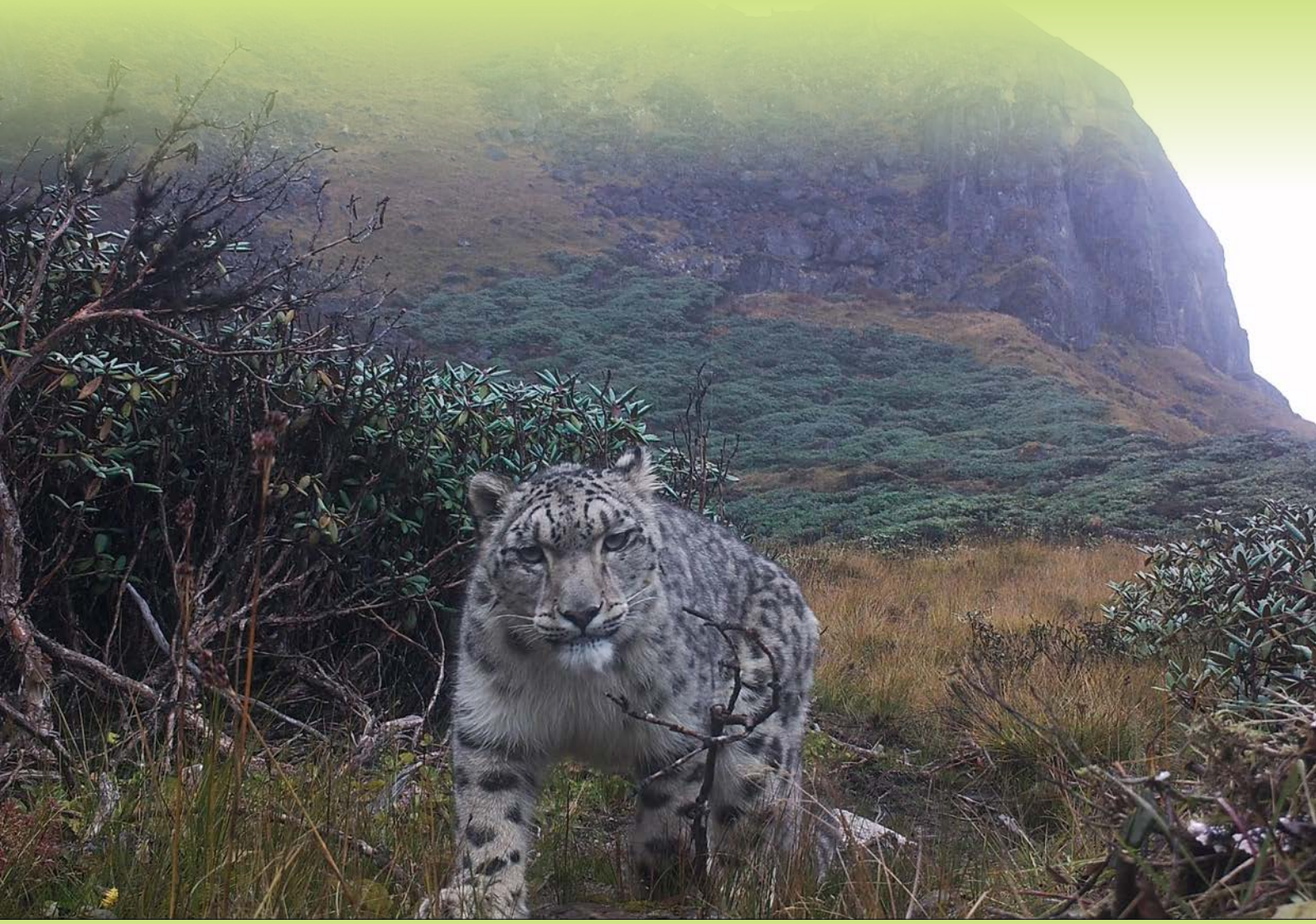
TECHNICAL REPORT

NATIONAL SNOW LEOPARD SURVEY OF BHUTAN 2014 – 2016

(PHASE II) : CAMERA TRAP SURVEY FOR POPULATION ESTIMATION



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Department of Forests and Park Services
Thimphu, Bhutan
August 2016

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Citation:

DoFPS. 2016. National Snow Leopard Survey of Bhutan 2014 – 2016 (Phase II): Camera Trap Survey for Population Estimation. Department of Forests and Park Services, Ministry of Agriculture and Forests, Thimphu, Bhutan.

Photo credits:

· National Snow Leopard Survey of Bhutan (Phase II): Camera Trap Survey 2015 – 2016

· Department of Forests and Park Services

Printed at:

Omega Traders, New Delhi

ISBN: 978 - 99936 - 817 - 8 - 6

DEDICATION

This technical report on National Snow Leopard Survey - Phase II: Camera Trap Survey for Population Estimation is dedicated to the jubilant celebration of the birth of His Royal Highness The Gyalsay Jigme Namgyel Wangchuck, “The Crown Prince of Bhutan”.

DEDICATION

In fond memories of Mr. Ratna of Wangchuck Centennial National Park who lost his life during the Phase II of the National Snow Leopard Survey.

Scouring the high mountains to look for sign and images of the rare and elusive snow leopard *Panthera uncia*, commonly known as the "Ghost of the High Mountains", is considered a very challenging task to many. In September 2015, when the intensive camera trapping exercise for the nation-wide surveys was mid way through in those areas, the Department lost a young forester, late Ratna Bahdhur Mongar, who had volunteered to traverse the most difficult terrain for setting up camera traps. The deceased from Wangchuck Centennial National Park was known among colleagues as a very cheerful and friendly person, and highly dedicated to his task. The Department in particular the snow leopard team will fondly remember his truly dedicated service.

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Ministry of Agriculture and Forests
Tashichhodzong
Thimphu : Bhutan

PREFACE

In the current millennium, the world is witnessing an unprecedented rate of habitat and biodiversity loss due to many anthropogenic influences. Consequently, conservation of biological resources, including wildlife, has become more challenging with additional threats from climate change which may have an adverse impact on the fragile mountain ecosystems of the Himalayas. Therefore, there has never been a more urgent need to take stock of the top iconic mountain predator, the snow leopard, which regulates alpine ecosystems by keeping in balance the populations of mountain ungulates. In due recognition of the tremendous ecological role of the snow leopard, delegates of the twelve Asian countries convened in 2013 at Bishkek, Kyrgyzstan, and solidified their strong commitment to conserve this dwindling predator vide the "Bishkek Declaration 2013".

Bhutan has been very fortunate to have been inhabited by the magnificent snow leopard that coexists with a suite of remarkable carnivores and their prey species in the alpine ecosystems. The presence of this endangered predator was confirmed in most of the northern protected areas, but except in Jigme Dorji National Park and Wangchuck Centennial National Park, no concrete evidences were gathered from rest of the areas. As such, there was no nationally consolidated and reliable estimate of snow leopard abundance in the country, and thereby pragmatic snow leopard management plan could not be prepared.

Amazingly, the critical conservation partners such as the World Wildlife Fund – Bhutan Programme, Bhutan Trust Fund for Environmental Conservation, the World Bank-International Development Agency and the Nature and Biodiversity Conservation Union came forward to support the Royal Government's initiative such as this nationwide survey of snow leopard. To all these donors and partners, I extend my heartfelt gratitude and appreciations. I also acknowledge the hard work and sacrifices put in by our dedicated core team members and field staffs who gave their heart and soul towards this daunting project "National Snow Leopard Survey of Bhutan 2014-2016".

I have many reasons to rejoice from the successful completion of this first ever scientific venture. First, I am glad to proclaim that Bhutan is first among the 12 snow leopard range countries to have conducted a nationwide survey of snow leopard. Second, I am very pleased to know that Bhutan has 96 individuals of snow leopard, a number that epitomizes our government's strong national will in strengthening the legacy of our Beloved Monarchs to conserve nature. Third, I am impressed by the fact that this study was conducted by a team of Bhutanese professionals, yet again providing our national capacity to conduct large-scale scientific studies, in addition to the National Tiger Survey of Bhutan 2014-2015.

Further, I am optimistic that results from this nationwide survey report will have far-reaching impacts in the lives of our people. The first conservation step resulting from the survey will be to draft a snow leopard landscape conservation plan which will comprehensively include measures to conserve viable populations of snow leopard and their prey while mitigating negative impacts on people's livelihoods and sustenance. This in turn will be a landmark achievement of the global initiative to 'Conserve 20 snow leopard landscapes by 2020'.

(Yeshey Dorji)
MINISTER

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Ministry of Agriculture and Forests
Department of Forests & Park Services

FOREWORD

Bhutan's highland ecosystems are adorned by the presence of the magnificent snow leopard. Unfortunately, this marvellous cat species is being threatened across its distributional range by habitat degradation, prey depletion, conflicts with humans, and climate change.

In the face of increasing threats to snow leopard conservation, we are fortunate to sustain a sizeable number of this rare and elusive species, and the credit goes to the overwhelming support of the Royal Government of Bhutan, conservation partners, donors, and the extraordinarily dedicated team of forestry professionals, particularly the frontline field staffs. I join our honourable minister in thanking the donors, key collaborators, and the forestry staff for their concerted efforts to save this charismatic cat from facing extinction.

As far as Bhutan is concerned, our national snow leopard conservation program is guided by the "National Snow Leopard Ecosystem Protection Programme 2013-2018". One of the key components of this programme was to establish reliable baseline information about snow leopard in line with which the Department of Forest and Parks Services ventured into a nationwide snow leopard survey, which was partitioned into two phases: Phase I – sign and prey base survey, and Phase II – camera trap survey for population estimation. The first ever National Snow Leopard Survey has generated large amount of data which could be used for management and monitoring of snow leopard and blue sheep, its principal prey. The survey is not only exemplary and astounding in revealing many unknown facts, but also a great testimony to our collective conservation success.

In this regard, I congratulate the Wildlife Conservation Division of our department for appropriately coordinating and facilitating this huge scientific task, right from survey coordination to data analysis and ultimate publication of this report.

(Phento Tshering)
DIRECTOR

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Ministry of Agriculture and Forests
Department of Forests & Park Services
WILDLIFE CONSERVATION DIVISION

"Managing Bhutan's Natural Heritage"

ACKNOWLEDGEMENT

Firstly, I would like to congratulate all members of the national snow leopard survey for successfully completing this mammoth nation-wide level survey with full dedication. Support rendered throughout the survey by field protected areas office is immensely appreciated. This survey would not have been possible without the unconditional dedication of the field staffs who were involved in the survey. I, on behalf of the project management, would like to sincerely thank all the survey members for their collective professionalism and contributions.

Through the series of national level camera trap surveys, firstly the tiger survey and now completing this snow leopard survey, the capacity of the field staff has greatly strengthened. It is hoped that in the near future, the field offices will be in good position to coordinate such nation-wide surveys with much greater coordination by building on past experiences.

Through this report, snow leopard population estimates and their distribution are known for Bhutan. With such a baseline data from national sign and camera trap survey, there are yet more to be accomplished in order to ensure Bhutan continues to harbour viable breeding populations of snow leopard. Guided by the national snow leopard ecosystems protection program (2013-2018) and with these baseline information established, the bigger task ahead now is to develop the country's landscape species conservation plan.

Lastly, I take this opportunity to join our honourable minister and director in thanking our conservation partners and donors for their generous support for national snow leopard survey, particularly the World Bank's International Development Association (WB-IDA), the World Wildlife Fund (WWF), the Nature And Biodiversity Conservation Union (NABU) and the Bhutan Trust Fund for Environmental Conservation (BTFEC). The former Director General is also highly acknowledged for his support.

(Sonam Wangchuk)
CHIEF OF WILDLIFE

EXECUTIVE SUMMARY

The snow leopard (*Panthera uncia*) is a top predator and a flagship species for the alpine ecosystems. In recognition of its endangered status, this rare cat species receives maximum protection. It is listed in Appendix I of CITES and Schedule I of the Forest and Nature Conservation Act of Bhutan 1995.

In Bhutan, snow leopard conservation is guided by the National Snow Leopard Ecosystem Protection Programme (NSLEP). In line with this programme, the Royal Government of Bhutan authorized the National Snow Leopard Survey of Bhutan (2014-2016) project which was divided into two phases. In the Phase I, prey base and sign surveys were accomplished while in the Phase II, camera trap survey was conducted to estimate snow leopard population. Both these nationwide surveys were conducted by a team of Bhutanese professionals as in the National Tiger Survey of Bhutan 2014-2015.

Recognizing the highly cryptic nature of the snow leopard, a method to maximize detection probability was employed wherein latest models of camera traps were stationed in survey grids with highest likelihood of snow leopard capture determined during the Phase I survey. The field survey crew was carefully selected and thoroughly trained in camera handling, stationing, monitoring and retrieval. They were also trained in data management, individual identification, and building capture histories. The spatially-explicit capture-recapture (SECR) model using the Bayesian approach and the package 'SPACECAP' in R programme was employed to analyze the capture-recapture data for estimating snow leopard abundance and density.

In a 90-day sampling period using 202 trap stations and 404 camera traps, 63 individuals of snow leopards were identified, and the SECR model yielded 96 (SE ± 8) individuals with an the estimated abundance range of 79 to 112 individuals (95% confidence interval). The estimated density for the whole country was 1.08 (SE ± 0.09) individuals per 100 km^2. The largest density of 6.1 individuals per 100 km^2 was estimated in Jigme Dorji National Park. The Programme PRESENCE yielded estimated snow leopard occupancy of 43.25% (SE ± 4.09).

Going by the estimated population and density, Bhutan is indisputably a stronghold for snow leopard conservation in the Eastern Himalayas. Bhutan is also the first country among the 12 snow leopard range countries to have conducted a nationwide survey of snow leopard. This historic survey has revealed Jigme Khesar Strict Nature Reserve and northern part of Paro Territorial Forest Division as the new areas of snow leopard occurrence in Bhutan. Potentials for snow leopard reintroduction exist in Bumdeling Wildlife Sanctuary and Sakteng Wildlife Sanctuary, both situated in the east.

Several policy and management recommendations are offered which will ensure maximum survival of snow leopard in the country. The most urgent activity to be pursued immediately after this nationwide survey is rigorous patrolling and surveillance in the snow leopard range areas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AIC	Akaike Information Criterion
BTFEC	Bhutan Trust Fund for Environmental Conservation
BTSL	Bhutan Snow Leopard
BWS	Bumdeling Wildlife Sanctuary
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DEM	Digital Elevation Model
DoFPS	Department of Forests and Park Services
G	Grid
GIS	Geographical Information System
IDA	International Development Assistance
IUCN	International Union for Conservation of Nature
JDNP	Jigme Dorji National Park
JKSNR	Jigme Khesar Strict Nature Reserve
M.a.s.l	Meters above sea level
MOAF	Ministry of Agriculture and Forests
NABU	Nature and Biodiversity Conservation Union
NSB	National Statistical Bureau
NSLEP	National Snow Leopard Ecosystem Protection Programme
NSLSB	National Snow Leopard Survey of Bhutan
PTFD	Paro Territorial Forest Division
SECR	Spatially-explicit capture-recapture
SWS	Sakteng Wildlife Sanctuary
WB	World Bank
WCD	Wildlife Conservation Division
WCNP	Wangchuck Centennial National Park
WWF	World Wildlife Fund

Chapter 1

INTRODUCTION

1.1. Conservation significance and status

The endangered snow leopard (*Panthera uncia*) is globally recognized as a top predator and an ecological indicator of the alpine ecosystem. It is popularly known to be highly elusive because of sparse distribution and inhabiting highly rugged terrains that are mostly inaccessible to humans. Currently, this rare cat is known to be distributed across twelve Asian countries: Afghanistan, Bhutan, China, India, Kazakhstan, Krygz Republic, Mongolia, Nepal, Pakistan, Russia, Turkmenistan, and Uzbekistan.

In Bhutan, the snow leopard is known by different local names, such as *gangzig*, *chenzig*, *chenggu* and *tsagay*. It is found in the northern alpine ecosystems, right from Jigme Khesar Stricture Nature Reserve (JKSNR) in the west to Wangchuck Centennial National Park (WCNP) in the east-central part. Although, it is generally revered as an icon of the snow-capped mountains, it often comes into conflict with humans due to its predation of livestock (mostly calves).

Because of its highly elusive nature, snow leopards are hard to study, and the conventional sign-based surveys may yield unreliable estimates. Although, waiting to be substantiated, the global snow leopard population is estimated between 4,080 and 6,590 (Thinley *et al* 2015). Currently, there is limited information available on snow leopard ecology, and distribution in Bhutan (Thinley *et al* 2015). Until the current nationwide survey, the official records of snow leopard presence were based on the park-wide surveys in Jigme Dorji National Park (JDNP) and WCNP (Shrestha & Tenzin 2015) which revealed the occurrence of 21 and 15 individuals respectively.

Like tiger (*Panthera tigris*), this endangered cat also receives one of the highest global legal protections through national and international legislations. For instance, it is listed under the Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In Bhutan, the snow leopard is placed under Schedule I of the Forest and Nature Conservation Act of 1995, and thus benefits from being one of the totally protected species. The monetary fine for killing a snow leopard is now raised to Ngultrum (Bhutanese currency) 1 million from the earlier rate of Nu.50, 000 (1 US Dollar is equivalent to Nu. 67). Separate fines and penalties are also being imposed for possession of different body parts of the species. There is no official record of snow leopard poaching in Bhutan, but one cannot rule out the possibility of clandestine killing and trade due to close proximity of the international borders in the north and south of the country.

The conservation of snow leopards in Bhutan is largely guided by the National Snow Leopard Ecosystem Protection Programme (NSLEP). The national goal is *"to maintain a viable interconnected population of breeding snow leopards in Bhutan and trans-boundary landscape, a population existing predominantly on wild prey and in harmonious co-existence with the communities and conservation goal of the mountain ecosystem of Bhutan"*.

Based on the results of the National Snow Leopard Survey Phase-I: Sign and Prey Base Survey, it has been determined that almost one-third of the country's total land surface area is basically a suitable snow leopard habitat (Thinley *et al* 2016). This means, Bhutan offers tremendous potential for long-term survival of this dwindling cat species, and thus stands out as one of the strongholds for snow leopard conservation in the Eastern Himalayas. However, there remain challenges and threats which the conservationists have to continuously face. The greatest challenge is posed by predominantly pastoralist livelihood of the people sharing space with the snow leopard in the northern frontier. The yak herders have to bear with this domineering cat predating on their livestock. Every year, the Department of Forests and Park Services records numerous cases of livestock depredation by snow leopard. In the past, the Department used to compensate the livestock losses to snow leopard and tiger, but the scheme had to be discontinued mainly because of lack of funds and unsustainability of such compensation scheme. Besides, the snow leopard's fate is indirectly determined by threats to its principal prey, the blue sheep, which is seemingly affected by fodder competition from yaks and horses and medicinal plant collections. Therefore, there is an urgent need to develop scientifically sound management interventions to address these issues to ensure effective conservation of the species (NSLEP 2012).

1.2. Rationale for the National Snow Leopard Survey of Bhutan (Phase II): Camera trap survey (2015-2016)

In Bhutan, the first snow leopard survey was initiated in the 1980s using sign and anecdotal information which is now considered obsolete and non-rigorous (Jackson & Fox 1997). Park level snow leopard camera trap survey was carried out in JDNP and WCNP in 2012 and 2013. However, no national level survey was conducted, and there was no idea of how many snow leopard individuals exist in Bhutan. There is a rough estimate of 100-200 individuals occurring in Bhutan which is extrapolated from the neighboring countries (WCD 2012), but this figure is very unreliable. As a result, Bhutan has not been able to pursue active management of the species and its prey. In view of the increasing threats to snow leopard (Thinley *et al* 2015), there is an urgent need of a snow leopard management plan for which a scientifically reliable estimate of abundance and density is a crucial requirement. Only with baseline information on abundance and density can the conservationists gauge their success or failure in species conservation. Therefore, the National Snow Leopard Survey Phase II was launched to determine the abundance and density of snow leopards in Bhutan using latest models of camera traps. This activity was earmarked as a priority activity in the National Snow Leopard Ecosystem Protection Programme of 2012 (WCD 2012). Results of this survey, together with those of the Phase I survey (Thinley *et al* 2016) will eventually pave the way towards development of a landscape conservation plan for the snow leopard.

1.3. Objectives of the National Snow Leopard Survey of Bhutan (Phase II): Camera trap survey (2015-2016)

The main objective of the National Snow Leopard Survey of Bhutan (Phase II): Camera Trap Survey 2015-2016 was to obtain a scientifically reliable estimate of snow leopard abundance and density in Bhutan.

The secondary objectives were to:

- establish a national photographic database of snow leopards and their sympatric predators and prey; and
- develop the capacity of the frontline staff in surveying and monitoring of snow leopards and their prey using the latest survey methods and equipments.

1.4. Salient features of the survey (Phase II)

This National Snow Leopard Survey-Phase II: Camera Trap Survey for Population Estimation is unique in that the survey was carried out by a team of Bhutanese professionals, signifying an improvement in the national capacity to conduct rigorous scientific exploration. It is also the first survey on a national scale among the 12 snow leopard range countries. The survey has used latest methods in animal population estimation and improved models of camera traps.

Chapter 2

STUDY AREA DESCRIPTIONS

2.1. Physiography

Located in the Eastern Himalayas, Bhutan is a landlocked country with an area of 38,394 km^2. The country has altitudes ranging from 150 to 7,500 m.a.s.l (meters above sea level) across its 170 km north-south distance, and 95% of the country is above 600 m.a.s.l. The country is situated between two bio-geographic realms: the Indo-Malayan realm, which is composed of the lowland forests of South and Southeast Asia and the Palaearctic realm, which is composed of the conifer and alpine meadows of Northern Asia.

Bhutan can be divided into three broad physiographic zones with distinct altitudinal variations: southern foothills, inner Himalaya, and greater Himalaya.

