TECHNICAL REPORT

NATIONAL SNOW LEOPARD SURVEY OF BHUTAN 2014 - 2016 (PHASE I): SIGN AND PREY BASE SURVEY

Wildlife Conservation Division,
Department of Forests and Park Services,
Thimphu, Bhutan
May 2016

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National Snow Leopard Survey of Bhutan 2014-2016 (Phase I): Sign and Prey

Base Survey .

Department of Forests and Parks Services

DEDICATION

This technical report on National Snow Leopard Survey - Phase I: Sign and Prey Base Survey is dedicated to the jubilant celebration of the birth of His Royal Highness The Gyalsay Jigme Namgyel Wangchuck, "The Crown Prince of Bhutan".

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ROYAL GOVERNMENT OF BHUTAN
Ministry of Agriculture and Forests
Tashichhodzong
Thimphu:Bhutan

MINISTER

PREFACE

Bhutan is known as a biodiversity hotspot with diversity of species thriving from an altitude of 150 to 7000 m.a.s.l. The lowlands are largely inhabited by predators such as tigers, leopards and dholes, and their main prey such as sambar, barking deer and guar while the highlands are predominated by predators such as snow leopard and grey wolf and their prey such as blue sheep, marmot and musk deer.

Conservation of all ecosystems is crucial. Especially, conservation of the alpine ecosystem is of paramount importance in the current face of water scarcity and impending threats of climate change. Snow leopard is an umbrella species in the alpine ecosystem, and thus, the survival of many species is ensured while conserving this apex predator. Therefore, snow leopard and its prey species merit strong conservation focus in order to achieve optimal integrity of alpine ecosystem.

In light of the importance of snow leopard conservation, I am pleased that the Department of Forests and Parks Services has successfully completed the nation-wide snow leopard sign and prey base survey. Such a survey of national scale is not only first of its kind in Bhutan but also amongst the entire snow leopard range countries. This phase one report has generated tremendous database on snow leopard and its prey which is instrumental for the successful conduct of the phase two survey: population estimation using camera traps. Further, the database will be useful for the upcoming development of the national snow leopard conservation management plan. These are testament to Bhutan's strong commitment towards biodiversity conservation. They also reflect an enhanced national capacity to pursue large scale scientific explorations.

I, on behalf of the Royal Government of Bhutan, would like to convey our heartfelt appreciation to all the donors for generously supporting this historic national level survey. At the same time, we would like to reaffirm our political will and support for the conservation of snow leopards and their prey in the country which will go a long way to support the global initiative to 'Conserve 20 snow leopard landscapes by 2020'.

(Yeshey Dorji)
MINISTER

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Royal Government of Bhutan
Ministry of Agriculture and Forests
Department of Forests & Park Services

ACKNOWLEDGEMENT

The Department of Forests and Park Services is pleased to acknowledge the series of scientific studies and subsequent publications recently coordinated by the Wildlife Conservation Division. In addition to the recent nation-wide tiger survey, the current nation-wide snow leopard survey is another hallmark of conservation achievement in Bhutan. As part of the national snow leopard survey which was planned in two phases, the report on the phase one survey is timely and instrumental. This highly commendable report has opened our eyes to many important facets of snow leopard conservation besides providing indispensible data for the phase two survey.

The successful conduct of this phase one survey would not have been possible without the unwavering dedication and sacrifices of the field staff who were involved in the survey. I, on behalf of the Department, would like to sincerely thank all the survey team members for their collective professionalism and contributions.

Also, this important survey would not have happened if not for the generous support of our donors and conservation partners. I would like to put to record the kind assistance of our notable donors, particularly the World Bank's Internal 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). Concurrently, the co-funding and policy support from the Royal Government of Bhutan has been pivotal in the successful conduct of this survey and I would like to gratefully acknowledge such a national commitment.

Thank you and Tashi Delek!

(Phento Tshering)
Director

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EXECUTIVE SUMMARY

In August 2014, the first nation-wide snow leopard survey began with sign and prey-base survey (Phase I) across all possible areas of occurrence in Bhutan: Jigme Khesar Strict Nature Reserve, northern part of Paro Territorial Forest Division, Jigme Dorji National Park, Wangchuck Centennial National Park, Bumdeling Wildlife Sanctuary and Sakteng Wildlife Sanctuary.

