appendix IV: National snow leopard survey teams

Team JDNP and JSWNP during the training workshop at Punakha

Team WCNP and BWS during the training workshop at Bumthang

Team JKSNR, DFO Thimphu and DFO Paro during the training workshop at Haa

Training opening session at Lamai Gompa, Bumthang, being graced by UWIFoRT Head Specialist

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