2.2. Climatic conditions

Bhutan's climatic conditions is largely determined by the physiography with varying temperature ranges and rainfall patterns in each physiographic zones (DoFPS 2015). Generally, the amount of rainfall is higher in summer during which the rain is brought by the southwest monsoon from the Indian Ocean, accounting for 60-90% of the total rainfall. The southern belt has hot and humid climate with almost constant temperature (between 15 and 30^0C) year-round and average rainfall ranging between 2,500 and 5,000 millimetres. The central inner Himalayas has cool and temperate climate with average rainfall of 1,000 millimetres. The greater Himalayas or northern region has an alpine climate with average rainfall of approximately 400 millimetres.

2.3. Eco-floristic zones

Bhutan's vegetation can be classified into three eco-floristic zones, namely, the alpine, temperate, and sub-tropical zones (Table 2.1). The variability in rainfall, temperature and elevation results in sharp variability in ecosystems and biodiversity from one physiographic zone to other. From a total of 80.89% of Bhutan's forest cover, 70.46% is composed of tree cover. The country's forest types can be divided into six major categories: the broadleaved forest encompassing 43.99%, the mixed coniferous forest (15.99%), fir forest (4.77%), blue pine forest (2.08%), chirpine forest (2.80%), mixed broadleaf & conifer forest (0.82%) and shrubs constituting 10.43% (DoFPS 2015).

Table 2.1: Descriptions of the distinct eco-floristic zones of Bhutan (Adapted from the Ohsawa 1987)

Eco – Floristic Zones	Main Forest Types and dominant flora (plants)
Alpine Zone Altitude – (4000 + masl)	Alpine meadows and scrubs dominated by Rhododendron scrubs, Juniper and medicinal plants and herb species such as *Aconitum, Gentiana, Nardostachys , Delphinium, Rhodolia, Meconopsis, Osnomas, Dactylorhiza, Ophiocordyceps sinensis, Picorrhiza, Frtillaria ,etc.*
Temperate Zone Altitude – (2000-4000 masl)	**Fir Forest – 3000 masl+** Fir forest consists either of largely pure stands of *Abies densa* or mixed with other species such as *Juniperus, Taxus and Larix.* **Mixed Conifer Forest – 2500- 3500 masl** Mixed conifer forest includes mixed stands of spruce, hemlock, juniper, fir, larch, taxus**.** Some broadleaf are also common particularly *Quercus semecarpifolia, Quercus griffithii, Rhododendron spp., Acer spp., Betula sp.* **Blue Pine Forest- 1500- 3200 masl** Blue pine forest consists of pure or dominant stands of blue pine. It is sometimes mixed with *Quercus semecarpifolia, Populus rotundifolia* and *Rhododendron spp.* **Broadleaf mixed with Conifer – 2000-2500 masl** Consists of blue pine mixed with poplar, and other species such as *Castanopsis, Quercus, Persea, Litsea, Populus ciliate.*
Sub Tropical Zone Altitude - (150-2000 masl)	**Broadleaf Forest – 1000-2000 masl** Represented by species of *Castanopsis, Lithocarpus, Schima, and Quercus.* **Chir pine Forest – 700- 2000 masl** Pure stands of Chir pine or in association with *Quercus lanata, Quercus griffithii, Quercus glauca* and *Alnus nepalensis* along water courses. **Tropical Lowland Forest - <700 masl** Broadly classified as semi- evergreen but varies from almost totally deciduous on exposed dry slopes to almost evergreen in the moist valleys. Forests are multi- storied with high species diversity. Floristic composition consists of tropical species like *Shorea robusta, Terminalia myriocarpa, Bombax ceiba, Daubanga grandifolia, Sterculia villosa, Acacia catechu, Terminalia nudiflora*.

2.4. People's livelihood

About 69% of Bhutan's total population reside in rural areas (NSB 2013), subsisting primarily on agriculture and livestock raising. Approximately 16.8% of the country's GDP is contributed by the agriculture sector (NSB 2015).

Pastoralism is a predominant livelihood style in the highland communities of Bhutan which share space with snow leopards. Livestock rearing is indispensible part for the highland people (WCD 2012), and yaks form integral component of pastoral system, providing milk, butter, cheese and meat for home consumption. In addition to yaks, horses and mules are also raised for transportation of goods in areas beyond road-points. In general, yak herders throughout the northern region of the country have large herds of yaks. Such dependence on livestock production in the upland communities has

put snow leopard conservation in a difficult position because of occasional livestock depredation by the predator.

The upland people's income is largely supplemented from sale of medicinal plants. In fact, an abrupt change in their socio-economic status was observed after the government legalised collection of *Yartsa Guenbub* (*Ophiocordyceps sinensis)* – an high value medicinal fungus which is popularly known as Chinese caterpillar. Most of people could afford to purchase permanent zinc sheet roofs for their houses thereby reducing demand for wooden shingles. They could also afford to purchase solar lighting systems which dramatically cut down the demand for wood to light up in the evening. However, they could also afford to purchase and keep more number of yaks which in turn could potentially lead to overgrazing and fodder competition with blue sheep. Hike in yak population could also lead to more incidences of yak predation by snow leopard.

2.5. Human-snow leopard interactions

Bhutan has an increasing trend in human-wildlife conflicts, judging from the records of 2014 and 2015. A total of 202 cases of livestock depredation were recorded in 2015 as compared to 61 cases in 2014. From Nu.0.57 million paid as compensation to the livestock owners, 80.60% was for damages caused by tiger and leopard which also includes snow leopard (DoFPS 2015).

Currently, there is no information of how yak owners perceive snow leopards, except that it is highly revered by most communities as deity of the mountains. So far, there is no official record of any retaliatory killing of snow leopards by yak herders in Bhutan (Thinley *et al* 2014). This could be probably because of strong Buddhist sentiments and also because of people's fear of the law which prohibits killing of any wild animals.

Human-snow leopard interface also exists indirectly from sharing of fodder and space between its principal prey, the blue sheep, and livestock, mainly the yaks and horses. Large herds of blue sheep are commonly seen foraging with yaks and horses in the alpine meadows. It is not known whether there is overgrazing by yaks, and if there is intense grazing competition with blue sheep.

Humans may also negatively impact snow leopard by disturbing the snow leopard and blue sheep habitats and interfering with their ecology during massive collection of medicinal plants in summer. The nature and degree of impact is yet to be determined.

Chapter 3

MATERIALS AND METHODS

3.1. Brief introduction

Tracking snow leopard is inexplicably difficult because of its shy and elusive nature (McCarthy *et al* 2010) and highly rugged habitats (Subbotin & Istomov 2009). Besides, they occur in very low density with sparse distribution (Green 1987).

Because of the inherent issues with snow leopard ecology and past methods, camera trap survey has become a method of choice for estimating and monitoring its population size (McCarthy *et al* 2010). In fact, camera traps have now been regularly used in wildlife studies ranging from presence-absence surveys to estimating animal abundances and densities. Numerous wildlife studies have used camera traps since their invention in the early twentieth century (O'Connell *et al* 2011). Therefore, camera traps (which are non-invasive or passive detectors) were used for the current nation-wide survey to estimate snow leopard population abundance and density in the country.

Careful planning is vital for successful conduct of camera trap based photographic capture-recapture studies to estimate animal abundance and densities (Karanth *et al* 2002), particularly to maximize the capture probabilities for the target species. Hence, the entire survey design was geared towards maximizing the probabilities of snow leopard capture and recapture and minimizing heterogeneous capture probability among the individuals (Karanth *et al* 2011c).

Proper selection of detectors (particularly the camera trap models), laying out of trapping arrays, monitoring of detectors, and handling of data; all of these contribute towards trapping success (Karanth & Nichols 2002). These methodological aspects were carefully considered during the camera trapping exercise. Another important aspect was to position the camera traps such that the identifiable portions of the snow leopard – mainly the rump, tail, and foreheads – are captured. In fact a comprehensive survey manual which fully addresses the above concerns was published, distributed and briefed to the field staffs (See Thinley *et al* 2015c).

3.2. Survey planning and preparation

3.2.1. Organization and training of survey crew

As with the National Tiger Survey of Bhutan 2014-15 (Thinley *et al* 2015a), a national core team composed of members with different working experiences on snow leopard was formed to ensure systematic conduct of the nation-wide snow leopard survey. In order to support the core team, focal persons were identified from the field offices (Appendix table 3).

Acknowledging that many problems and errors related to field activities are due to inexperience of surveyors (Kucera & Barrett 2011), the survey crew were thoroughly trained in setting, handling, and stationing of camera traps (Figure 3.1).

Figure 3.1: Staffs from field offices who were trained on camera trap stationing, monitoring, and retrieval.

3.2.2. Reconnaissance survey

Following the snow leopard survey manual (Thinley *et al* 2015), an intensive reconnaissance or preliminary survey was conducted in all potential areas of snow leopard occurrence, including Sakteng Wildlife Sanctuary, prior to the camera trap survey to identify optimal areas for stationing camera traps. Basically, sign and prey base surveys were conducted throughout the potential areas to identify the best camera trapping stations. Please refer to the Phase I report of the National Snow Leopard Survey of Bhutan 2014-2016 (Thinley *et al* 2016) for more explanations, including notes on probable areas of snow leopard and blue sheep distributions in the country.

3.2.3. Grid lay out and selection

Based on the reconnaissance survey, initially a total of 237 grids (each measuring 4 km x 4 km) were selected, but during the course of camera placement 13 were left out because of inaccessibility due to bad weather condition (Table 3.1; Fig. 3.2). The grids corresponded to areas with high probability of snow leopard occurrence determined during the Phase I survey and during field observations.

Table 3.1: Number of grids assigned to each field office for stationing camera traps in each survey area.

Survey area	Number of grids
Jigme Khesar Strict Nature Reserve	17
Paro Territorial Division	20
Jigme Dorji National Park	102
Wangchuck Centennial National Park	63
Bumdeling Wildlife Sanctuary	21
TOTAL	**223**

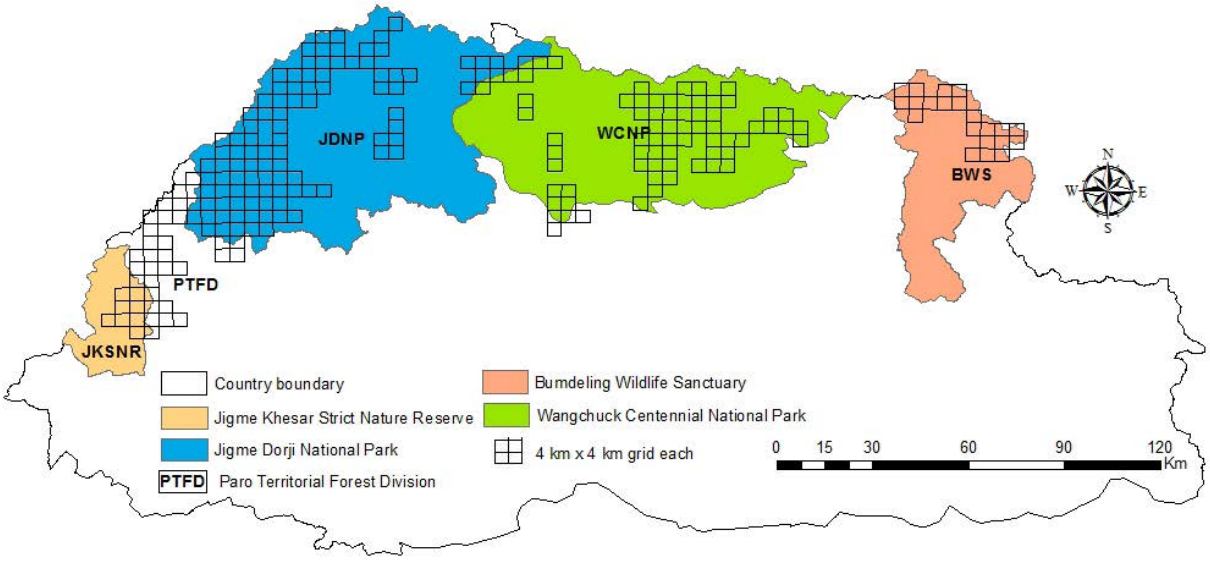

Figure 3.2: Map of survey grids and survey areas for the National Snow Leopard Survey of Bhutan – Phase II.

3.3. Camera trapping

3.3.1. Selection of camera trap models

Most of the cameras that were used for the National Tiger Survey were reused for the National Snow Leopard Survey. A total of 446 camera traps (Uway™ – 145, Scoutguard™ – 212, Reconyx™ – 67, and Cuddeback™ – 22) were used (Fig. 3.3). The cameras were initially tested for suitability in the higher altitudes with very low temperature, which sometimes fell below minus 15 degree centigrade. Marked differences in performance were observed among different camera models in terms of image quality and number of images, as noted by Swann *et al* (2011). For instance, Reconyx gave better quality of images and the battery lasted longer as compared to other models. Uway was comparatively less efficient in capturing images which were poorer in resolution, and the battery ran out much faster. Moreover, quite often the day time images appeared black and white, and it automatically changed the date setting and image – video mode. With regard to Scoutguard, the trigger time for the next image was comparatively longer, and thus the opportunity to capture images of additional individuals in a snow leopard group could have been missed. Although Reconyx was the most superior model, due to limited funding only 67 could be made available during the conduct of the survey. Generally, all models used in this survey were able to work for more than 30 days with full set of (rechargeable) batteries. Considering the cost, rechargeable batteries were used and replaced during each monitoring period.

Figure 3.3: Different models of camera traps used for the National Snow Leopard Survey of Bhutan - Phase II.

3.3.2. Camera trap installation and trapping array

In each 4 km x 4 km grid, two cameras were stationed somewhat close to one another at trapping site (Fig. 3.4), because images from multiple cameras stationed at a site can enable us to better identify the individuals which in turn will help in yielding precise population estimates (Swann *et al* 2011). The cameras were placed at specific heights and angles to capture identifiable portions of the snow leopard, such as thighs, limbs, tail, and foreheads, as these portions have distinct pelage patterns reliable for individual identification (Jackson *et al* 2006). Two cameras were placed facing opposite to one another, separated by considerable distance so as to avoid flash from one triggering the other, in order to be able to capture images of individuals travelling in both directions. Also, cameras were stationed in the most probable sites of detection that are usually the areas most frequently visited by snow leopards, such as ridgelines, scent marking areas, ridge saddles, undisturbed human and animal trails, and base of cliffs (Appendix Fig. 1).

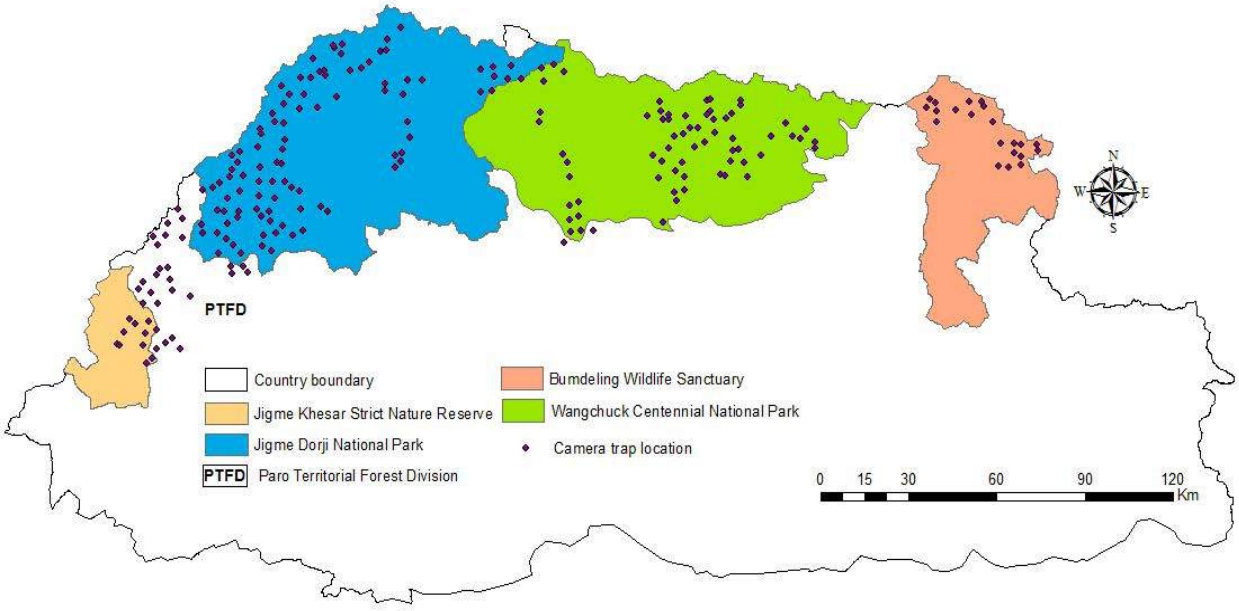

Figure 3.4: Locations of the camera trap stations for the National Snow Leopard Survey of Bhutan – Phase II.

The gaping holes between the camera stations (Fig. 3.4) could not be avoided because of highly rugged terrains, inaccessibility due to inhospitable weather, non-functionality of cameras (6 in JDNP) and loss of cameras (2 from JDNP and 8 from WCNP). Due to casualty of staff and poor weather condition none of the lost cameras could be replaced, but the non-functional ones were replaced during the monitoring period. Some of the holes were deliberately left because they were deemed least probable areas for snow leopard occurrence based on reconnaissance survey (Phase – I) results.

3.3.3. Trap duration and monitoring

The cameras were stationed with effect from 25 September 2015, but the last camera was stationed on 30 September 2015, and the first date of camera retrieval was on 23 December 2016. Therefore the effective trap duration was 90 days (from 1 October 2015 to 29 December 2015), amounting to a total of 20,070 trap-days and 18,180 trap-days if 21 traps from BWS are excluded (due to complete absence of capture for the entire trap duration). All snow leopard images captured before and after this trap duration were not included in the mark-recapture analysis for population estimation.

The assumptions of a closed population (Otis *et al* 1978) were upheld even with a sampling duration of 90 days, because no incidences of birth, death, immigration, and emigration were reported or known during the survey period.

In due consideration of the ethical and societal concerns, cameras were not baited to attract snow leopard individuals. Use of live baits could have otherwise increased the detection probability.

The cameras were monitored only once between installation and retrieval because of logistical and financial constraints. During each monitoring period, batteries were replaced, disoriented cameras were repositioned, memory cards were replaced or emptied, non-functional cameras were replaced, camera lenses were cleaned, and obstructing objects between camera lens and animal paths were removed.

3.4. Data management

3.4.1. Image sorting

Two workshops were held for data management; one after the first monitoring and one after the retrieval period. All images of snow leopards were sorted by survey site and station/grid number. For proper data management and identification of individuals, the field focal persons and some survey team members from the respective field offices were called for data sorting, individual identification, and creating capture histories.

3.4.2. Identification of individuals

Like tigers, snow leopards are naturally marked with distinct pelage patterns on the limbs, rumps, thighs, and tail (dorsal side). Using these markers, individuals were unambiguously identified to avoid mistaking the same individual as two or more individuals or the vice versa so as to obtain reliable estimates of capture probabilities and population abundance (Karanth *et al* 2011b).

Most of the cameras didn't take pictures as desired; hence, combination of images from tail, forehead, thighs, and limbs were used for unique characterization of individuals. The identified individuals were thoroughly compared with the rest individuals to avoid double or undercounting. A rule for individual identification and determining capture and recapture of individuals was adapted and modified from Jackson *et al* (2005) and Jackson *et al* (2006)

1. At the outset, a unique individual was identified from a single or multiple images of the

same individual (obtained from photo-burst images) with distinct pelage patterns on tail, forehead, limbs, and rump portions. Each individual was assigned with a primary feature (most clear and distinct body part with unique rosette or spot pattern) and secondary feature (an additional body part with somewhat distinct rosette or spot pattern and other features such as number of accompanying individuals; Appendix Fig. 2).

2. In absence of unique marks/markers on images, plausible attributes such as time, date, and location of capture (distance between capture sites) were used as primary feature to differentiate between the individuals. For example, in PTFD, the snow leopard found in Khemla under Dotey geog was situated very far from the one found in Taklungla under Tsento Geog. It was logically not possible for a snow leopard to travel from Taklungla to Khemla within 2-3 days. Therefore, the difference of 2-3 days in capture between the two sites led us to treat them as two different individuals.
3. In isolated grids, capture of two or three individuals in an image led us to identify two or three distinct individuals.
4. A photograph was positively assigned to a unique individual and considered as an initial capture if there was a mismatch of the primary features while comparing with the previously identified individual.
5. A photograph was designated as recapture of a previously identified individual if there was a match of the primary feature and at least 1 secondary feature.
6. Photo-burst images were considered as belonging to one individual and one capture event.
7. Images that could not be assigned primary and second features were discarded and treated as non-capture.

During the individual identification workshop, each survey team presented their identified individuals with capture and recaptures to a plenary session consisting of other survey teams (using two projectors) during which the above rule or guideline was used to vet the authenticity of each individual as a uniquely identified individual. In order to avoid double counting of individuals, particularly in the adjacent survey sites (park or division), comparisons were made between JKSNR and Haa Range of PTFD, Paro Range (PTFD) and Soe Park Range (JDNP), and Lunana Park Range (JDNP) and Western Park Range (WCNP).

3.4.3. Building the capture history

A capture history was built using the date stamps on the images of captures and recaptures and the location IDs (grid or camera station codes). Considering our sampling duration of 90 days, a time interval of 10 days was treated as one sampling occasion and resulted in a total of 9 sampling occasions. Karanth *et al* (2011a) suggested a minimum of 2 to a maximum of 30 sampling occasions for a closed capture-recapture model. Capture of an individual in any of the camera trap on a particular sampling occasion was considered as "1" and non-capture as "0". Multiple captures of an individual in a single trap location during the same sampling occasion was treated as a one capture incident.

3.5. Data analysis

3.5.1. Analysis of capture success and activity pattern.

Capture success was computed as number of snow leopard images (identifiable) obtained per 100 trap days. The activity pattern was graphed as number of snow leopard images obtained during a particular time period on a 24 hour time scale. Based on the frequency of images obtained during different time periods, nocturnal, diurnal, or crepuscular habit of the target animal was deduced.