This phase one survey, with the prime objective of understanding snow leopard and its prey distribution, lasted about a year. A total of 395 grids, each measuring 4 by 4 km, were surveyed across the potential habitats. Within each survey grid, the adequately trained survey teams looked for snow leopard and blue sheep signs, including sightings, and recorded their habitat utilizations. The MaxEnt model was used to predict the distributions of snow leopard and blue sheep.

A total of 345 snow leopard signs were encountered, and they were dominated by scats, followed by tracks. Majority of signs were encountered in JDNP, while the least number of signs were found in JKSNR. As regards to blue sheep, 426 signs were recorded, with droppings dominating the signs as in the case of snow leopard signs. Blue sheep signs showed similar pattern like that of the snow leopard with highest numbers recorded in JDNP, and BWS recorded the least. SWS did not record any sign of both snow leopard and blue sheep.

More than 50% of the snow leopard signs were found in alpine meadows. Highest number of snow leopard signs was observed in southeast aspect; between 30^{o} and 400^{o} slopes; and from 4,300 to 4,600 m altitudinal range. Blue sheep also showed similar habitat utilization pattern with most of the signs observed in alpine meadows, but in northeast aspect, between 0^{o} and 30^{o} slopes, and from 4,300 to 4,600 m.

MaxEnt model showed high probability of snow leopard occurrence in central part of JKSNR, northern part of PTFD, northern and west parts of JDNP, Western and Central Range of WCNP, and northern part of BWS's Dungzam Range. These areas also had high density of blue sheep, which was the environmental variable that mostly influenced the model gain for snow leopard distribution. Snow leopard distribution map clearly showed a declining probability of occurrence from west to east Bhutan. The model also showed the highest probability of blue sheep occurrence in most of JDNP, northern part of PTFD, central part of JKSNR, lower half of WCNP, and upper right portion of BWS. Land cover variable mostly influenced the MaxEnt model of blue sheep distribution.

Bhutan has vast swathe of suitable areas for snow leopard and blue sheep occurrence based on the phase I survey findings. In order to maintain Bhutan as an important stronghold for snow leopard conservation in the eastern Himalayas, several management recommendations are offered of which the strong emphasis should be afforded to maintain the alpine meadows and habitat connectivity between potential habitats. Data generated from this report could be used in careful planning of the Phase II survey, which involves estimating snow leopard population using camera traps, and for drafting of the snow leopard landscape conservation plan for Bhutan.

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LIST OF ACRONYMS

AUC	Area Under Curve
BTFEC	Bhutan Trust Fund for Environmental Conservation Bumdeling
BWS	Wildlife Sanctuary
CITES	Convention on International Trade in Endangered Species of Wild Flora and Fauna
DEM	Digital Elevation Model
DoFPS	Department of Forest and Parks Services
GIS	Geographical Information System
ICIMOD	International Centre for Integrated Mountain Development
IDA	International Development Assistance
IUCN	International Union for Conservation of Nature
JDNP	Jigme Dorji National Park
JKSNR	Jigme Khesar Strict Nature Reserve
JSWNP	Jigme Singye Wangchuck National Park
KLCDI	Kanchenjunga Landscape Conservation and Development Initiative Project
MaxEnT	Maximum Entropy
MoAF	Ministry of Agriculture and Forests
NABU	Nature And Biodiversity Conservation Union
NSLSB	National Snow Leopard Survey of Bhutan
PTFD	Paro Territorial Forest Division
PNP	Phrumsengla National Park
RGoB	Royal Government of Bhutan
RNRRDC	Renewable Natural Resource Research and Development Centre
ROC	Receiver Operating Characteristics
SWS	Sakteng Wildlife Sanctuary
WB	World Bank
WCD	Wildlife Conservation Division
WCNP	Wangchuck Centennial National Park
WWF	World Wildlife Fund

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CHAPTER ONE: INTRODUCTION

1.1. Background and Rationale

The snow leopard (*Panthera uncia*) is a globally endangered cat species, as per the IUCN's (International Union for the Conservation of Nature) Redlist database (IUCN 2013). In due recognition of its endangered status, the species is listed as one of the totally protected species in Schedule I of the Forest and Nature Conservation Act of Bhutan 1995 and also Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; Hussian 2003).

Snow leapord image captured in camera trap placed in JKSNR

The Royal Government of Bhutan greatly appreciates and values the conservation significance of this high profile predator. However, due to lack of adequate funding and technical expertise nation-wide survey of snow leopard and its prey base could not be conducted in the past although such a need was felt since a long time ago. As such, there has been a dearth of information about its population status, distribution pattern, and prey base in the country. In absence of such scientific details, the Department of Forests and Park Services (DoFPS) of the Ministry of Agriculture and Forests (MoAF) could not come out with concrete scientific management and action plans to ensure proper management of this iconic species.

In view of the mounting threats to snow leopard and its prey (Thinley et al. 2014), the Department felt the urgent need to conduct their population assessment at the national scale, in order to establish the baseline population figures for current management and future monitoring purposes. The Department through Wildlife Conservation Division (WCD) took the initiative to mobilize funds from numerous potential donors for this huge scientific venture.

Fortunately, with financial support from various agencies, notably the World Bank's International Development Association (WB-IDA) Project, the World Wildlife Fund (WWF) - Bhutan Programme, the Nature Conservation for Biodiversity Union (NABU Germany), the Bhutan Trust Fund for Environmental Conservation (BTFEC), Kanchenjunga Landscape Conservation and Development Initiative Project (KLCDI), International Centre for Integrated Mountain Development (ICIMOD) and also with co-financing from the Royal Government of Bhutan (RGoB), the DoFPS this time has been able to carry out the first ever National Snow Leopard Survey of Bhutan (hereafter referred to as the NSLSB). As a nodal agency for wildlife management within the Department, the WCD assumed the role as the project management office to effectively guide and coordinate the entire survey process. The Renewable Natural Resources Research and Development Centre (RNRRDC) at Yusipang, which is the research arm of the DoFPS, also provided technical expertise right from the scientific design phase till data analysis and drafting of the reports.

As per the scientific norm, a comprehensive sign survey precedes any detailed camera-trap survey (Karanth et al. 2002) for population estimation. This is to identify optimal areas to place camera traps and to maximize detection probabilities of the target species (Karanth et al. 2011). Therefore, the NSLSB was systematically divided into two phases, primarily to achieve scientific rigor. The Phase I of the survey focussed on snow leopard sign and prey base survey while the Phase II concentrated on camera trap survey of snow leopards to estimate its population abundance in the country.

Coinciding with the dry season, which is good for spotting animal signs, the Phase I of the NSLSB kicked off in late August of 2014 in all the potential areas of snow leopard occurrence in Bhutan, including Bumdeling Wildlife Sanctuary (BWS) and Sakteng Wildlife Sanctuary (SWS).

1.2. Objectives of the NSLSB Phase I

The NSLSB Phase I was carried out with the following prime objectives to:

a) know the abundance and distribution of snow leopard signs;
b) determine habitat utilization characteristics of snow leopard;
c) understand the distribution of blue sheep (*Pseudois nayaur*), which is the principal prey of snow leopard; and
d) identify optimal areas of snow leopard occurrence for placement of camera traps during the Phase II of the NSLSB.

1.3. Scope and utility of the Phase I report

The NSLSB Phase I report is confined to the activities of the NSLSB that were carried out in Phase I of the survey. The report explains in detail all key activities that were performed in the Phase I in order for the activities in the Phase II to be fully accomplished. This publication drew mostly upon the data and survey reports submitted by the focal persons from the respective survey areas (*viz.,* parks and division).

As planned, the NSLSB Phase I report was used as the main basis for planning and execution of the Phase II survey. Particularly, findings from the Phase I survey helped in the implementation of the Phase II activities with regard to selecting survey grids and locating prime areas within the selected grids for placement of camera traps.

Findings on prey base could be used for devising conservation plans for management of snow leopard and their prey species at the auto-ecological level as well as the syn-ecological level.