3.5.2. Estimation of density and abundance

Generally, there are two model-based approaches to estimating animal abundance and density from capture-recapture studies; one approach uses likelihood estimation (Borchers & Efford 2008) and the other uses Bayesian framework for inference (Royle & Young 2008). As in the National Tiger Survey of Bhutan 2014-15 and the tiger survey in JDNP in 2012 (Thinley *et al* 2015b), the Bayesian approach using data augmentation (Royle & Young 2008; Royle *et al* 2009) was used to estimate the number and density of snow leopard individuals. This approach was basically a spatially explicit hierarchical modelling process with a point process model that described spatial distribution of individuals and an observation model that described observation of individuals in camera traps (Royle *et al* 2009).

Modelling was performed in Programme R version *3.1.3* (R Core Team 2015) using the package 'SPACECAP' (Gopalaswamy *et al* 2012) version *1.1.0* (Gopalaswamy *et al* 2014). The model options: closed spatial capture-recapture model with half normal detection function, Bernoulli capture encounter process and trap response absent were used. A sufficiently large number of potential home range centres, extending several kilometres beyond the trapping array (Fig. 3.4) was derived using ArcGIS™ and the probable snow leopard distribution map produced in Phase-I survey (Thinley *et al* 2016). A large data augmentation, precisely 315 which was 5 times the number of identified individuals, was used to set an upper limit to the estimate of the number of individuals for the Markov-Chain Monte Carlo simulation. The model was run with 100,000 iterations; 10,000 burn-in (meaning 10,000 initial iterations were to be discarded); and 10 thinning rate (number of iterations skipped when reporting summary statistics). The model fit was assessed using Bayesian p-value; values close to 0 or 1 implied poor fit of the model (Royle *et al* 2011). Model convergence was assessed using Geweke test.

3.5.3. Estimation of occupancy

Snow leopard occupancy throughout Bhutan was estimated using the single season model in the Programme PRESENCE 8.9 (Hines 2006), which uses maximum likelihood approach to estimate occupancy based on the various occupancy models developed by MacKenzie *et al* (2006).

Chapter 4

RESULTS AND DISCUSSIONS

4.1. Photographic capture success

In total, 1,219 images and 6 videos of snow leopard (Table 4.1) were obtained during the effective sampling period (1 October to 29 December 2016). Of these, only 701 images and 4 videos showed clear images of desirable body parts and thus were usable for capture-recapture analysis.

The snow leopard images were captured from JSKNR, PTFD, JDNP, and WCNP. Although 21 camera stations with 42 camera traps were deployed in BWS for the entire sampling period, not a single individual or image of a snow leopard was captured.

Based on the number of usable images and 18,180 trap days (excluding those from BWS) a photographic capture success of 3.85 images per 100 trap days was achieved. This figure could be used for rapid monitoring programs in the future.

96% of the total images were dominated by ghost or falsely triggered images. The livestock, mostly yaks and horses, made up 2.9% of all images while the other mammals (red fox *Vulpes vulpes*, Asiatic black bear *Ursus thibetanus*, blue sheep *Pseudois nayaur*, and Asiatic wild dog *Cuon alpinus*) and birds (Himalayan snow cock *Tetraogallus himalayensis* and blood pheasants *Ithaginis cruentus*) including snow leopards represented 1.1%.

Table 4.1: Summary of the number of usable and unusable images of snow leopard obtained from the camera traps during the nation-wide camera trap survey 2015-2016.

Survey areas	# of images unusable for individual identification	# of images usable for individual identification	# of videos unusable for individual identification	# of videos usable for individual identification	# of captures/ recaptures
JKSNR	52	163	0	0	24
PTFD	14	75	2	0	20
JDNP	357	299	0	0	91
WCNP	95	164	0	4	31
Total	**518**	**701**			**166**

While gleaning through the images, only 16.7% of the images showed foreheads (facing directly toward the camera at 45^{o} angle), 17.4 % showed fully visible torso, 1.7 showed all limbs, and 10.4 showed dorsal surface of the tail (Table 4.2). These proportions reflect marginal quality of camera trap images for individual identification.

4.2. Individuals identified

In a 90-day total sampling period using 202 trap stations (excluding 21from BWS) and 404 detectors, 63 individuals of snow leopards could be identified (Appendix Fig. 2). Only 166 captures (initial captures with recaptures) were obtained from the usable images obtained from 18,180 trap days, yielding a capture probability of mere 1 capture per 100 trap days. In fact, only 59 of 202 trap stations (excluding 21 stations from BWS) captured the identified individuals (Table 4.3; Appendix Table 1). A very low capture probability like this could be typical of highly elusive and rare species in the mountainous and marginal areas of the Himalayas, such as in Bhutan.

Table 4.2: Proportion of snow leopard body parts recognizable from the camera trap images obtained during the nation-wide camera trap survey 2015-2016.

Body parts	# of images (% sample)			
	JDNP (n=656)	WCNP (n=259)	JKSNR (n=215)	PTFD (n=89)
Facial angle				
Not visible	303 (46.2)	161 (62.2)	84 (39.1)	14 (15.7)
Looking toward camera (45°)	107 (16.3)	23 (8.9)	55 (25.6)	28 (31.5)
Looking away from camera (≥ 90°)	111 (16.9)	53 (20.5)	11 (5.1)	33 (37.1)
Looking sideways to camera (approx. 90°)	107 (16.3)	28 (10.8)	62 (28.8)	14 (15.7)
Extent of torso visible				
Not visible	123 (18.8)	114 (44)	52 (24.2)	29 (32.6)
Fully visible	114 (17.4)	71 (27.4)	84 (39.1)	57 (64)
Visible (approx. 75%)	71 (10.8)	14 (5.4)	25 (11.6)	1 (1.1)
Visible (approx. 50%)	165 (25.2)	24 (9.3)	15 (7)	1 (1.1)
Visible (≤ 25%)	141 (21.5)	39 (15.1)	31 (14.4)	1 (1.1)
Number of limbs visible				
None	237 (36.1)	122 (47.1)	67 (31.2)	28 (31.5)
1	114 (17.4)	16 (6.2)	19 (8.8)	5 (5.6)
2	141 (21.5)	35 (13.5)	41 (19.1)	18 (20.2)
3	81 (12.3)	64 (24.7)	52 (24.2)	29 (32.6)
All limbs	11 (1.7)	25 (9.7)	28 (13)	9 (10.1)
Extent of tail visible				
Not visible	183 (27.9)	135 (52.1)	71 (33)	39 (43.8)
Completely visible (dorsal surface)	68 (10.4)	59 (22.8)	49 (22.8)	23 (25.8)
Completely visible (lateral surface)	102 (15.5)	2 (0.8)	52 (24.2)	3 (3.4)
Visible (approx. 50%)	127 (19.4)	29 (11.2)	26 (12.1)	11 (12.4)
Visible (≤ 25%)	81 (12.3)	37 (14.3)	51 (23.7)	13 (14.6)

Among the four survey areas (excluding BWS), JDNP had the highest number of identified snow leopards (n=31), followed by WCNP with almost half the number (n=17) and JKSNR with less than one-third the number (n=9). The PTFD had the least number of indentified individual (n=6), and this figure was expected considering the smallest snow leopard habitat it encompasses (Table 4.4).

Table 4.3: Number of stations with identified snow leopard individuals in different survey areas.

Survey area	Total # of camera stations	# stations with identified individuals
JKSNR	17	8
PTFD	20	6
JDNP	102	31
WCNP	63	14
TOTAL	**202**	**59**

Table 4.4: Survey areas with number of identified snow leopard individuals.

Survey areas	# of identified snow leopards	Snow leopard ID (Appendix Fig. 2)
JKSNR	9	BTSL_1, BTSL_2, BTSL_3, BTSL_4, BTSL_5, BTSL_6, BTSL_7, BTSL_8, BTSL_9
PTFD	6	BTSL_10, BTSL_11, BTSL_12, BTSL_13, BTSL_14, BTSL_15
JDNP	31	BTSL_16, BTSL_17, BTSL_18, BTSL_19, BTSL_20, BTSL_21, BTSL_22, BTSL_23, BTSL_24, BTSL_25, BTSL_26, BTSL_27, BTSL_28, BTSL_29, BTSL_30, BTSL_31, BTSL_32, BTSL_33, BTSL_34, BTSL_35 BTSL_36, BTSL_37, BTSL_38, BTSL_39, BTSL_40, BTSL_41, BTSL_42, BTSL_43, BTSL_44, BTSL_45, BTSL_46
WCNP	17	BTSL_47, BTSL_48, BTSL_49, BTSL_50, BTSL_51, BTSL_52, BTSL_53, BTSL_54, BTSL_55, BTSL_56, BTSL_57, BTSL_57, BTSL_58, BTSL_59, BTSL_60, BTSL_61, BTSL_62, BTSL_63

Judging from the individuals captured on each camera stations, 4 pairs (BTSL_45 and BTSL_46 in Lunana Range of JDNP; BTSL_49 and BTSL_50 in Western Range of WCNP; BTSL_51 and BTSL_52 of Central Range in WCNP; and BTSL_58 and BTSL_59 of Central Range in WCNP) and 1 threesome group (BTSL_53, BTSL_54, and BTSL_55 of Central Range in WCNP) were observed. Most of these groups are adult siblings, not mating pairs, as the images were obtained during September to October and not during mating season, which normally occurs between January and early April (Jackson *et al* 2005).

4.3. Photographic capture-recapture patterns

Among the 63 identified snow leopard individuals, only one individual, BTSL_6 (Bhutan Snow Leopard 6), was captured on 4 different camera stations while 3 individuals (namely, BTSL_15, BTSL_26, and BTSL_47 each) were captured on 3 different stations, and 16 individuals (namely, BTSL_1, BTSL_4, BTSL_9, BTSL_10, BTSL_17, BTSL_24, BTSL_25, BTSL_27, BTSL_38, BTSL_39, BTSL_40, BTSL_46, BTSL_58, BTSL_60, BTSL_61, and BTSL_62 each) were captured on two different stations. The rest 44 individuals (70%) were captured on only 1 station (Figs. 4.1a and 4.1b; Appendix Table 2), potentially indicating highly localized distribution of individuals. On the whole, the snow leopards did not travel far distances, and none of the individuals moved from one protected area to another.

Regarding capture frequency, BTSL_17 was captured the highest number of times with 12 captures

followed by BTSL_15 captured 10 times (Fig. 4.1a) and BTSL_46 captured 8 times (Fig. 4.1b; Appendix Table 2). Almost half of the total individuals (40%, n=25) were captured only once, pointing to a great degree of difficulties faced in capturing the individuals during the survey. Such difficulties may also be faced for radio-collaring and relocating individuals in the future.

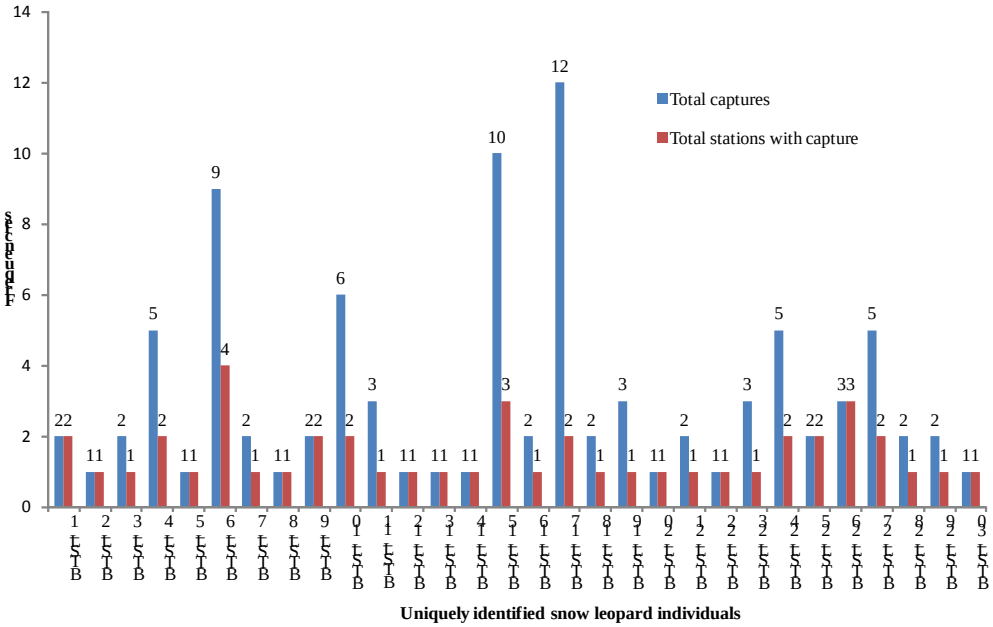

Figure 4.1a: Pattern of individual snow leopard capture (BTSL_1 to BTSL_30) with regard to capture frequency and captures in different number of camera stations.

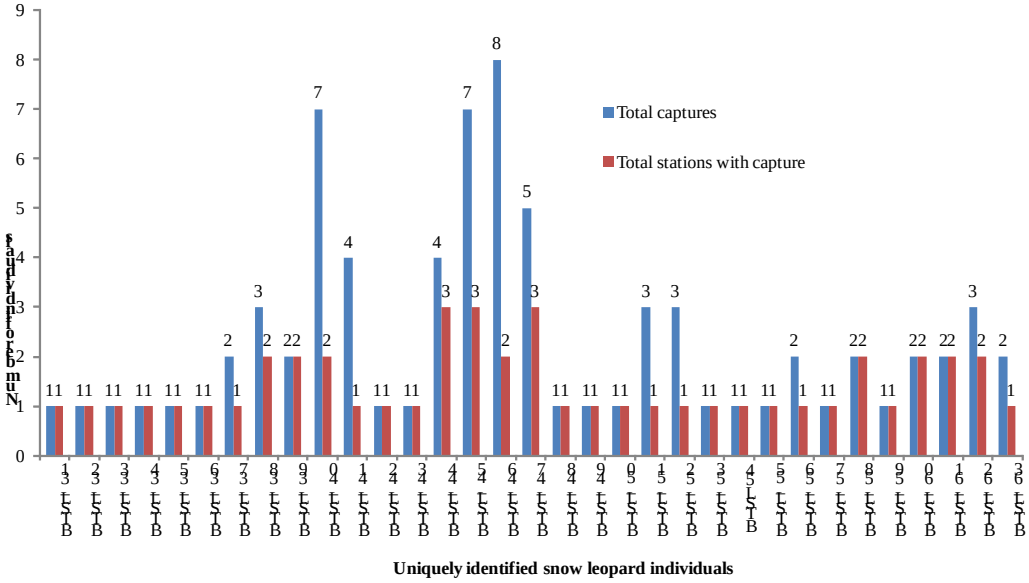

Figure 4.1b: Pattern of individual snow leopard capture (BTSL_31 to BTSL_63) with regard to capture frequency and captures in different number of camera stations.

Among the camera stations, stations G9 in JKSNR, G78 in JDNP, and G170 in WCNP captured the highest number of different individuals (i.e., 4 each; Appendix Table 1). Succeeding these stations, G47, G55, and G79 (all in JDNP) captured 3 individuals each. Fifteen stations captured 2 individuals each and majority (38 stations) captured only 1 individual. Such a pattern of capture on camera stations further reconfirms difficulties in capturing individuals and low capture probability for the snow leopards in Bhutan.

Analyzing the capture pattern by sampling occasion, highest number of captures (n=33; Fig. 4.2) occurred during the fifth occasion (41-50 days) and the least (n=7) during the last occasion (81-90 days). The total number of captures dipped from 26 in the first occasion to 10 in the second occasion but rose to 23 in the third occasion and then fell again to 17 in the fourth occasion. After the fifth occasion, the capture frequency steadily declined. About 15% of the total captures occurred during the first sampling occasion, underscoring the importance of proper setting up of the camera traps although first 7 days were treated as trial period and captures during this period were not considered for analysis.

The cameras performed very well during the first and second months of trapping period, looking at 35% and 43% of total captures respectively. Only 22% of the captures happened in the third month, but this figure was not significantly lower than in the first two months which showed that cameras performed almost equally throughout the sampling period assuming equal exposure of all individuals to the traps.

Looking at the capture pattern by number of unique individuals captured in each sampling occasion, the number of new individuals captured was the highest during the first occasion (n=15; 23% of all individuals) after which it suddenly fell to 6 in the second occasion, then fluctuated for a while until it climbed up to 12 in the fifth occasion, and eventually plummeted to 0 in the eight occasion (Table 4.5; Fig. 4.3). Surprisingly, 4 new individuals showed up during the last sampling occasion. This shows that the sampling period of 90 days is not sufficient to capture all individuals. In fact, another new individual was captured in JKSNR after 100 days (Ghalley 2016). Cameras were left in this protected area until 120 days to check if new individuals appeared.

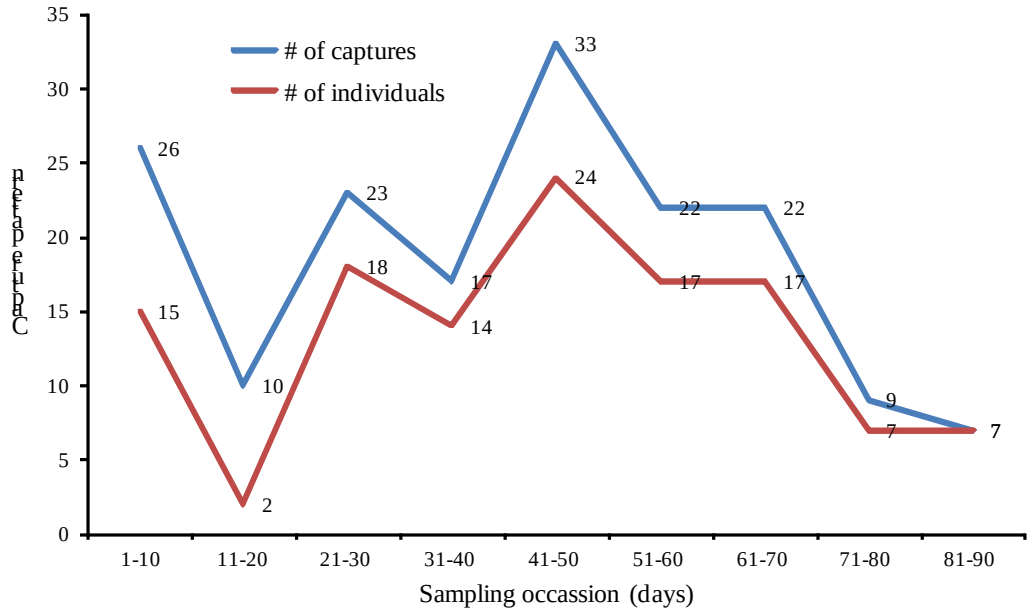

Figure 4.2: Pattern of snow leopard capture by sampling occasion.

Even cumulative capture curve (Fig. 4.3; Table 4.5) showed a continuously rising trend, instead of a plateau, indicating that the duration of the sampling period was not enough to capture all individuals. Therefore, the conventional 60- day sampling period is not recommended for the typical geophysical settings of the Bhutanese Trans-Himalaya, unlike in other snow leopard range countries. In the case of this survey, even 90-day period was not sufficient, and therefore a minimum of 100 days is recommended for future surveys to capture all individuals in the country.

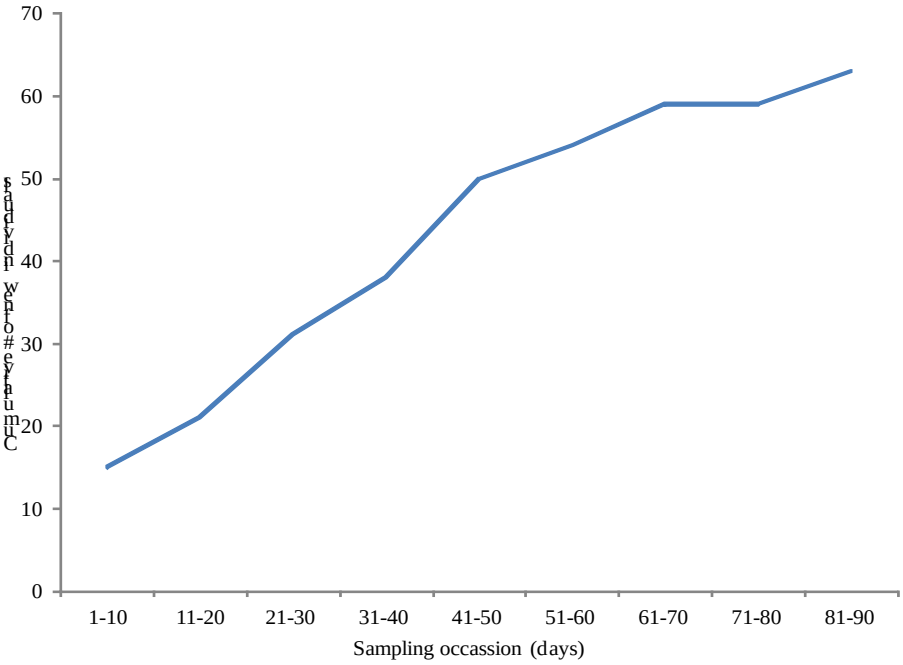

Figure 4.3: Cumulative capture curve showing the number of new snow leopard individuals captured in each sampling occasion.

Table 4.5: Number of new snow leopard individuals captured in each sampling occasion.

Sampling occasion	# of new individuals	Cumulative # of new individuals	Individual ID
1-10	14	14	BTSL_4, BTSL_6, BTSL_7, BTSL_16, BTSL_17, BTSL_22, BTSL_23, BTSL_45, BTSL_46, BTSL_51, BTSL_52, BTSL_58, BTSL_59, BTSL_60
11-20	6	20	BTSL_24, BTSL_26, BTSL_27, BTSL_32, BTSL_40, BTSL_62
21-30	11	31	BTSL_8, BTSL_34, BTSL_38, BTSL_39, BTSL-41, BTSL_44, BTSL_48, BTSL_53, BTSL_54, BTSL_55, BTSL_57
31-40	7	38	BTSL_1, BTSL_2, BTSL_11, BTSL_21, BTSL_29, BTSL_61, BTSL_63
41-50	12	50	BTSL_10, BTSL_14, BTSL_18, BTSL_19, BTSL_25, BTSL_28, BTSL_30, BTSL_35, BTSL_36, BTSL_37, BTSL_47, BTSL_56
51-60	4	54	BTSL_3, BTSL_20, BTSL_31, BTSL_33
61-70	5	59	BTSL_9, BTSL_12, BTSL_13, BTSL_42, BTSL_43,
71-80	0	59	-
81-90	4	63	BTSL_5, BTSL_49, BTSL_50, BTSL_15

4.4. Estimates of snow leopard abundance and density

The estimated number of snow leopard from the current NSLSB Phase II was 96 (SE ± 8) individuals, and the estimated abundance range was 79 to 112 individuals based on the model's 95% confidence interval (Table 4.6). This estimate is plausible considering the extent of blue sheep distribution in the country (Thinley *et al* 2016). The estimate is also closer to 100 individuals estimated by (Jackson & Fox 1997) as cited by (MCCarthy & Chapron 2003).

The overall estimated density was 1.08 (SE ± 0.09) individuals per 100 km^2 (the SPACECAP programme showed densities values in animals per sq. km). The Bayesian model yielded densities varying from 0.02 to 6.1 individuals (Fig. 4.4) per 100 km^2. The highest density was shown in the areas adjoining Soe and Lingzhi Park Ranges of JDNP. All other high density areas (1.5 to 6.1 individuals per km^2) coincided with areas where snow leopards were captured more frequently with more number of individuals. The model showed probable snow leopard densities in BWS and SWS in areas suitable for snow leopards even though no individuals were captured in these protected areas. This indicates that snow leopards could survive in these protected areas if introduced because of the presence of potential prey species – blue sheep and yaks in BWS and yaks and cattle in SWS (Thinley *et al* 2016).

Sex was not used as a covariate in the model because only a few photographs showed male genital which was the only body part that allowed identification of individual gender. However, the model reasonably fit well with the data with the Bayesian p-value of 0.71.

Table 4.6: Summarized posterior values from the SPACECAP (Bayesian) model.

Parameters	Mean	SD	95% Lower level	95% Upper level
sigma	8106.79	536.75	7036.88	9121.23
lam0	0.02	0.00	0.02	0.03
psi	0.26	0.03	0.19	0.31
N	96.41	8.47	79.00	112.00
density per km^2	0.0108	0.0009	0.0088	0.0125
p1=p2	0.02	0.00	0.02	0.03

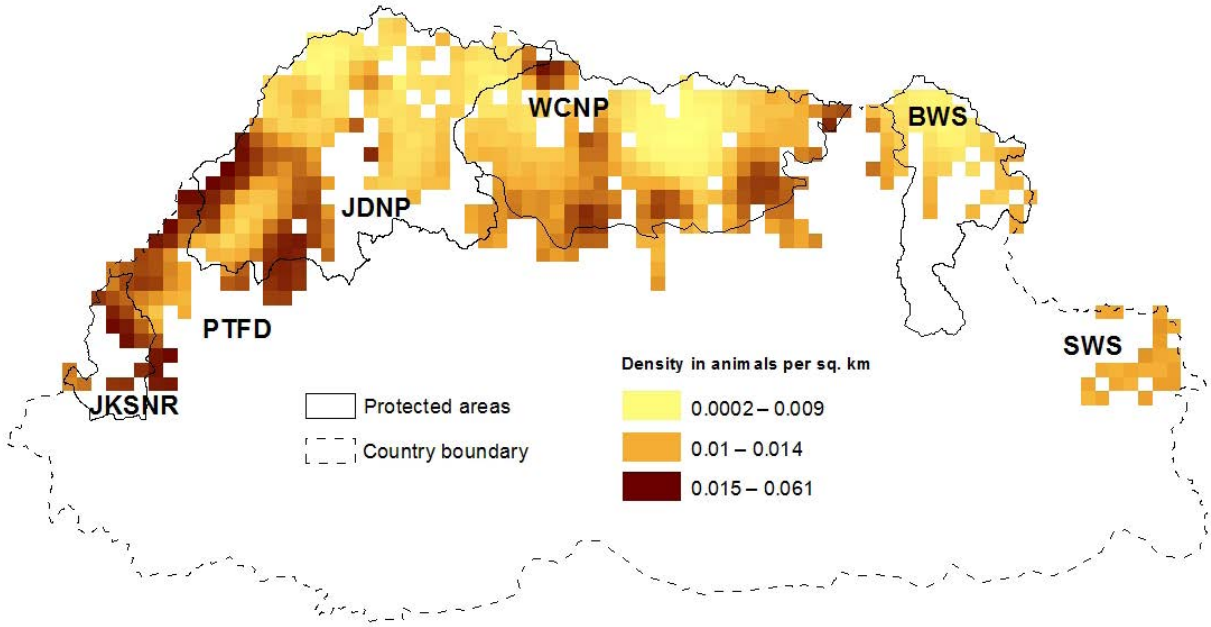

Figure 4.4: Map of Bhutan showing posterior snow leopard density (in animals per 1 km^2) yielded by SPACECAP model. The densities in BWS and SWS are to be construed as probable because of the absence of individuals there as determined during the survey.

4.5. Activity pattern

The total number of independent snow leopard images on a 24 hour time scale showed bimodal distribution with two distinct peaks (Fig. 4.5), one in the early morning (6 am) and the other in the evening (8 pm), possibly indicating a crepuscular habit similar to that of the tiger. However, since images were obtained during all time periods snow leopards could be active during both day and night.

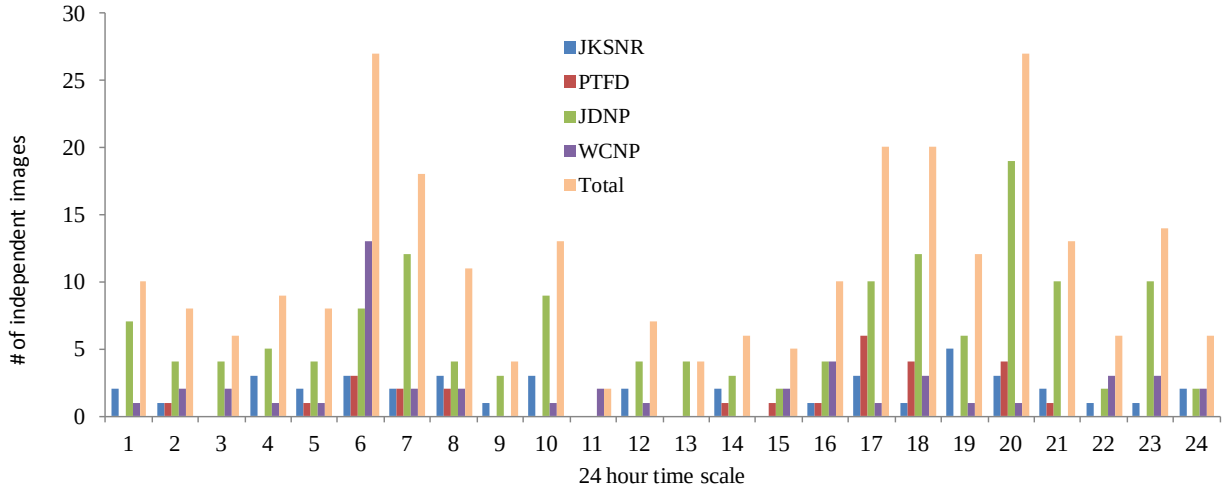

Figure 4.5: Graph showing activity pattern of snow leopard in Bhutan based on the number of independent images obtained on a 24 hour time scale.

Blue sheep, the principal of snow leopard in the Bhutanese Trans-Himalaya (Thinley *et al* 2014; Shrestha & Tenzin 2015), is active throughout the day (Harris 2014). Snow leopards could be following blue sheep during the day time, and in the night, it could be going after the yaks and other species.

4.6. Estimates of occupancy

At the national level, the snow leopard occupancy in Bhutan was estimated at 43.25% (SE ± 4.09) with a naive occupancy of 37.75%, using the single season model with single species and survey-specific detection model which had the lowest AIC (Akaike Information Criterion) value (Table 4.7). The percentage of occupancy for snow leopard in Bhutan is very low, which could be because snow leopards are concentrated in few pockets. This figure could be used for rapid monitoring programmes in the future.

Table 4.7: Selection of single season occupancy model for snow leopard in Bhutan

Model	AIC	deltaAIC	AIC weight	No. of parameters	-2 * Log Likelihood
1 group, survey-specific P	992.18	0	0.4996	10	972.18
1 group, constant P	1005.12	12.94	0.0008	2	1001.12

Using the same occupancy model for the individual survey area areas, the snow leopard occupancy ranged from 41.28 (SE ± 8.41) in WCNP to 49.36 (SE ± 12.84) in JKSNR (Table 4.8).

Table 4.8: Selection of single season occupancy model for snow leopard in different survey areas of Bhutan

Survey area	Naive occupancy	Estimated occupancy	Standard error
JKSNR	0.4706	0.4936	0.1284
PTFD	0.4000	0.4195	0.1160
JDNP	0.3922	0.4478	0.0581
WNCP	0.3231	0.4128	0.0841

4.7. Other findings

Throughout the entire survey period, with 446 camera traps stationed for 90 days, not a single picture of Eurasian lynx (*Lynx lynx*) have been taken although this medium-sized cat has been expected to occur in Bhutan (Wangchuk *et al* 2004). However, images of sympatric predators such as red fox (*Vulpes vulpes*), Asiatic black bear (*Ursus thibetanus*), and Asiatic wild dog (*Cuon alpinus*) were obtained in several stations (Appendix Fig. 3).

4.8. Challenges and field constraints

The results and findings from this nationwide survey are gathered from the best available data obtained despite several challenges and field constraints:

1) Poor unexpected weather conditions impeded the field staffs from timely monitoring and retrieval of some of the cameras in very remote locations, such as in Gangchenzoekha in WCNP and Lunana in JDNP.

2) Lack of appropriate field gears and first aid kits limited the productivity of the field staffs who suffered frequent frostbites and altitude sickness. Sadly, one of the survey team members from WCNP lost his life during camera stationing.

3) The exorbitant porter and pack pony charges forced the field staff to forego some of their essential personal belongings for the sake of carrying cameras and batteries.

4) Due to lack of adequate funding, required number of the superior camera trap model (Reconyx) could not be purchased; otherwise the results would have been better.

Chapter 5

KEY FINDINGS AND MANAGEMENT IMPLICATIONS

5.1. Bhutan a snow leopard stronghold

Now with strong empirical evidence, Bhutan can boast of harbouring an estimated 96 individuals of snow leopard. This is a very good number, indicating a highly viable population which has huge potentials for growth and stability. Coupled with strong political will and support from the government and the people and vast tracks of contiguous suitable habitats for snow leopards, Bhutan is certainly a stronghold for snow leopard conservation in the Eastern Himalayas. Bhutan government needs to continue maintaining the habitat quality and contiguity in order to ensure long-term survival of this species which is gradually approaching the brink of extinction.

5.2. New records of snow leopard occurrence

Through this nationwide survey, presence of snow leopards in most of JKSNR is known, and for the first time PTFD has been recognised as a snow leopard area outside the protected areas. These new discoveries could stimulate conservationists to rethink about the corridor connecting JKSNR and JDNP via PTFD. The currently existing corridor is meant only for the tiger, while there is a long stretch of suitable snow leopard habitat in the north which could potentially connect snow leopard populations of JDNP, JKSNR, and PTFD.

5.3. Potentials for snow leopard rehabilitation and introduction

Even though cameras were placed in BWS for the same survey duration, not a single image has been obtained. Nonetheless, many images of blue sheep have been obtained from several camera stations. Field reports claim regular sighting of blue sheep in Singye Dzong and Shingphel areas, offering potentials for rehabilitation of few snow leopard individuals in the near the future. In fact, there used to be several individuals in the past according to local yak herders and monks residing in the remote hermitages.

Likewise, SWS also offers potentials for introduction of blue sheep and snow leopard. Recently, two males and two adult females of takin (*Budorcas taxicolor*) have been introduced in the park, and they are currently doing well. Similar exercise could be done for blue sheep.

5.4. Snow leopard hotspots

Among the protected areas, JDNP and WCNP stand out as the snow leopard hotspot with 31 and 17 identified individuals respectively (Table 4.4). While the notion of hotspot and cold spot may not be

appealing to some conservation biologists and practitioners, it is nonetheless important to recognise these two parks as the best bets for snow leopard conservation. In any case, the number of snow leopards should not be the sole criterion for allocating fund and manpower resources.

Even within the parks and territorial divisions (Figure 4.4), there are prominent snow leopard hotspots, meaning areas of concentration and prominent sightings. These areas need to be safeguarded through regular patrolling and habitat protection.

5.5. Potentials for yak depredation

Due to the presence of good number of snow leopards, there could be high chances of yak depredation in many areas. The tolerance and acceptance capacity of the yak owners towards snow leopard will have to be increased or maintained through innovative mechanisms such as compensation and insurance schemes. The currently existing schemes need to be revisited and boosted with supplemental top-ups.

5.6. Emerging threats to snow leopards

The increasing trends in medicinal plant collection and ecotourism in the alpine areas have been recognised as new emerging threats to blue sheep due to interference in breeding and competition for fodder. These will in turn affect the snow leopard's food chain and ultimate sustenance. There is a need to conduct an in-depth study on the impacts of these activities on blue sheep and snow leopard.

5.7. Long sampling period

Given the unique geophysical terrain, the prescribed maximum sampling period of 60 days is not practicable in Bhutan, and a minimum of 100 days is recommended to capture all the individuals. Therefore, the conservation community need to accept this new reality, and hence should be willing to allocate adequate budget, equipments, and manpower for similar surveys in the future.

5.8. Localized populations

Looking at the capture and recapture patterns of individual snow leopards it was evident that the individuals kept themselves to the respective territories. There was no long-distance movement of individuals from one protected area to another. Even within the protected areas, the individuals of one park range did not mingle with those of the other ranges. Such ranging patterns need to be investigated during the upcoming radio collaring exercise.

Chapter 6:

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Indisputably, Bhutan is a stronghold for snow leopard conservation in the Eastern Himalayas. The number of snow leopards in the country is estimated at 96 (SE ± 8) individuals, ranging between 79 to 112 individuals based on 95% confidence interval. The overall estimated density of snow leopard was 1.08 (SE ± 0.09) individuals per 100 km^2. This first nationwide camera trap survey of snow leopard has led to the discovery of new populations in JKSNR and PTFD.

6.2. Recommendations

For ease of understanding, the recommendations are grouped as policy and technical recommendations.

6.2.1. Policy recommendations

6.2.1.1. Intensive patrolling and vigilance

In light of the close proximity of snow leopard populations to the international border, there is a huge risk of poaching and trade of snow leopard parts. As a result of this survey, most of the habitats and populations unknown to poachers have been revealed, and there could be high chances of snow leopards being poached after this survey. In view of such danger, the wildlife managers and their field staffs should enhance vigilance and patrolling in the respective snow leopard hotspot areas.

6.2.1.2. Handing over of individual snow leopards to respective field offices

As in case of tiger (Thinley *et al* 2015a), the Chief Forestry Officers of the field offices should be held in charge of protecting the identified snow leopards in their respective areas. They should ensure safety of their snow leopards for which commensurate funds, equipments, and manpower resources need to be provisioned.

6.2.1.3. Re-mapping of the existing corridors

The biological corridor which links JKSNR to JDNP via PTFD needs to be re-mapped to encompass the stretch of suitable snow leopard habitats in the northern border before any dramatic events happen in this potential area that could constraint snow leopard movement. Such a proactive measure is deemed urgent to ensure maximum survival of snow leopard in the country.

In the similar note, the Department may look into the possibility of creating a new corridor between WCNP and BWS to possibly allow the dispersal of snow leopards from the former to the latter.

6.2.1.4. Revamping compensation and insurance schemes

In the past few years, the Department of Forests and Park Services through the Wildlife Conservation Division has established several livestock insurance schemes in the snow leopard areas. Effectiveness of these schemes towards snow leopard conservation needs to be assessed. Wherever, the insurance schemes are deemed dysfunctional compensation schemes should fill up the gaps.

6.2.1.5. Development of a climate-smart snow leopard landscape conservation plan

A comprehensive snow leopard landscape conservation plan which is not only climate-smart but people-sensitive is required for ensuring long-term survival of snow leopards and their prey species in the country. The plan while attempting to mitigate threats to snow leopards should simultaneously address the issue of persistent livestock predation by snow leopards. Measures to adapt to the impending threats of climate change to snow leopards also need to be clearly spelled out in the plan. There is also need to issue guidelines for compensation and insurance schemes, which could be drafted, based on the current experiences, and improved through periodic reviews.

6.2.2. Technical recommendations

There are several grey areas in our scientific knowledge of snow leopards in Bhutan, and therefore the following recommendations are aimed at filling up these gaps.

6.2.2.1. Impact of climate change on snow leopard

It is not known how the climate change will affect snow leopards, except the pre-emptive notion that upward altitudinal shit in vegetation zones may affect the habitat or grazing areas for blue sheep which will subsequently affect snow leopard populations. Effects of climate change on people's livelihood and its resulting effect on snow leopard is also yet to be known. Therefore, there is a need to assess the impact of climate change on snow leopard, blue sheep, and the people's livelihood in the alpine regions.

6.2.2.2. Prey population

In Phase I of the NSLSB, distribution and habitat selection of blue sheep were known, but the estimates of population abundance could not be determined due to insufficient data and time. So far, the only abundance study of blue sheep is done in Lingzhi Park Range (Leki *et al* 2016). It is recommended that this study be replicated to other parts of the snow leopard areas in order to determine availability and adequacy of prey.

6.2.2.3. Habitat use and movement ecology

In other parts of global snow leopard range, snow leopards are known to move great distances, but contrastingly the individuals in Bhutan have been found to be somewhat localized. In order to know the spatio-temporal movements, habitat selection, and factors underlying the localized distributions, it is recommended that a few individuals be tagged with GPS collars.

6.2.2.4. Dietary selection

There is no published record on the dietary selection of snow leopards in Bhutan. It is not known how much of snow leopard diet is constituted by livestock and the natural preys. Therefore, a detailed study needs to be conducted on seasonal dietary selection of snow leopard through scat analysis.

6.2.2.5. Genetic characterisation

The scientific community needs to know the genetic makeup of the snow leopards in Bhutan, so that they can determine if there is any trend in speciation or development of traits that enables them to adapt to the typical climatic conditions of the Eastern Himalayas. Such understanding will enable wildlife managers to provide adequate opportunities for development of evolutionary and adaptive traits.

6.2.2.6. Human-snow leopard interactions

There is no official record of retaliatory killing and poaching of snow leopards in Bhutan. However, the possibility of retaliation cannot be ruled out, and there is a need to know how likely the local people are to retaliate against the snow leopard as a result of livestock depredation. There is also no idea about what is the current benchmark of people's tolerance and acceptance capacity of snow leopards. In order to fill these information voids, a thorough socio-economic survey needs to be conducted.

6.2.2.7. Impact of medicinal plant collection, ecotourism, and cattle grazing

A detailed scientific study is recommended to understand the impact of medicinal plant collection, ecotourism, and cattle grazing on snow leopard and blue sheep

6.2.2.8. Snow leopard reintroduction

Before reintroduction, a detailed feasibility study needs to done on whether snow leopards will actually survive in BWS and SWS. There is a need to know how many blue sheep are actually occurring in BWS, and check whether the local populations are enough to sustain certain number of snow leopards. Likewise, the feasibility of blue sheep introduction in SWS needs to be determined, only after which snow leopards may be introduced.

6.2.2.9. Choice of camera trap models and batteries

For similar nationwide camera trap surveys in future, it is highly recommended that the investigators used a model that provides high resolution images, produces less number of ghost pictures (with optimum sensitivity), consumes battery efficiently for long duration, and takes picture in the night without flashes. As of now, Reconyx™ is rated as the best model, and for future surveys any model which has features described before is to be used.

In the very remote locations where chances of camera trap monitoring is slim, surveyors should use

standard non-rechargeable batteries but enough to last a survey season.

6.2.2.10. Trap duration

For future surveys in Bhutan, it is recommended that cameras be stationed in the field for a minimum of 100 days in order to be able to capture all individuals. The cameras need to be monitored at least once in every 30-day period.

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Appendix Figure 1: Photographs of field staffs installing camera traps.

BWS survey members stationing camera trap

JKSNR members setting up camera trap station

JKSNR members testing stationed camera trap

Laya range survey members replacing camera trap batteries

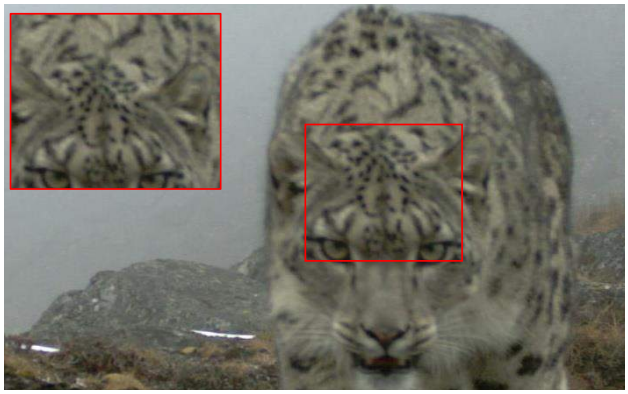
JKSNR members checking camera trap batteries

Camera trap installed on stone stupa

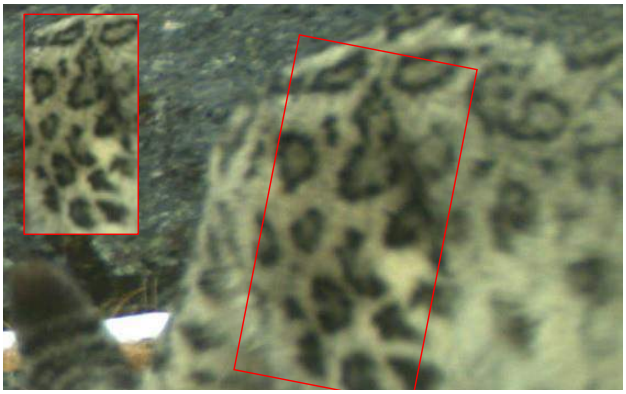
A camera trap installed in a stupa along a ridge-line in Lingshi range, JDNP

Camera trap installed at a valley bottom in Paro division

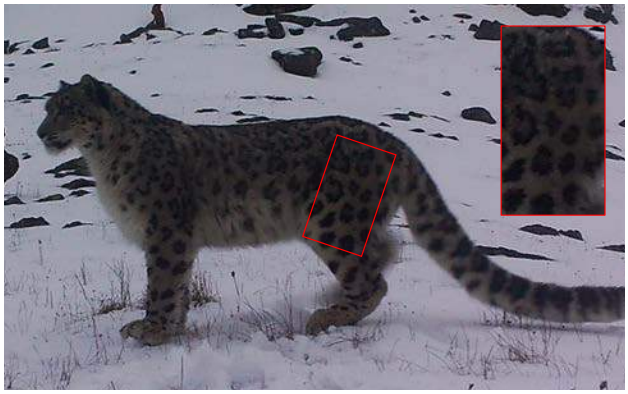
Appendix Figure 2: Images of identified snow leopard individuals showing the primary and secondary features marked with red rectangles.