In due course of the Phase I survey, a technical team was formed to design a survey manual for surveying and monitoring of snow leopards (Please refer to Thinley et al. 2015a).

CHAPTER 2: MATERIALS AND METHODS

2.1. Survey area selection

Using the elevation range of 3,500 to 5,500 meters as the sole criterion, the potential areas of snow leopard occurrence in Bhutan were mapped in ArcGIS. This elevation range was selected based on the field records of snow leopard signs observed in the Jigme Dorji National Park (JDNP) and Wangchuck Centennial National Park (WCNP) during the respective park-wide snow leopard surveys in 2012. However, areas with no possibility of snow leopard occurrence such as Dagala also featured in the map (Fig. 2.1), and the NSLSB core team members omitted such places. The final map of potential snow leopard habitat (Fig. 2.2) was similar to the one developed by the WWF (Fig. 2.3) in its snow leopard action strategy for the Himalayan region (Wikramanayake et al. 2006), except that the areas in Jigme Singye Wangchuck National Park (JSWNP), Phrumsengla National Park (PNP), and Dagana Dzongkhag (administrative district) were excluded in the latter. The total area of snow leopard habitat in Bhutan comes to approximately 8,783.23 km^2, using the elevation criterion.

The core team decided to conduct sign survey in the Jigme Khesar Strict Nature Reserve (JKSNR), JDNP, WCNP, BWS, northern part of Paro Territorial Forest Division (PTFD), and even SWS, as these areas appeared as the potential areas for snow leopard. Although, there has not been a single record of snow leopard presence in the SWS, the team decided to conduct sign survey there because of the greater likelihood of snow leopard presence in the sanctuary, judging from the presence of large tracts of alpine meadow - a prime habitat for blue sheep and Himalayan marmot (*Marmota himalayana*).

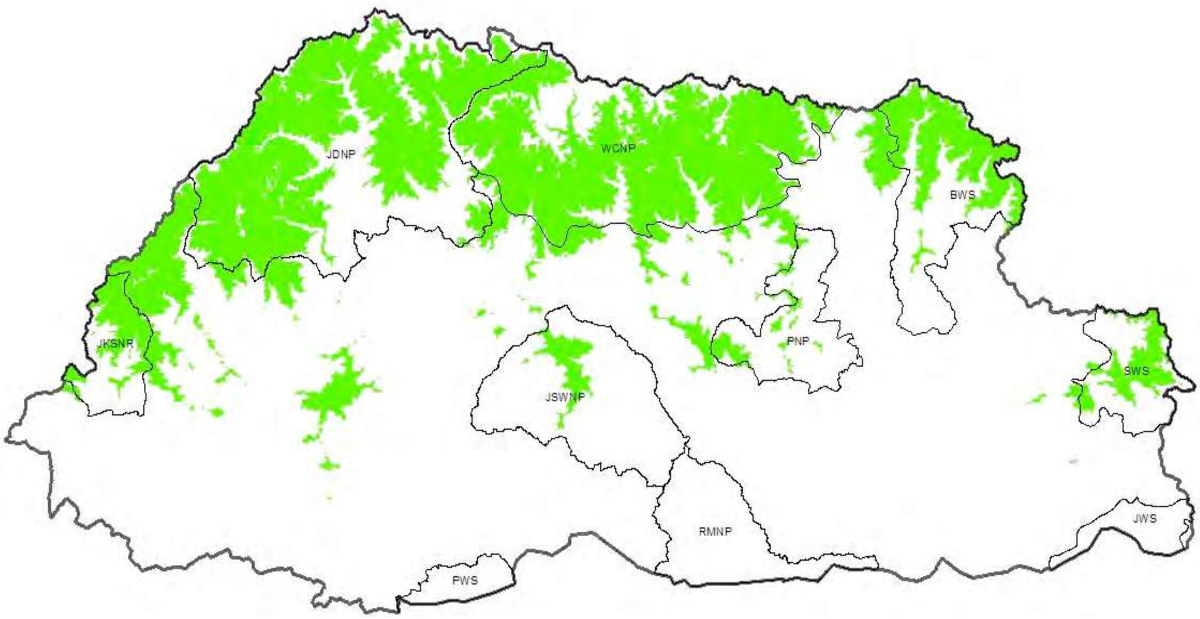

Figure 2.1: Potential snow leopard habitat in Bhutan based on the elevation range of occurrence (3,500 to 5,500 meters)