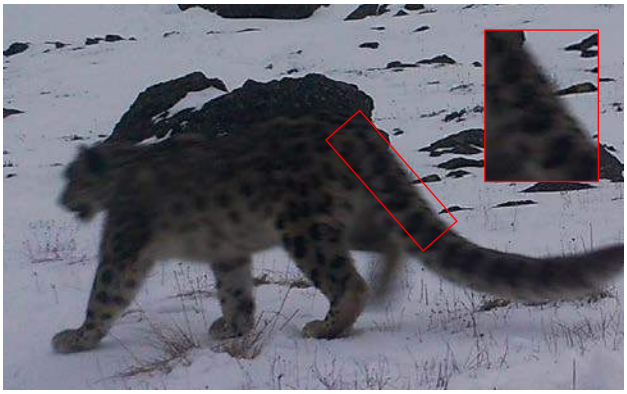
BTSL_01 (Head)



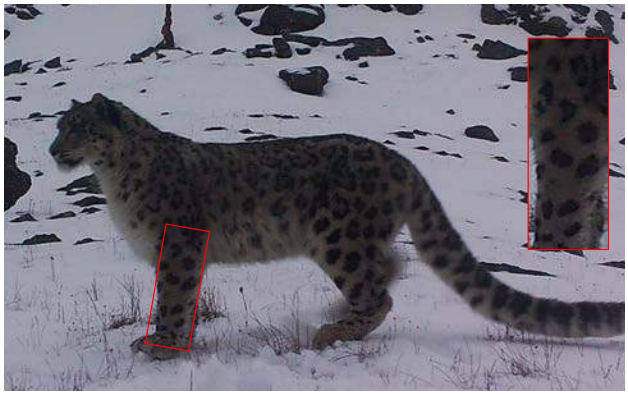
BTSL_01 (Right Flank)



BTSL_02 (Left Flank)



BTSL_02 (Dorsal Tail)

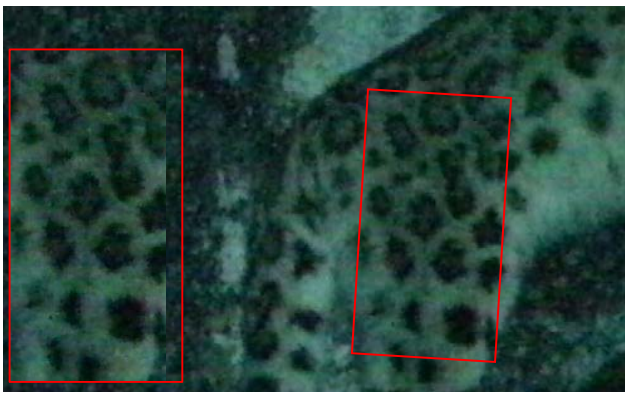


BTSL_02 (Left Front Limb)

BTSL_03 (Dorsal Tail)

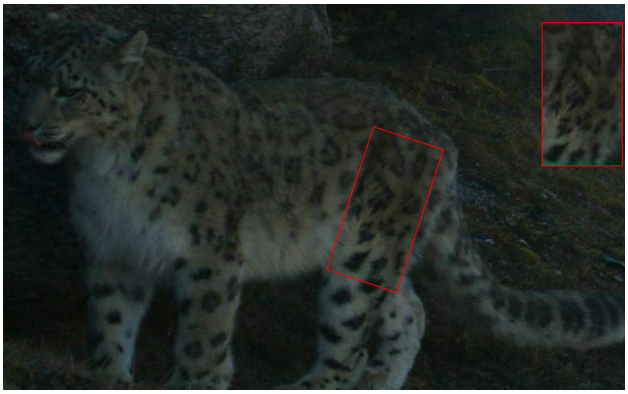
BTSL_03(Left Front Limb)

BTSL_03 (Right Front Limb)

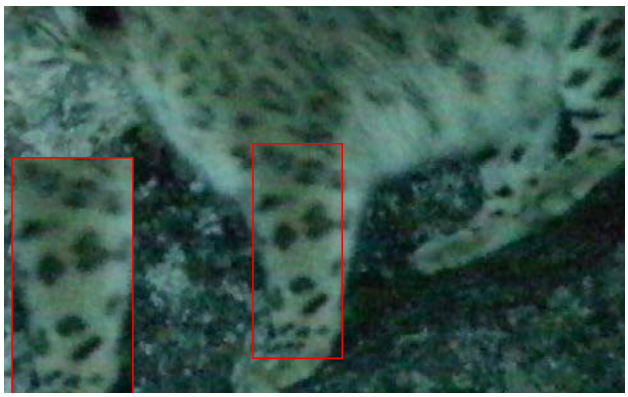


BTSL_03 (Right Flank)

BTSL_04 (Left Hind Limb)

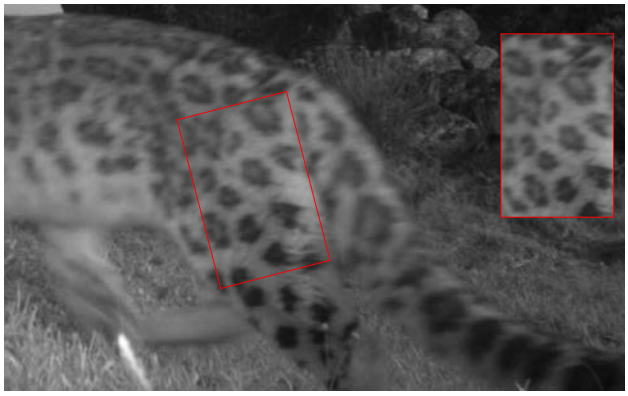


BTSL_04 (Left Flank)



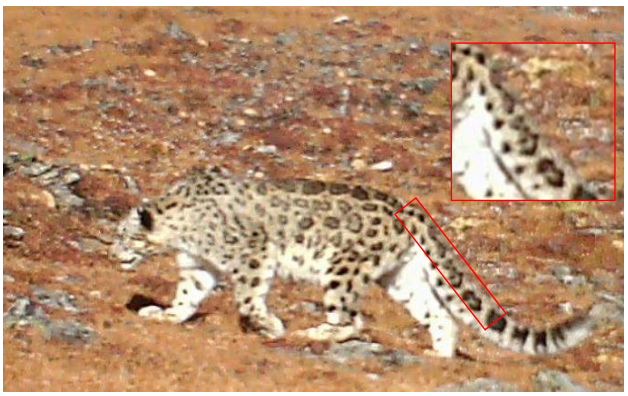
BTSL_04 (Left Front Limb)

BTSL_04 (Head)

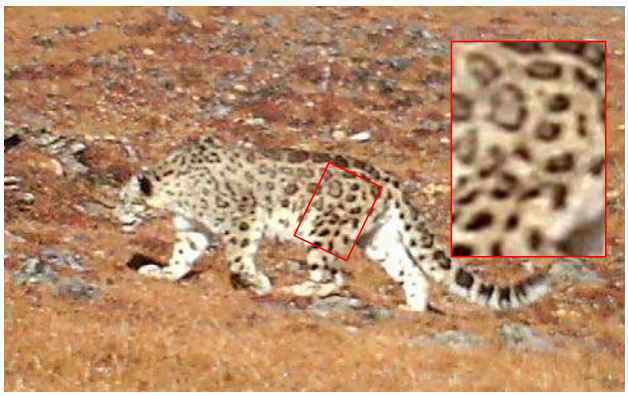


BTSL_05 (Left Flank)

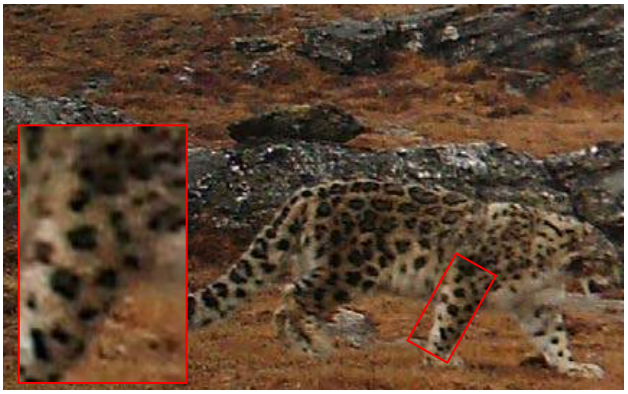
BTSL_05 (Dorsal Tail)



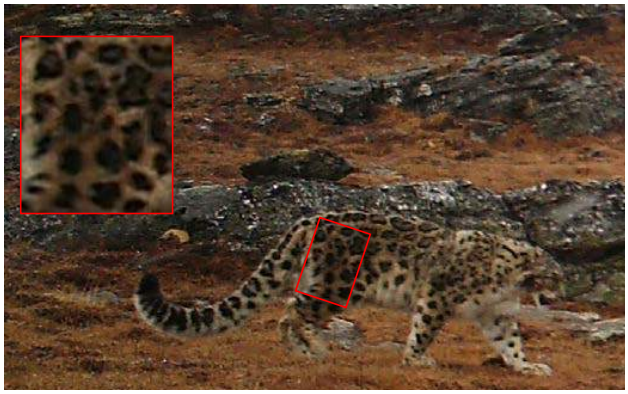
BTSL_06 (Left Dorsal Tail)



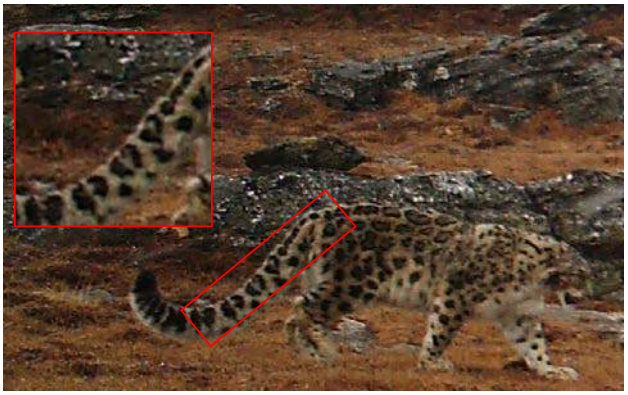
BTSL_06 (Left Flank)



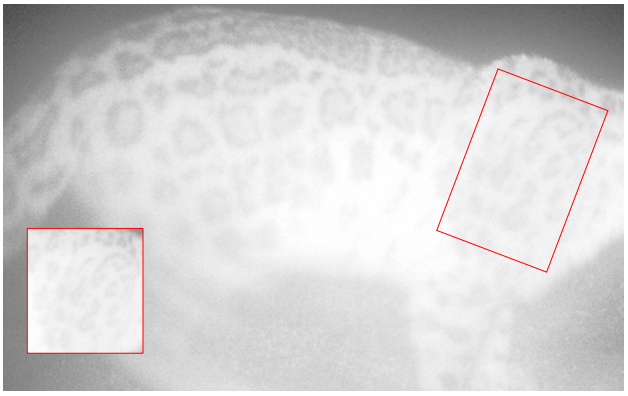
BTSL_06 (Right Front Limb)



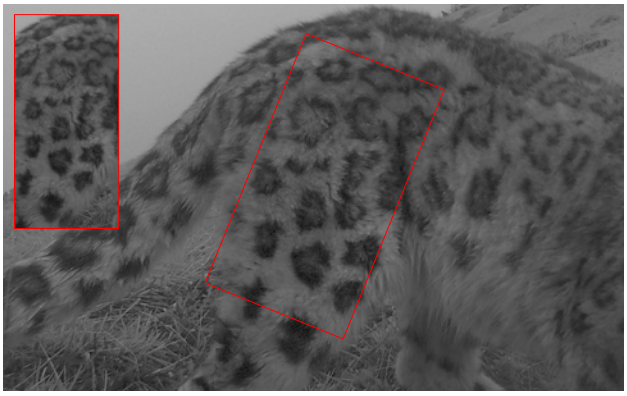
BTSL_06 (Right Flank)



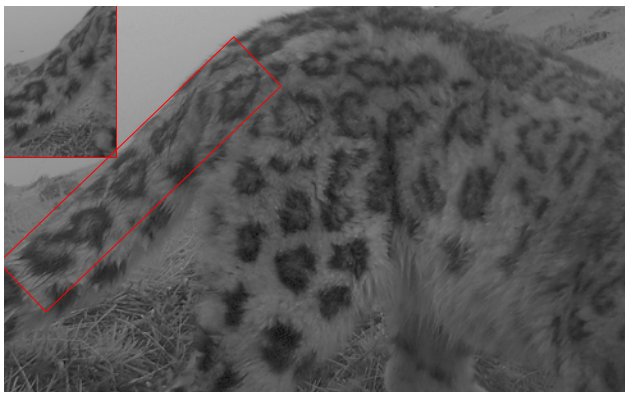
BTSL_06 (Right Dorsal Tail)



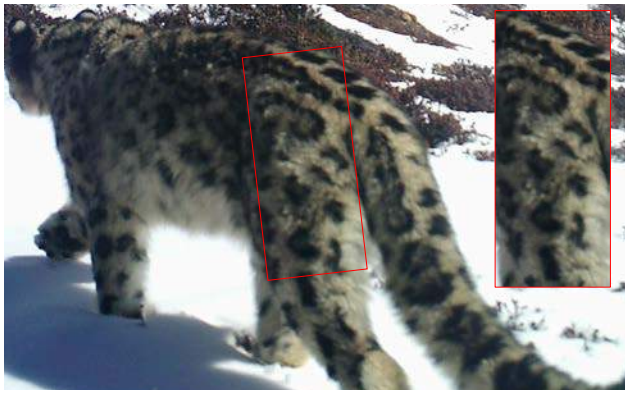
BTSL_07 (Right Shoulder)



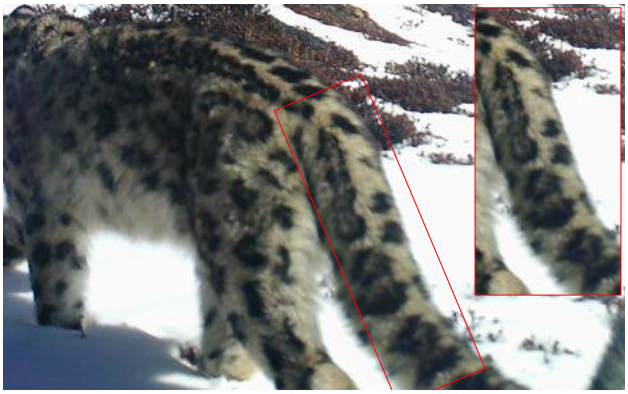
BTSL_07 (Right Flank)



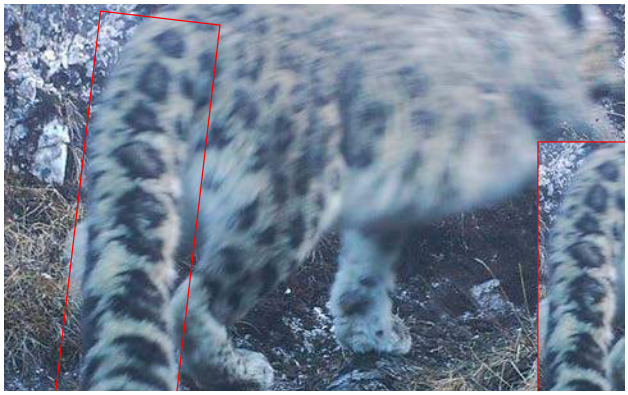
BTSL_07 (Right Dorsal Tail)



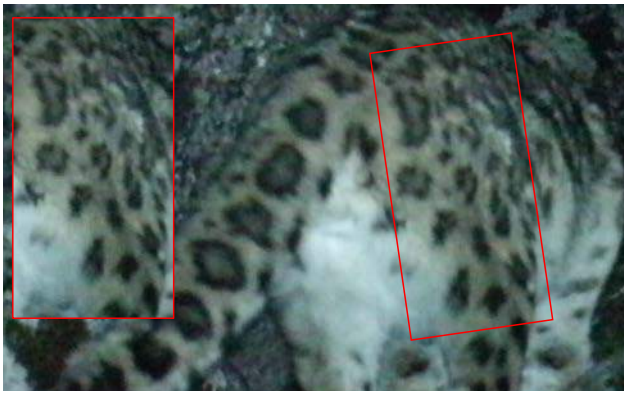
BTSL_08 (Right Flank)



BTSL_08 (Left Dorsal Tail)



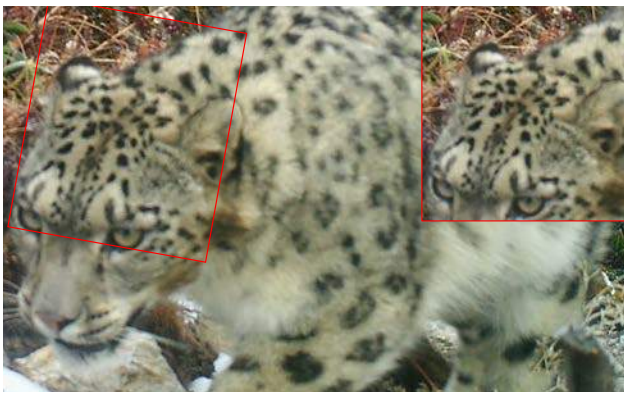
BTSL_09 (Right Dorsal Tail



BTSL_09 (Right Flank)

BTSL_10 (Dorsal Tail)

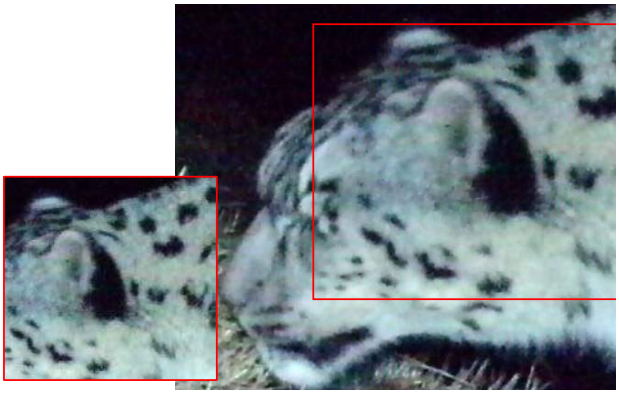
BTSL_10 (Left Front Limb)



BTSL_11 (Head)

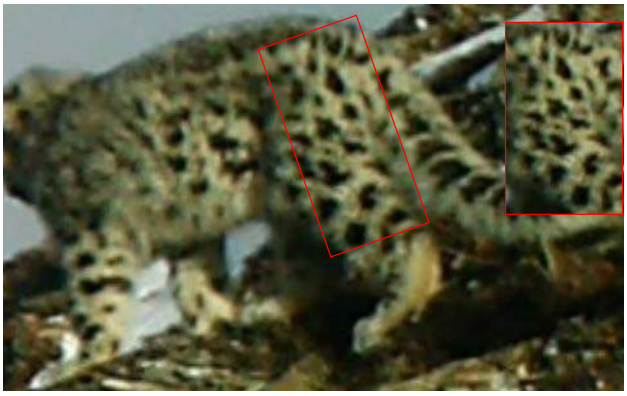
BTSL_11 (Dorsal Tail)

BTSL_12 (Dorsal Tail)

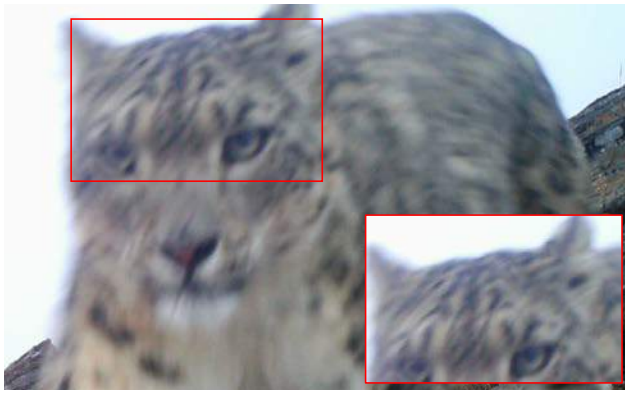


BTSL_12 (Head)

BTSL_13 (Right Flank)

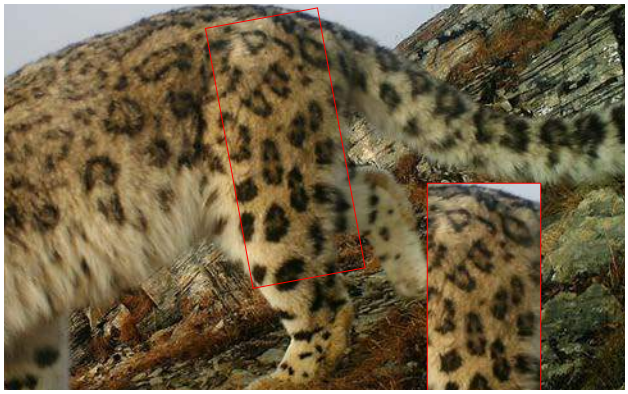


BTSL_14 (Left Flank)

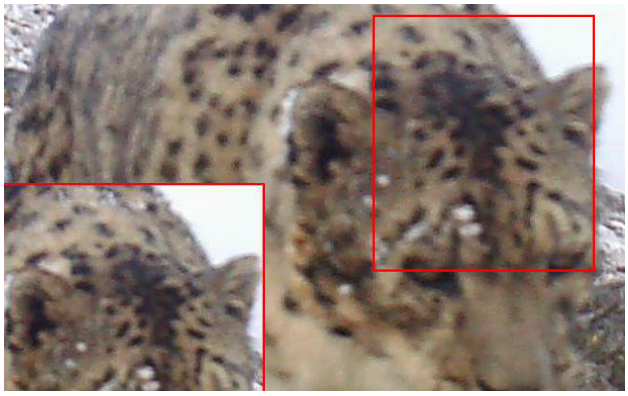


BTSL_15 (Head)

BTSL_15 (Dorsal Tail)



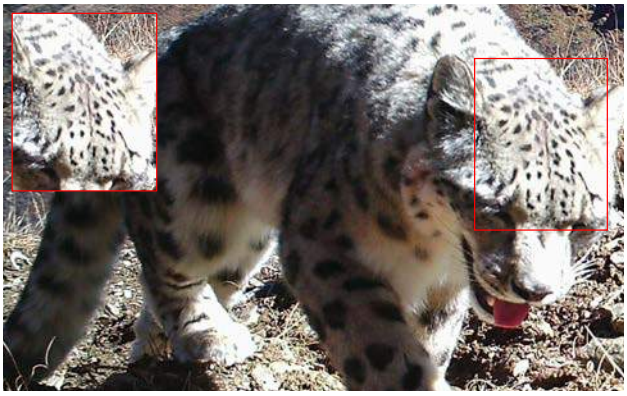
BTSL_15 (Left Flank)



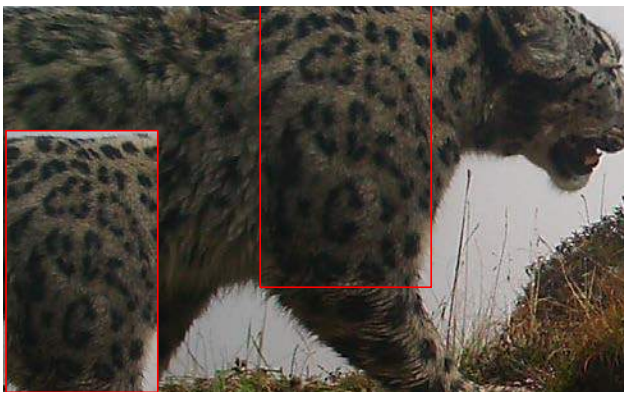
BTSL_16 (Head)

BTSL_16 (Dorsal Tail)

BTSL_17 (Left Flank)



BTSL_17 (Head)

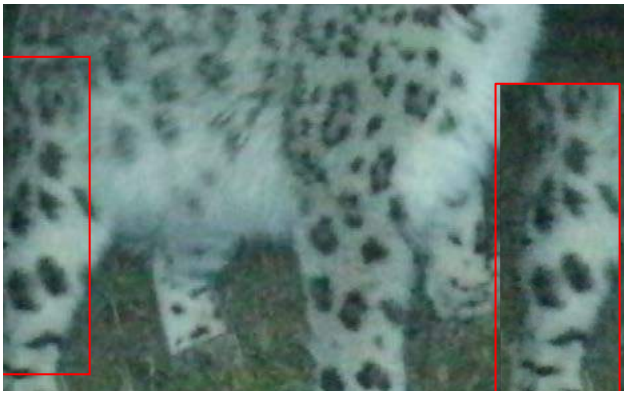


BTSL_17 (Right Shoulder)

BTSL__17 (Right Flank)

BTSL_18 (Right Dorsal Tail)

BTSL_18 (Right Flank)

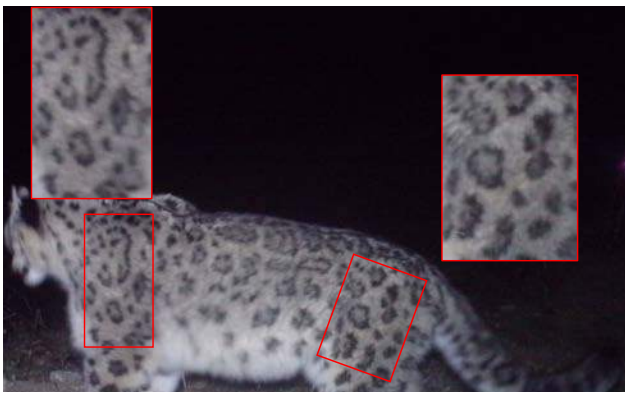


BTSL_19 (Hind Limb)

BTSL_19 (Shoulder)

BTSL_19 (Front Limb)

BTSL_20 (Dorsal Tail)

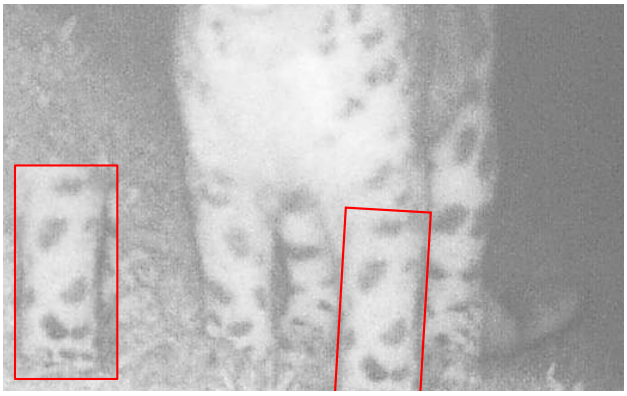


BTSL_20 (Left Shoulder & Flank)

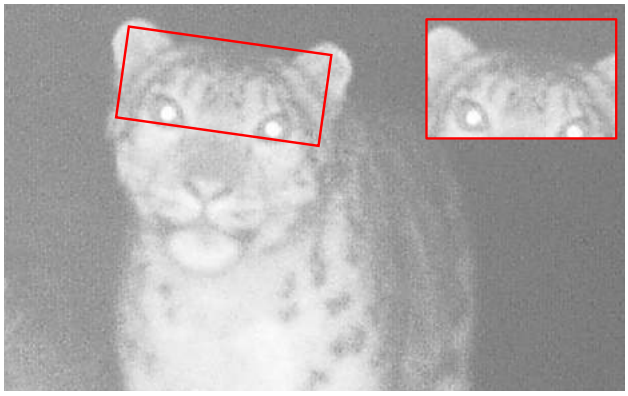
BTSL_21 (Left Flank)

BTSL_21 (Left dorsal tail)

BTSL_22 (Dorsal Tail)



BTSL_22b (Left Front Limb)



BTSL_22b (Fore Head)

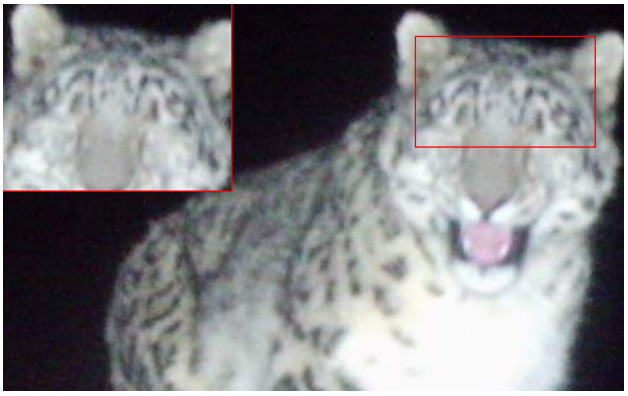
BTSL_23 (Left Flank)

BTSL_23 (Right Dorsal Tail)

BTSL_23 (Right Flank)

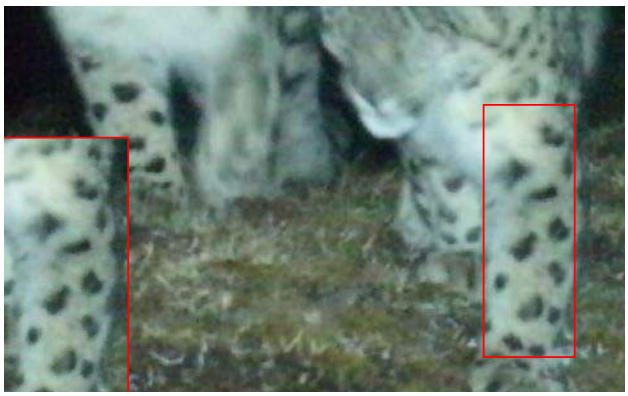
BTSL_24 (Right Flank)

BTSL_24 (Right Front Limb)



NTSL_25 (Head)

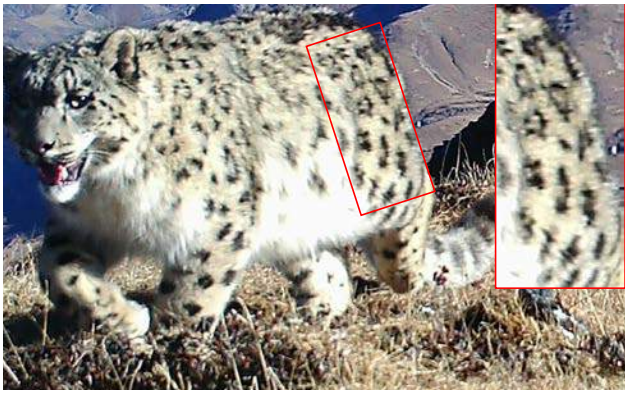
BTSL_25 (Right Front Limb)



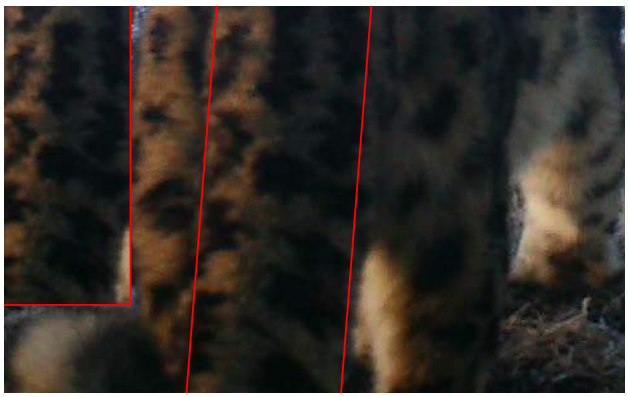
BTSL_26 (Left Front Limb)

BTSL_26 (Left Shoulder)

BTSL_27 (Right Front Limb)



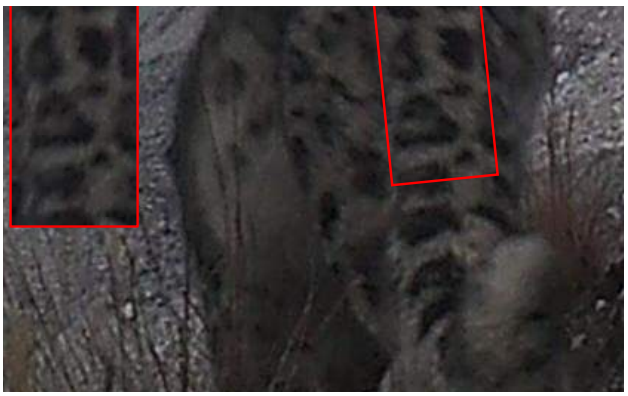
BTSL_27 (Left Flank)



BTSL_27 (Dorsal Tail)

BTSL_28 (Dorsal Tail)

BTSL_28 (Left Front Limb)



BTSL_29 (Dorsal Tail)

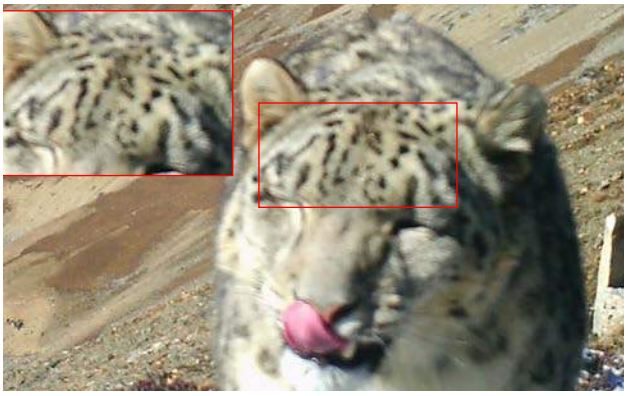
BTSL_29 (Left Flank)

BTSL_30 (Dorsal Tail)

BTSL_30 (Left Flank)

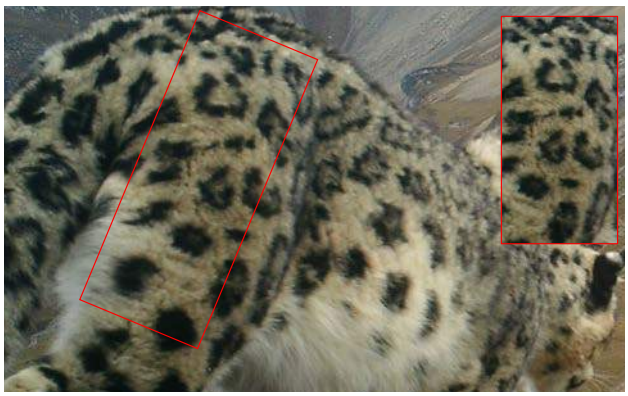
BTSL_31 (Back)

BTSL_31 (Right Front Limb)

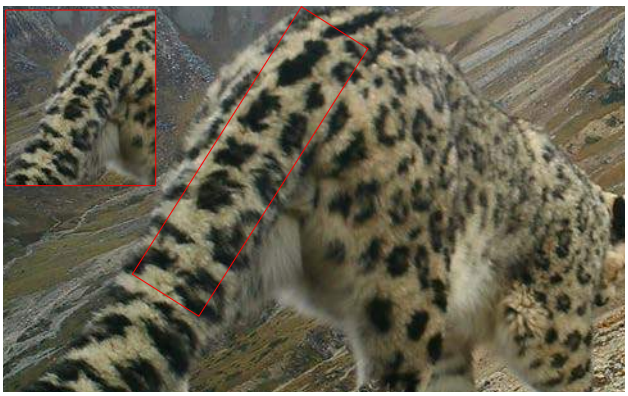


BTSL_32 (Head)

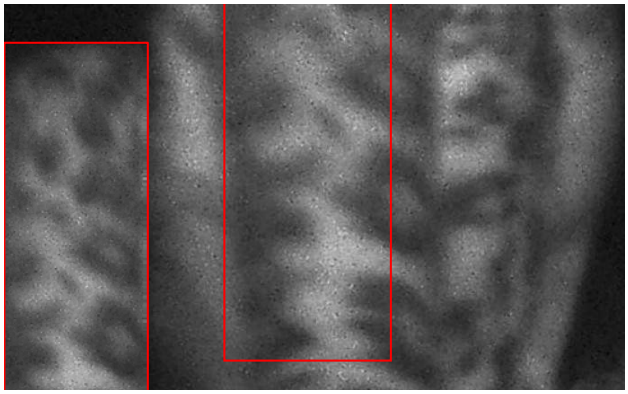
BTSL_32 (Right Front Limb)



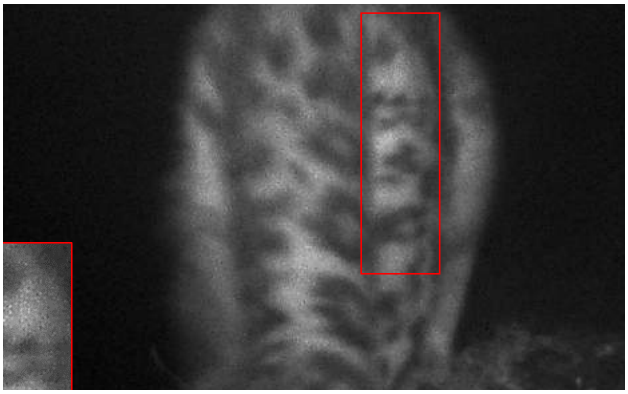
BTSL_32 (Right Flank)



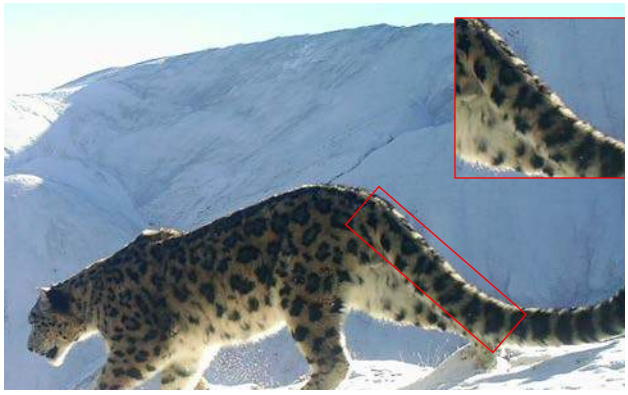
BTSL_32 (Right Dorsal Tail)



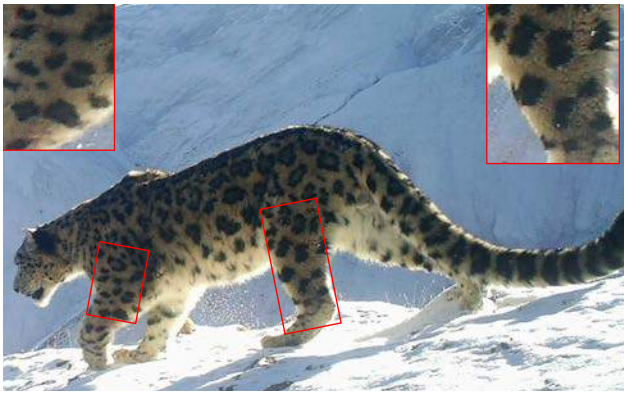
BTSL_33 (Dorsal Tail)



BTSL_33 (Right Flank)



BTSL_34 (Left Dorsal Tail)



BTSL_34 (Left Front shoulder & Hind Limb)

BTSL_35 (Dorsal Tail)

BTSL_35 (Back)

BTSL_36 (Left Front Limb)

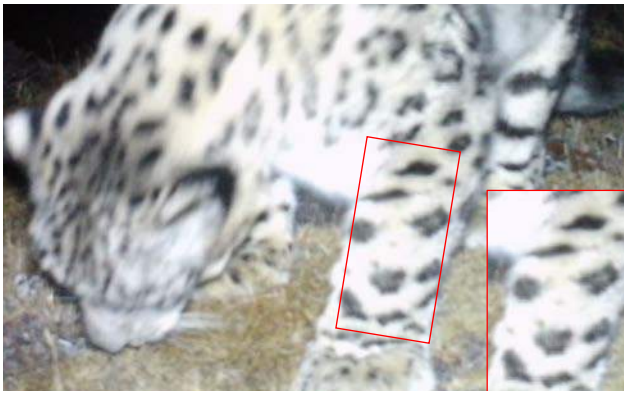
BTSL_36 (Dorsal Tail)

BTSL_37 (Dorsal Tail)

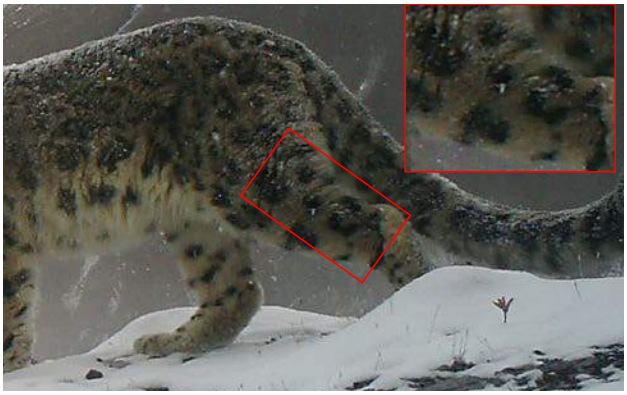
BTSL_37 (Left Flank)

BTSL_38 (Left Dorsal Tail)

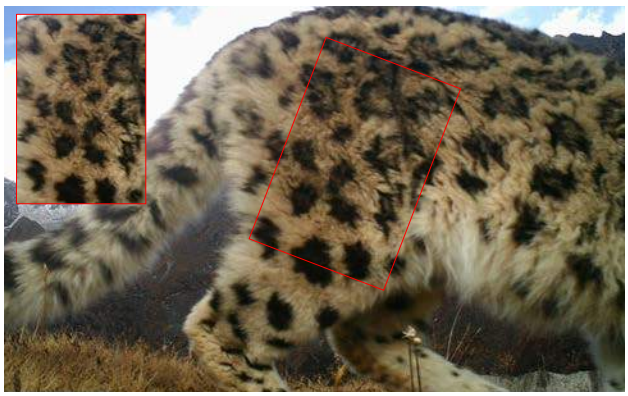
BTSL_38 (Back)



BTSL_39 (Left Front Limb)



BTSL_39 (Left Back Limb)

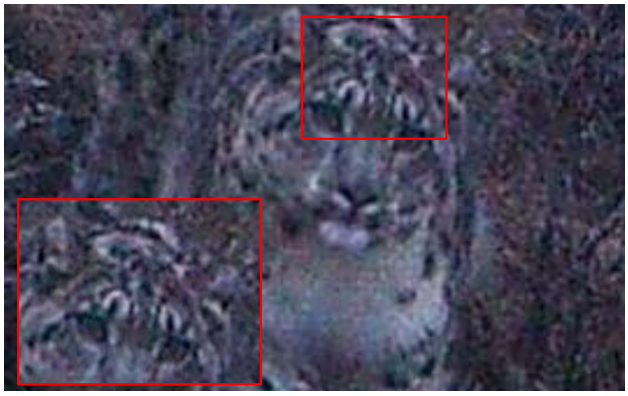


BTSL_40 (Right Flank)

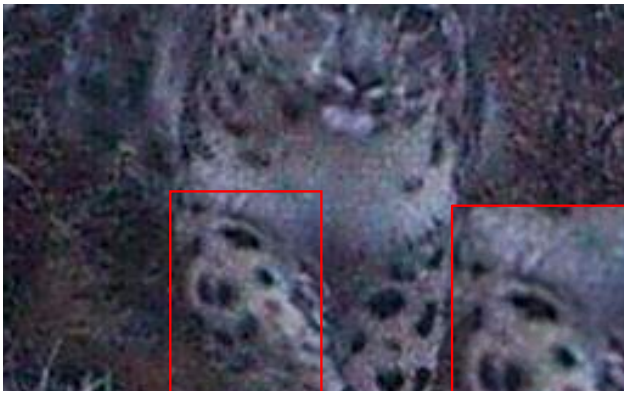
BTSL_40 (Right Hind Limb)