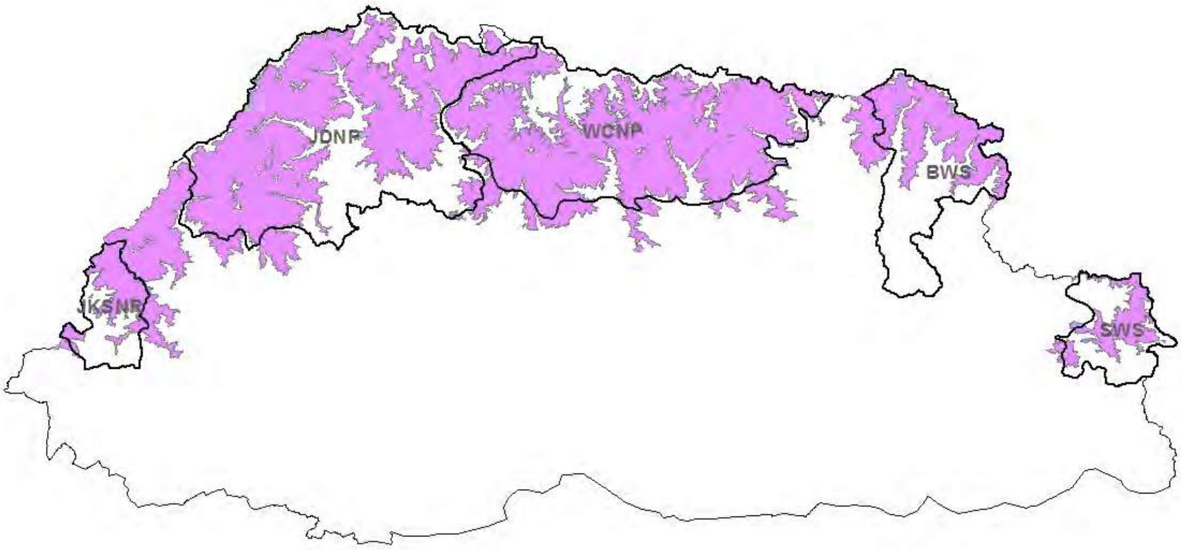

Figure 2.2: Potential snow leopard habitat in Bhutan based on the elevation range of occurrence (3,500 to 5,500 meters) and data from the field offices.

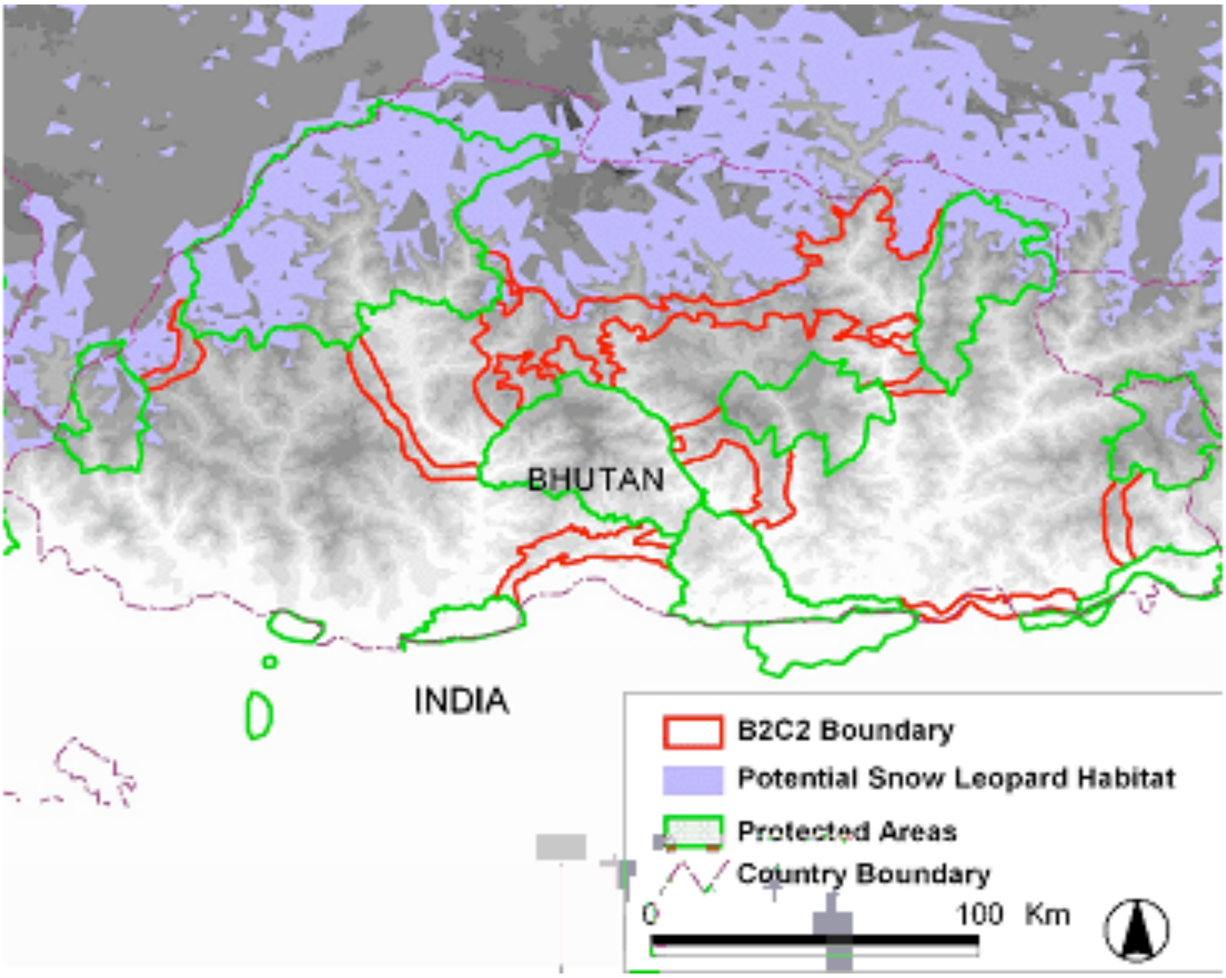

Figure 2.3: Potential snow leopard habitat in the Bhutanese trans-Himalaya (Sourced from the WWF US, 2005)

2.2. Survey area description

The survey areas are discussed individually for the sake of clarity and to achieve direct focus on the survey objectives. Only the area characteristics relevant to snow leopard and its principal prey, the blue sheep, are discussed. Some of the characteristics were sourced from the recent publication on the protected areas of Bhutan (DoFPS 2016).

2.2.1. Jigme Khesar Strict Nature Reserve (JKSNR)

The Jigme Khesar Strict Nature Reserve (formerly known as the Toorsa Strict Nature Reserve) is the only strict nature reserve in the country. Unlike in any other protected areas in Bhutan, the JKSNR does not have any permanent human settlements, except for a few nomadic livestock herding communities (TSNR 2011). Situated in the westernmost part of Bhutan bordering the Indian State of Sikkim, the reserve forms a part of the Kanchenjunga Landscape Conservation Area (NCD 2005). The reserve being a huge potential snow leopard habitat and with frequent sightings of blue sheep and Himalayan marmot, evidence of snow leopard is fairly common along the northern range of the reserve, including the recent sighting of a snow leopard in 2015.

2.2.2. Paro Territorial Forest Division (PTFD)

The Paro Territorial Forest Division is the only division amongst the 12 territorial forest divisions in the country that has sizable potential area for snow leopard. The northern part of the division harbours relatively undisturbed forest cover and vast swathe of alpine meadows and screes, offering ideal habitat for endangered wide ranging predators such as the tiger and snow leopard. Indeed, the biological corridor linking the JDNP and JKSNR passes through this portion of the division. Thus, the PTFD provides a crucial connectivity for the tiger and snow leopard populations residing in the JDNP and JKSNR.