BTSL_41 (Right Flank & Shoulder)

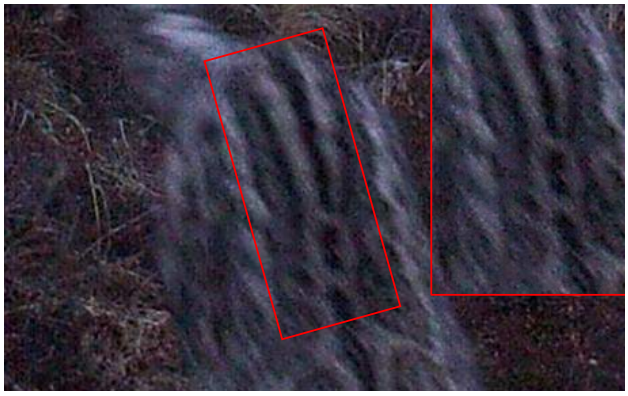
BTSL_41 (Right Front Limb)



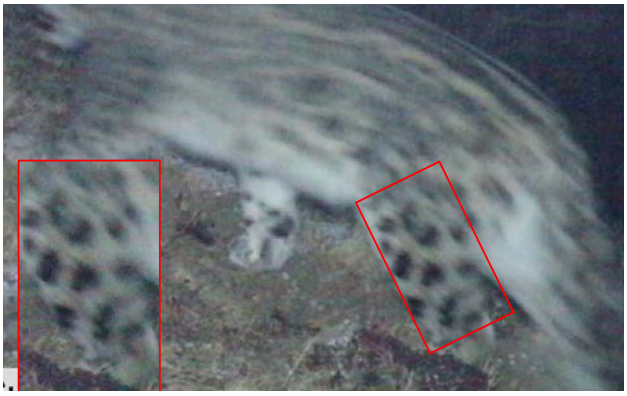
BTSL_42 (Head)



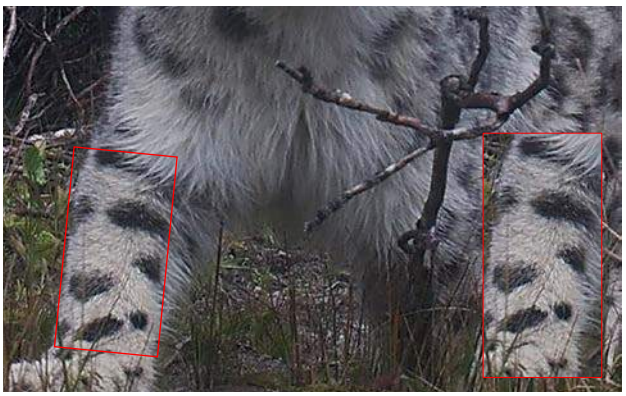
BTSL_42 (Right Front Limb)



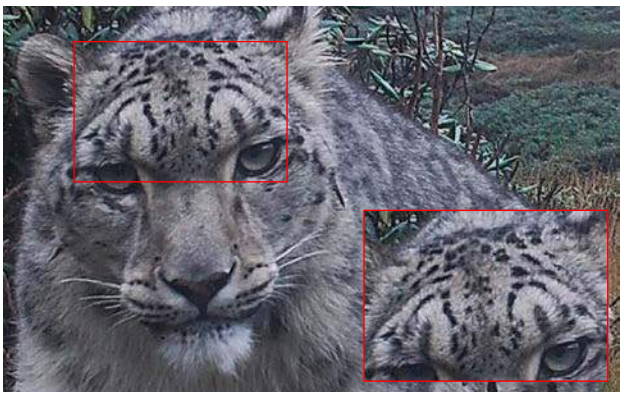
BTSL_43 (Back)



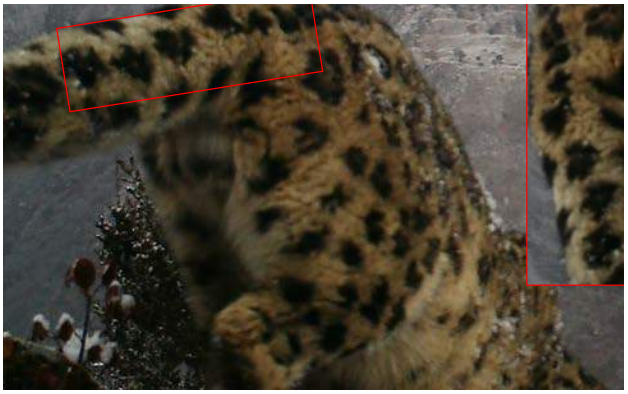
BTSL_43 (Left Hind Limb)



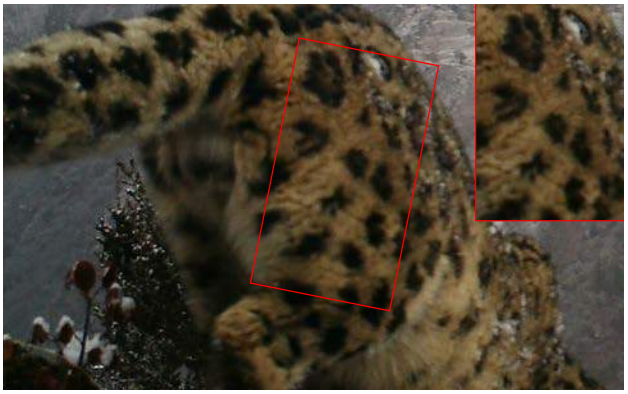
BTSL_44 (Right Front Limb)



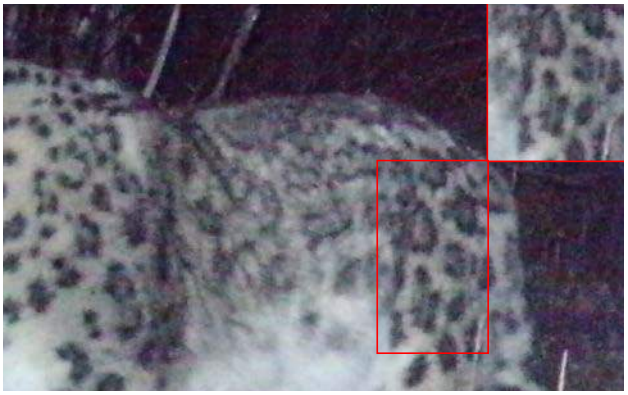
BTSL_44 (Head)



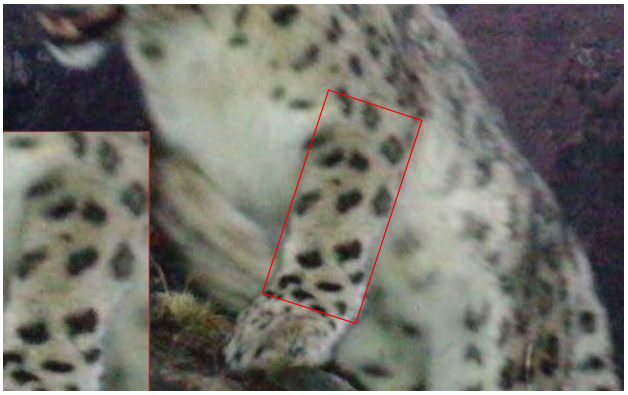
BTSL_45 (Right Dorsal Tail)



BTSL_45 (Right Flank)



BTSL_45 (Left Flank)

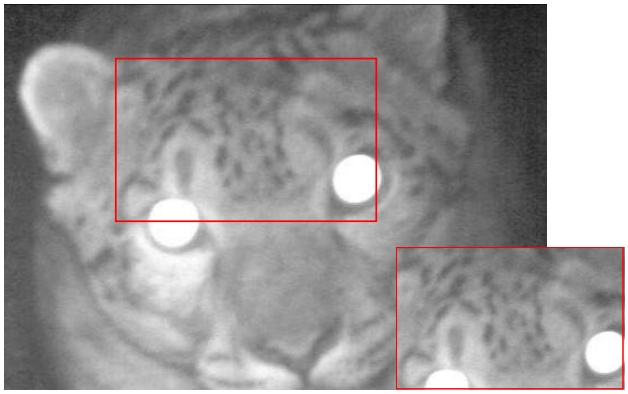


BTSL_45 (Left Front Limb)

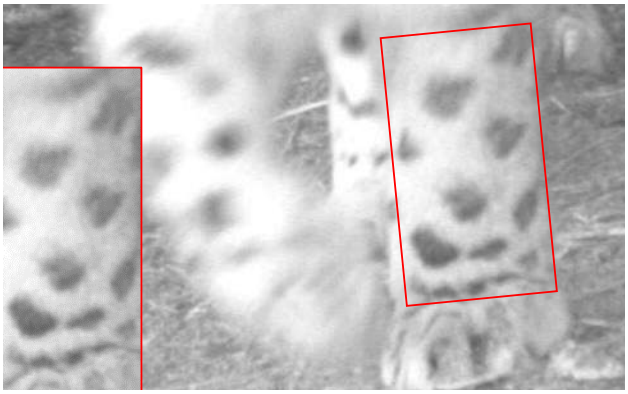
BTSL_46 (Right Flank)

BTSL_46 (Right Dorsal Tail)

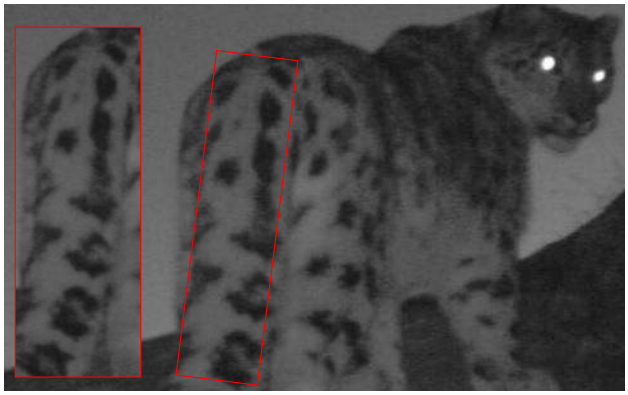
BTSL_46 (Left Flank)



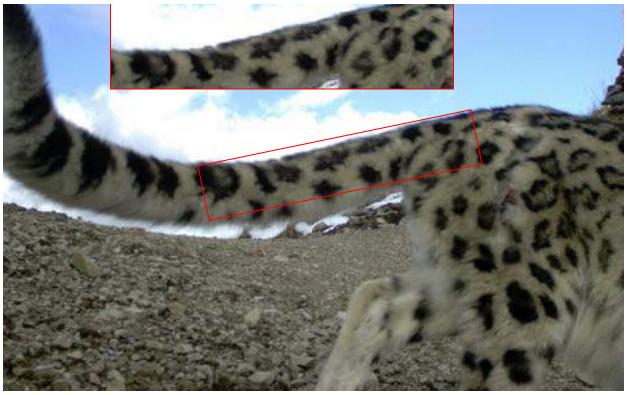
BTSL_47 (Head)



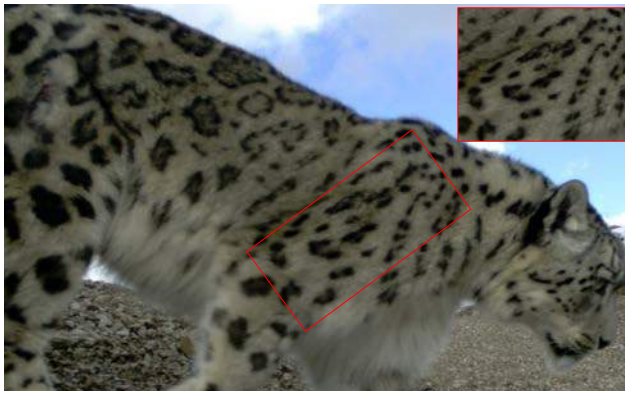
BTSL-47 (Left Front Limb)



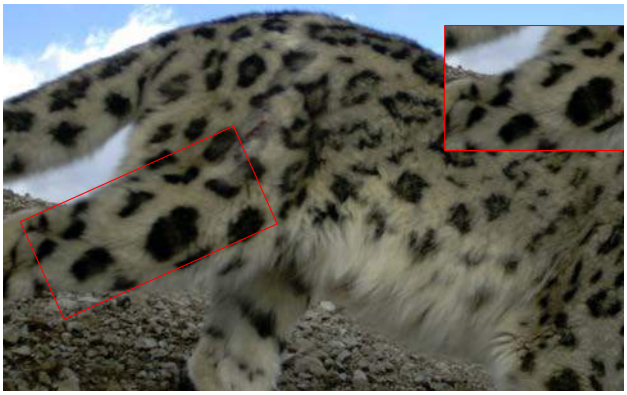
BTSL_47 (Dorsal Tail)



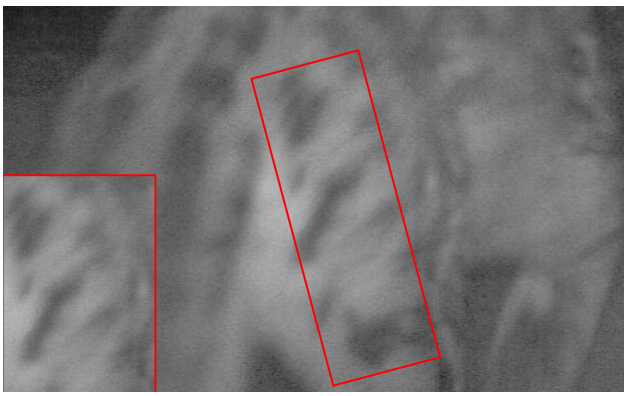
BTSL_48 (Right Dorsal Tail)



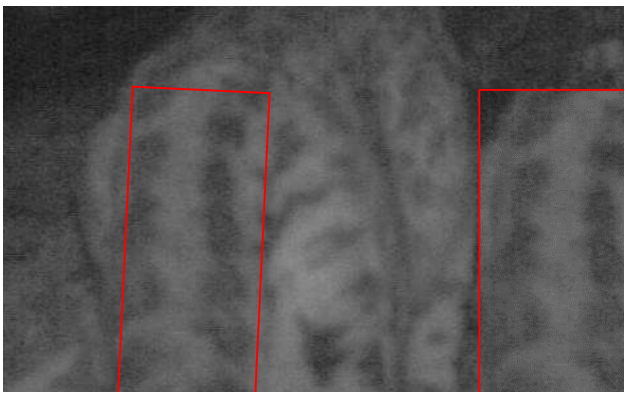
BTSL_48 (Right Shoulder)



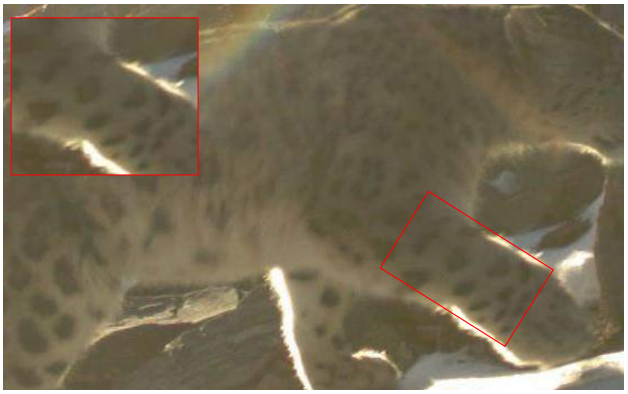
BTSL_48 (Right Hind Limb)



BTSL_49 (Right Flank)

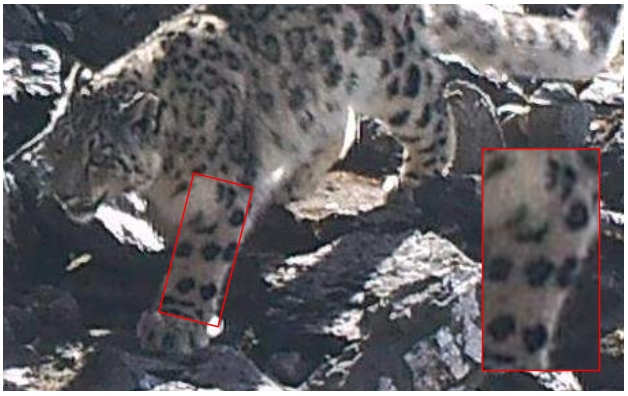


BTSL_49 (Dorsal Tail)



BTSL_50 (Right Front Limb)

BTSL_50 (Right Hind Limb)



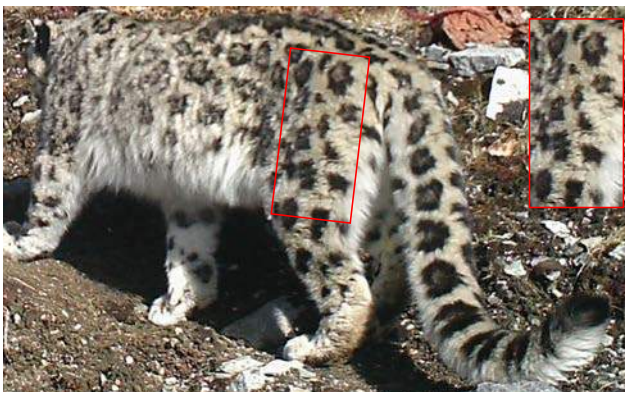
BTSL_51 (Left Front Limb)

BTSL_51 (Left Back Limb)

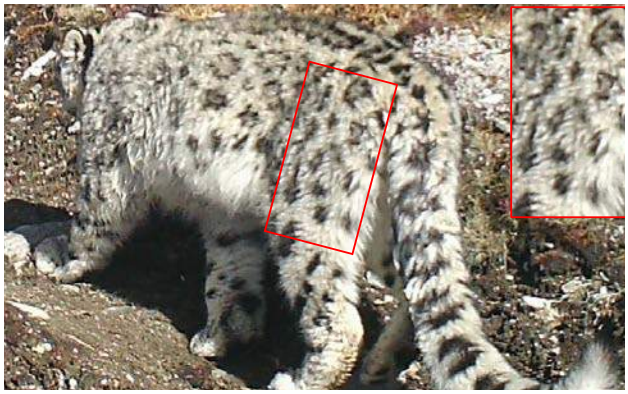
BTSL_52 (Left Front Limb)

BTSL_52 (Left Hind Limb)

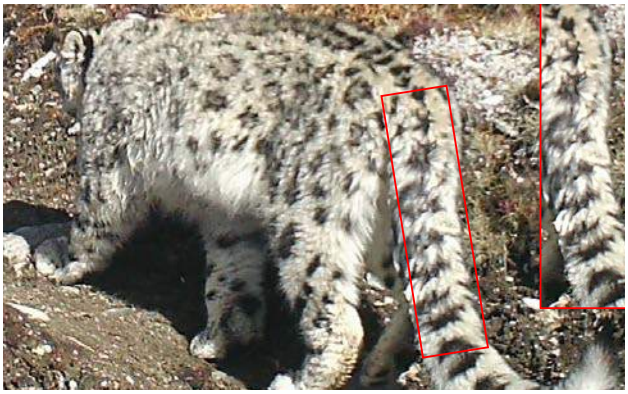
BTSL_53 (Left Dorsal Tail)



BTSL_53 (Left Flank)

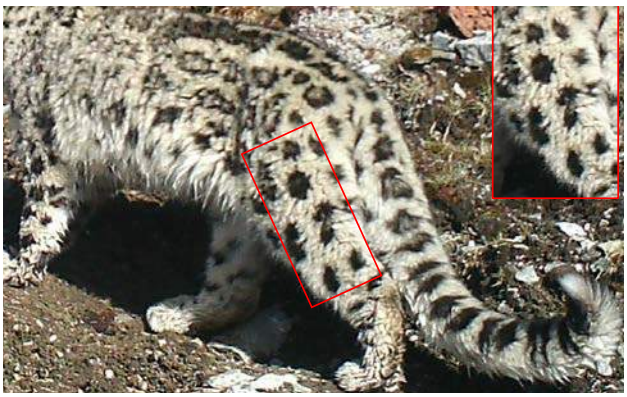


BTSL_54 (Felt Flank)



BTSL_54 (Left Dorsal Tail)

BTSL_55 (Left Dorsal Tail)



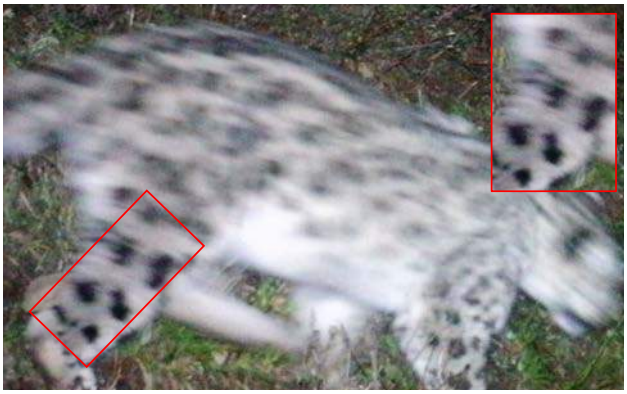
BTSL _55 (Left Flank)

BTSL_56 (Left Dorsal Tail)

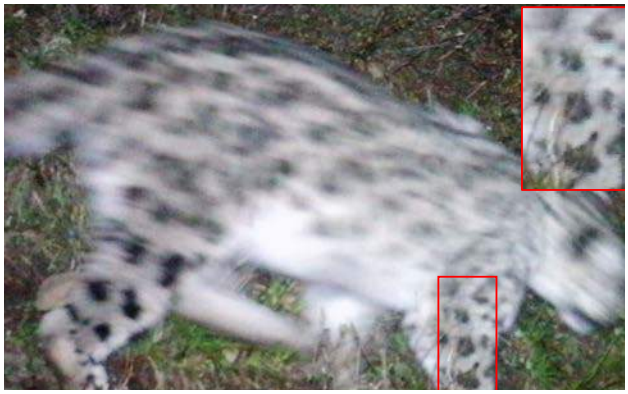
BTSL_56 (Left Flank)

BTSL_57 (Right Front Limb)

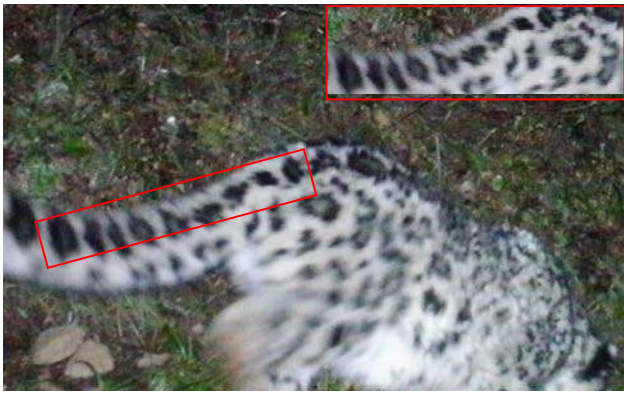
BTSL_57 (Right Hind Limb)



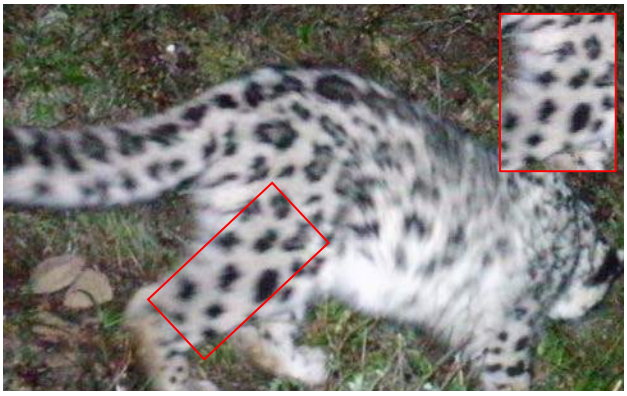
BTSL_58 (Right Hind Limb)



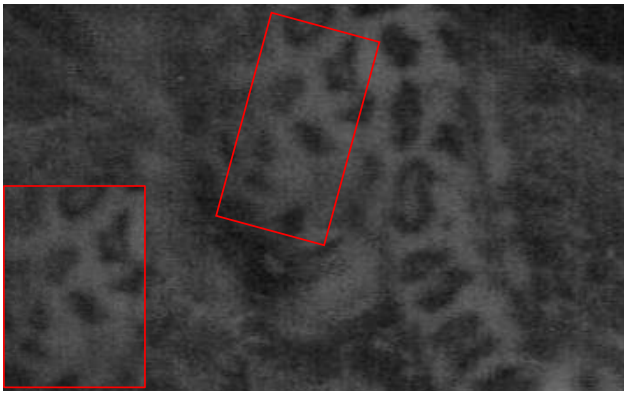
BTSL_58 (Right Front Limb)



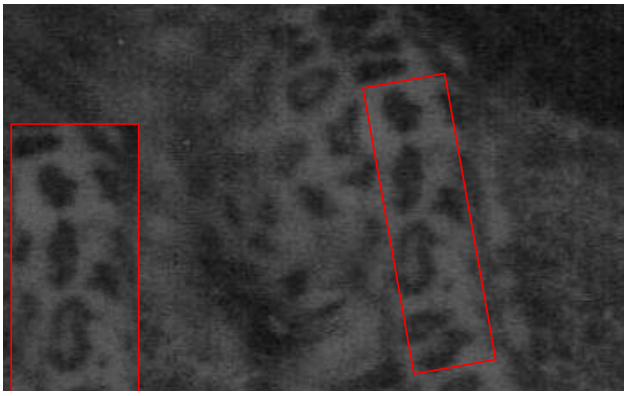
BTSL_59 (Right Dorsal Tail)



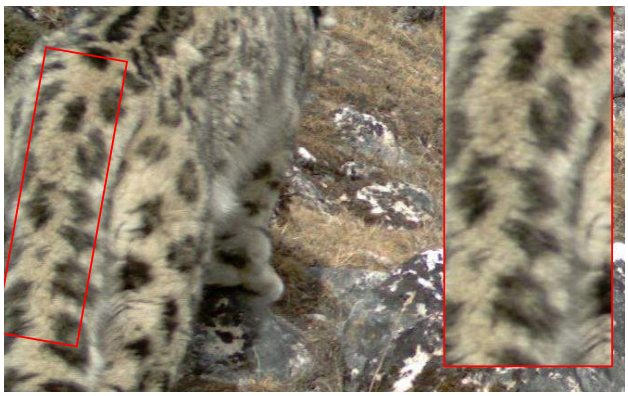
BTSL_59 (Right Hind Limb)



BTSL_60 (Left Flank)

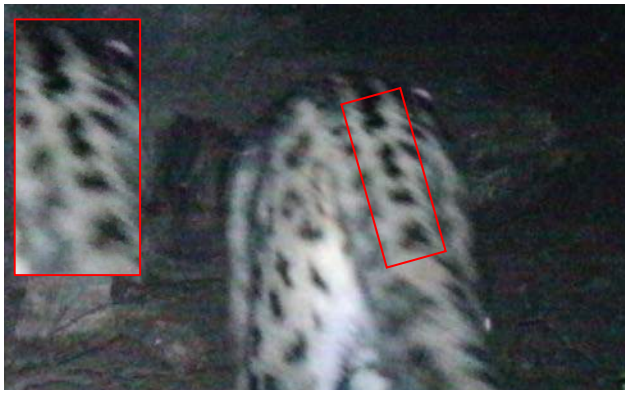


BTSL_60 (Left Dorsal Tail)

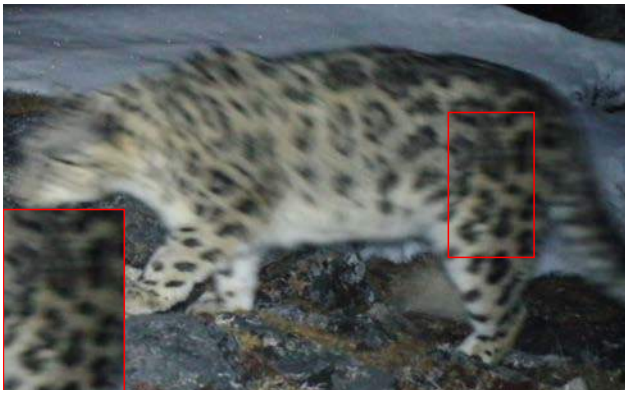


BTSL_61 (Right Dorsal Tail)

BTSL_61 (Right Flank)

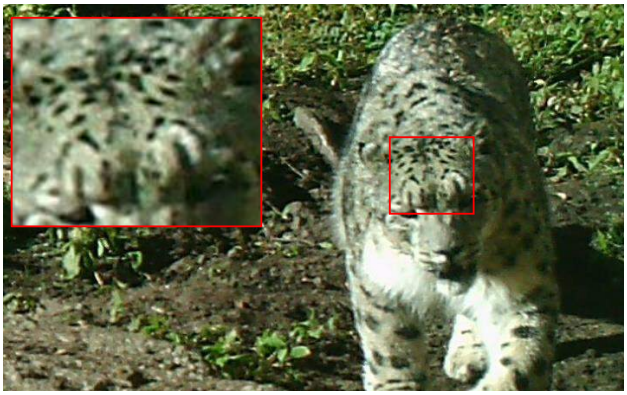


BTSL_62 (Dorsal Tail)

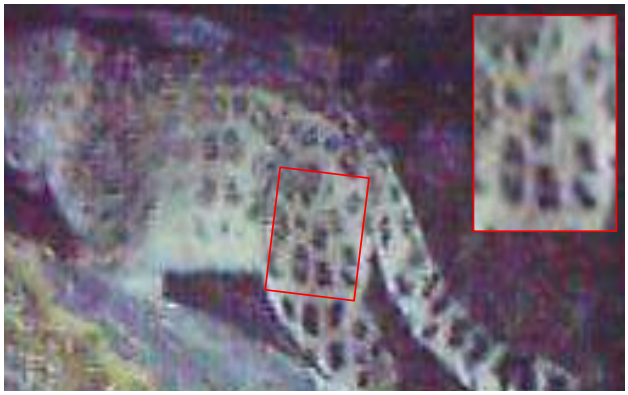


BTSL_62 (Left Flank)

BTSL_62 (Right Dorsal Tail)



BTSL_62 (Head)



BTSL_63 (Left Flank)

Appendix Figure 3: Images of sympatric predators found in the snow leopard habitats

Red fox (*Vulpes vulpes*)

Mountain weasel (*Mustela altaica*)

Asiatic wild dog (*Cuon alpinus*)

Asiatic black bear (*Ursus thibetanus*)

Asiatic golden cat (*Pardofelis temminckii*)

Yellow throated marten (*Martes flavigula*)

Appendix Table 1: Record of camera stations in each survey area with number of snow leopard individuals captured along with individual ID.

Station code	Survey area	# of Individuals	Individual ID
G2	JKSNR	2	BTSL_1, BTSL_6
G6	JKSNR	2	BTSL_1, BTSL_6
G8	JKSNR	2	BTSL_6, BTSL_7
G9	JKSNR	4	BTSL_3, BTSL_4, BTSL_8, BTSL_9
G11	JKSNR	1	BTSL_2
G12	JKSNR	1	BTSL_6
G13	JKSNR	1	BTSL_4
G14	JKSNR	2	BTSL_5, BTSL_9
G22	PTFD	1	BTSL_10
G23	PTFD	2	BTSL_10, BTSL_11
G32	PTFD	1	BTSL_15
G34	PTFD	2	BTSL_12, BTSL_13
G35	PTFD	2	BTSL_14, BTSL_15
G37	PTFD	1	BTSL_15
G40	JDNP	1	BTSL_21
G41	JDNP	1	BTSL_28
G42	JDNP	1	BTSL_37
G44	JDNP	1	BTSL_20
G47	JDNP	3	BTSL_26, BTSL_35, BTSL_36
G49	JDNP	1	BTSL_27
G50	JDNP	1	BTSL_17
G53	JDNP	2	BTSL_25, BTSL_26
G55	JDNP	3	BTSL_25, BTSL_26, BTSL_27
G56	JDNP	1	BTSL_17
G61	JDNP	1	BTSL_38
G65	JDNP	1	BTSL_23
G69	JDNP	2	BTSL_32, BTSL_33
G70	JDNP	1	BTSL_38
G72	JDNP	1	BTSL_22
G73	JDNP	1	BTSL_16
G78	JDNP	5	BTSL_18, BTSL_19, BTSL_29, BTSL_30, BTSL_31
G79	JDNP	3	BTSL_19, BTSL_34, BTSL_39
G80	JDNP	1	BTSL_39
G88	JDNP	1	BTSL_24
G89	JDNP	1	BTSL_44
G92	JDNP	1	BTSL_24
G93	JDNP	1	BTSL_44
G98	JDNP	1	BTSL_44
G103	JDNP	1	BTSL_41
G113	JDNP	1	BTSL_40
G123	JDNP	1	BTSL_40

G128	JDNP	1	BTSL_45
G129	JDNP	1	BTSL_45, BTSL_46
G130	JDNP	2	BTSL_45, BTSL_46
G142	JDNP	2	BTSL_42, BTSL_43
G145	WCNP	1	BTSL_47
G146	WCNP	1	BTSL_47
G147	WCNP	2	BTSL_49, BTSL_50
G148	WCNP	2	BTSL_47, BTSL_48
G151	WCNP	2	BTSL_51, BTSL_52
G153	WCNP	2	BTSL_58, BTSL_59
G163	WCNP	1	BTSL_62
G170	WCNP	5	BTSL_53, BTSL_54, BTSL_55, BTSL_56, BTSL_57
G180	WCNP	1	BTSL_63
G181	WCNP	1	BTSL_62
G186	WCNP	1	BTSL_60
G207	WCNP	1	BTSL_60
G208	WCNP	1	BTSL_61
G211	WCNP	1	BTSL_61

Appendix Table 2: Record of snow leopard individuals captured on camera stations in each survey area.

Individual ID	Total capture	Total stations with capture	Station code
BTSL_1	2	2	6, 2
BTSL_2	1	1	11
BTSL_3	2	1	9
BTSL_4	5	2	9, 13
BTSL_5	1	1	14
BTSL_6	9	4	2, 6, 8, 12
BTSL_7	2	1	8
BTSL_8	1	1	9
BTSL_9	2	2	9, 14
BTSL_10	6	2	22, 23
BTSL_11	3	1	23
BTSL_12	1	1	34
BTSL_13	1	1	34
BTSL_14	1	1	35
BTSL_15	10	3	32, 35, 37
BTSL_16	2	1	73
BTSL_17	12	2	50, 56
BTSL_18	2	1	78
BTSL_19	3	1	78
BTSL_20	1	1	44
BTSL_21	2	1	40
BTSL_22	1	1	72
BTSL_23	3	1	65
BTSL_24	5	2	88, 92
BTSL_25	2	2	53, 55
BTSL_26	3	3	47, 53, 55
BTSL_27	5	2	49, 55
BTSL_28	2	1	41
BTSL_29	2	1	78
BTSL_30	1	1	78
BTSL_31	1	1	78
BTSL_32	1	1	69
BTSL_33	1	1	69
BTSL_34	1	1	79
BTSL_35	1	1	47
BTSL_36	1	1	47
BTSL_37	2	1	42
BTSL_38	3	2	61, 70
BTSL_39	2	2	79, 80

BTSL_40	7	2	113, 123
BTSL_41	4	1	103
BTSL_42	1	1	142
BTSL_43	1	1	142
BTSL_44	4	3	89, 93, 98
BTSL_45	7	3	128, 129, 130
BTSL_46	8	2	129, 130
BTSL_47	5	3	145, 146, 148
BTSL_48	1	1	148
BTSL_49	1	1	147
BTSL_50	1	1	147
BTSL_51	3	1	151
BTSL_52	3	1	151
BTSL_53	1	1	170
BTSL 54	1	1	170
BTSL_55	1	1	170
BTSL_56	2	1	170
BTSL_57	1	1	170
BTSL_58	2	2	153, 159
BTSL_59	1	1	153
BTSL_60	2	2	186, 207
BTSL_61	2	2	208, 211
BTSL_62	3	2	163, 181
BTSL_63	2	1	180

Appendix Table 3: List of National Snow Leopard Survey (2015-2016) team members.

National Coordinator	
Dechen Lham	Wildlife Conservation Division
Core-group members	
1. Sonam Wangchuk	Wildlife Conservation Division
2. Dr. Phuntsho Thinley	Ugyen Wangchuck Institute for Environmental Conservation
3. Namgay Wangchuk	Jigme Khesar Strict Nature Reserve
4. Tandin Namgay	Wildlife Conservation Division
5. Kinzang Lham	Wildlife Conservation Division
6. Tenzin	Wangchuck Centennial National Park
7. Lhendup Tharchen	Jigme Dorji National Park
8. Phuntsho	Forest Resources Management Division

List of staff's involved in the survey from Jigme Khesar Strict Nature Reserve
1. Namgay Wangchuk
2. Ugyen Tshering
3. Ngawang Dorji
4. Ugyen
5. Phub Dorji
6. Bhakta Bdr. Ghalley, Reserve Focal
7. Gyeltshen Dorji
8. Tshewang Namgay
9. Rinzin Dorji
10. Sangay Gyeltshen
11. Kinley Tenzin
12. Guman Singh Biswa
13. Kezang Wangdi
14. Wangchuk
15. Dechen Wangda

List of staff's involved in the survey from Paro Territorial Division	
1. Sonam Dorji	Haa Range
2. Karma Rinchen	Haa Range
3. Nima Tshering	Haa Range
4. Nima Tshering Sherpa	Selela FMU
5. Tshering Nima	Lonchu FMU
6. Jigme Lhendup	Zonglela FMU
7. Lhab Tshering	Paro Range
8. Karma	Zonglela FMU
9. Tshering Norbu	Bitekha FMU
10. Kelzang	Haa Range
11. Tshering Phuntsho	Selela FMU
12. Dawa	Paro Division
13. Gado	Paro Division
14. Phuntsho Wangdi	Paro Division
15. Kaka Tshering	Paro Division

List of staff's involved in the survey from Jigme Dorji National Park	
1. Tandin Dorji	Range Focal, Ramina Park Range
2. Kado Drukpa	Ramina Park Range
3. Passang Gurung	Ramina Park Range
4. Tendrel Zangpo	Ramina Park Range
5. Bishnu Kumar Galley	Ramina Park Range
6. Thinley Wangchuk	Ramina Park Range
7. Thinley Wangchuk	Ramina Park Range
8. Norbu	Range Focal, Laya Park Range
9. Leki Wangdi	Laya Park Range
10. Prakash Karki	Laya Park Range
11. Tashi	Laya Park Range
12. Karma Wangchuk	Laya Park Range
13. Karma Jangchuk	Laya Park Range
14. Dagay	Range Focal, Lingzhi Park Range
15. Tshering Dorji	Lingzhi Park Range
16. Jangchuk Dorji	Lingzhi Park Range
17. Sonam Jamtsho	Lingzhi Park Range
18. Tandin Dorji	Lingzhi Park Range
19. Sonam Dorji	Lingzhi Park Range
20. Phub Dorji	Lingzhi Park Range
21. Wangchuk Phuntsho	Lingzhi Park Range
22. Ugyen Tshering	Lingzhi Park Range
23. Dorji Gyeltshen	Lingzhi Park Range
24. Dawa Rinchen	Lingzhi Park Range
25. Thinley Wangchuk	Lingzhi Park Range
26. Kuenley Sithup	Lingzhi Park Range
27. Lhaba	Range Focal, Soe Park Range
28. Pema Dorji	Soe Park Range
29. Tshering Yargay	Soe Park Range
30. Dorji Wangdi	Soe Park Range
31. Sangay Dorji	Soe Park Range
32. Kinley Dorji	Soe Park Range
33. Kunzang Wangchuk	Soe Park Range
34. Kezang Thinley	Soe Park Range
35. Pema Kuenzang Wangchuk	Soe Park Range
36. Youenten Jamtsho	Soe Park Range
37. Gyeltshen	Soe Park Range
38. Nindala	Soe Park Range
39. Rinzin Dorji	Park Focal, Park Headquarter

List of staffs from Wangchuck Centennial National Park	
1. Nado	Park Headquarter
2. Sonam Wangmo	Park Headquarter
4. Doley	Bumthang Territorial Division
5. Rinchen Dorji	Bumthang Territorial Division
6. Tshering Tobgay	Bumthang Territorial Division
7. Dorji Wangchuk	Eastern Park Range
8. Tilak Bdr. Ghalley	Eastern Park Range
9. Ugyen Galtsho	Eastern Park Range
10. Sither Dorji	Eastern Park Range
11. Chandra Kr. Gurung	Central Park Range
12. Choki Gyeltshen	Central Park Range
13. Kezang Tenzin	Central Park Range
14. Dechen Norbu	Central Park Range
15. Kezang Dawa	Central Park Range
16. Pema Tshering	Central Park Range
17. Jampel Nidup	Central Park Range
18. Ngawang Tashi	Western Park Range
19. Lakey Dorji	Western Park Range
20. Tshering Dhendup	Park Headquarter

List of staffs from Bumdeling Wildlife Sanctuary	
1. Tshering Dendup	Park Focal, Park Headquarter
2. Choining Zangpo	Dungzam Range
3. Tshering Chophel	Dungzam Range
4. Dorji Phuntsho	Dungzam Range
5. Dawa Gyalpo	Dungzam Range
6. Kunzang Thinley	Khoma Range
7. Kumbu Dorji	Khoma Range
8. Karma Sangay	Khoma Range
9. Tashi Dendup	Khoma Range
10. Pema Wangchuk	Khoma Range
11. Jamyangla	Serzhong Range
12. Sangay Dorji	Serzhong Range
13. Karma Tempa	Park Headquarter
14. Pankey Dukpa	Park Headquarter

Project Management Unit	
1. Sonam Wangchuck	Wildlife Conservation Division
2. Dechen Lham	Wildlife Conservation Division
3. Tenzin Dema	Wildlife Conservation Division

APPENDIX III: FORM FOR INSTALLATION OF CAMERA TRAPS

Form Number		Date		Elevation	
Grid number		Time		Latitude (N)	
Camera ID		WP name		Longitude (E)	
Battery status		Memory Card ID		Program mode	
Site Name		Name of Person(s)		Remarks	
Type of Feature Attracting Snow Leopard		**Snow Leopard Sign Present**		**Position on Slope**	
Travel Corridor		Pugmarks:		Lower	
Rock scents		Size:		Middle	
Scrape Site		Age Class:		Upper	
Kill		Scrapes:			
Trail		Number present:		**Ruggedness**	
Corral		Size:		Cliff	
Other (describe):		Age Classes:		Broken	
Trail Type		Rock scents:		Very Broken	
Well defined		Number present:		Rolling	
Moderately well defined		Age Classes:		Flat, Valley Floor	
Poorly defined or hard to see		Faeces:		**Topographic feature**	
Dominant Substrate		Number present		Cliff	
Rocky		Age Class		Ridgeline	
Gravelly		**Prey Sign Present**		Hill-slope	
Sandy		Blue Sheep		Valley Floor	
Fine grained:		Livestock		Stream Bed	
Vegetation Type		Hare		Scree/boulders	
Barren		Others:		**Rangeland Use**	
Grassland		**Human Presence**		Spring	
Scrubland		Daily		Summer	
Cropland		Once a week		Winter	
Meadow		Once a month		Year-round	
Other (describe):		Rarely visited		No Use	
Camera Settings					
Distance to trail			Angle to trail		
Aspect			Camera Ht.		

APPENDIX IV: FORM FOR MONITORING OF CAMERA-TRAPS

Form no.					
Camera trapping site details					
Grid number		Site name			
Northing		Easting		Elevation (m)	
Distance to human/animal trail (m)					
Angle to trail (degree)			Camera ht. above ground(cm)		
Aspect of camera site					
Status of the camera trap					
Date of camera monitoring			Time of camera monitoring		
Names of monitoring team members					
Total pictures recorded on **camera a**				**camera b**	
Battery status (remaining hours left - write hours and minutes properly)					
Camera a			**Camera b**		
Signs of wild animals around the cameras					
Conditions of the signs (fresh/old)					
Pasture use around the cameras and in the grid					
name of yak herding site	Northing	Easting	No. of yaks	No. of dogs	No. of humans
Write other observations:					
NOTES: 1. Use this form once in two weeks. Monitor cameras at least once in two weeks					
2. Record the new GPS coordinates of the cameras while shifting location within the grid					

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ISBN: 978 - 99936 - 817 - 8 - 6