2.2.3. Jigme Dorji National Park (JDNP)

The Jigme Dorji National Park is the second largest protected area (4,316 km^2) in Bhutan. Almost two-third of the park area is suitable for snow leopard and blue sheep, due to the presence of large tracts of alpine meadows and screes. In fact, the first photographic and video evidence of snow leopard in Bhutan was obtained from the park. During the camera trap survey of snow leopards in 2012, 18 adults and 3 cubs were identified from 410 images of snow leopards obtained in the park (Thinley et al. 2014). In addition, large herds of blue sheep can be commonly seen grazing together with domestic yaks along the major trekking routes in the park (Thinley et al. 2015b). A recent study by Leki et al. (2016) revealed that the Lingzhi Park Range alone is estimated to have 1,762 blue sheep in winter and 2,097 in summer. Therefore, JDNP is believed to be the largest stronghold for snow leopard conservation in the Bhutan as well as in the Eastern Himalayas.

2.2.4. Wangchuck Centennial National Park (WCNP)

Encompassing an area of 4,914 km^2, the Wangchuck Centennial National Park (formerly known as the Wangchuck Centennial Park) is the largest of the ten protected areas in Bhutan and the last park to be included under the PA system (WCP 2012). Next to the JDNP, WCNP is the second largest stronghold for snow leopard conservation in Bhutan. A survey conducted between 2012 and 2014 estimated 15 individuals of snow leopard in the park (Shrestha & Tenzin 2015). The park is also known to harbour many herds of blue sheep in the northern region.

2.2.5. Bumdeling Wildlife Sanctuary (BWS)

Bumdeling Wildlife Sanctuary is situated in the north-eastern part of Bhutan. Gazetted in 1994 to protect the representative mid and high altitude ecosystems of the eastern Himalayas, the sanctuary harbours huge expanse of ideal habitats for both the snow leopard and blue sheep (BWS 2013). Several small herds of blue sheep are being regularly spotted in the northern part of the sanctuary, but so far individuals of snow leopard and the evidences are yet to be seen, although yak herders have been complaining about losing their yaks to wild predators. In 1997, the biodiversity survey team noted the head monk of Singye Dzong reporting about the sighting of a snow leopard close to the monastery (personal communication, Sonam Wangchuk, Chief, WCD). Hence, the presence of the snow leopard is greatly expected in the sanctuary.

2.2.6. Sakteng Wildlife Sanctuary (SWS)

The Sakteng Wildlife Sanctuary is situated in the eastern most part of Bhutan. Most of the people living inside the sanctuary are yak herders who have maintained open pasturelands for ages (SWS 2013). The communal pasturelands provide good habitat for wild herbivores such as the blue sheep. The sanctuary officials stated that there used to be several blue sheep in the sanctuary, but nowadays they can hardly be seen. Nevertheless, the Himalayan marmot, which is another supplementary prey for the snow leopard (Schaller et al. 1988; Devkota et al. 2013), is commonly seen in the sanctuary. So far, there has not been a single case of livestock depredation by snow leopard in the sanctuary, but looking at the yak and marmot population one can expect snow leopards there.

2.3. Survey efforts and team composition

2.3.1. Survey efforts

On the whole, sign surveys and blue sheep surveys were conducted in all the survey areas for the duration of one year, starting from August 2014 till July 2015.


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Best timing for sign survey may depend on weather conditions in the survey areas (Ahlborn & Jackson 1988). The respective survey teams in each survey area, hence, started and ended their surveys at different time period, depending on the weather conditions. The survey teams tried their best to conduct sign surveys during dry periods when visibility and durability of signs were the maximum.

2.3.2. Survey team composition

In order to capitalize on site familiarity, the survey teams for each survey area were formed from the staff of the respective area. For example, the survey teams in the WCNP were composed of WCNP staffs only. Within each survey area, the specific survey grids were allocated to the specific park or division range staffs that were further split into several sub groups to cover specific grids within their own range areas. Also at the park level, a focal person was nominated to collect, compile, archive, and submit the survey data and reports to the national focal person (see *Annexure I* for the list of field focal persons).

At the central or national level, a focal person (or a national coordinator) was appointed at the office of the WCD to centrally coordinate the survey activities, archive the data, and publish survey reports at the national level. Also at the national level, a core team was formed to assist the national focal person in survey design, staff training, data collection, data analysis, and report writing (see *Annexure II* for the list of core team members).

2.4. Sign Survey methods

2.4.1. Survey grids

A total of 321 survey grids, each measuring 4 km x 4 km, were selected to conduct snow leopard sign survey (Fig. 2.4). The grids that contained topographic and landscape features where occurrence of snow leopard was unlikely were omitted. Due to inaccessibility and varying field conditions, some of the survey teams could not cover all the grids allocated to their respective division or park (Table. 2.1).

Table 2.1: The number of survey grids allocated to respective survey areas and the number of grids actually covered.

Survey area	# of grids allocated	# of grids covered
JKSNR	19	19
PTFD	30	30
JDNP	80	80
WCNP	118	106
BWS	72	50
SWS	36	36

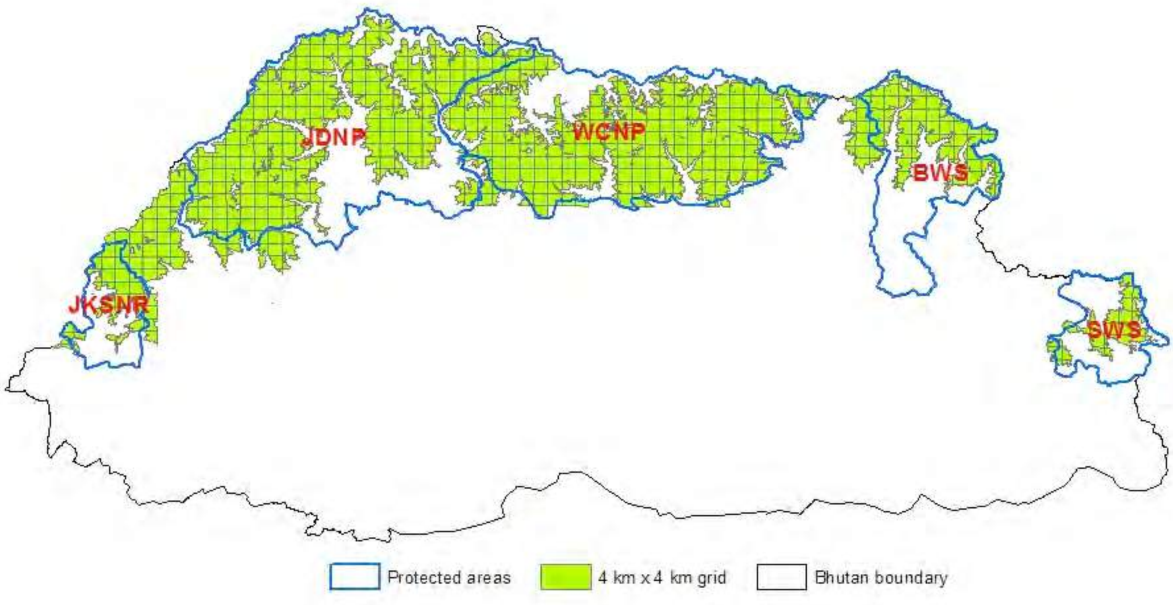


Figure 2.4: Grids (measuring 4 km x 4 km) for survey of snow leopard signs and prey base, particularly the blue sheep.

2.4.2. Detecting snow leopard signs

Within each survey grid, the survey teams looked for snow leopard signs, such as tracks, scats, scrapes, scent marks, and claw rakes. Efforts were concentrated on sites with high likelihood of spotting signs, usually in the marking sites such as the base of cliffs, ridgeline crests and saddles, meeting of the ridgelines near the confluences of rivers and streams, base of prominent rocky boulders, and well-defined trails (Ahlborn & Jackson 1988; Fox et al. 1988, 1991; Jackson & Hunter 1996; Jackson et al. 2005; Thinley et al. 2015a).

A survey format (*Annexure III*) was developed to record: a) type and condition of signs observed; b) location, elevation, and topographic features of sites where the signs were observed; and c) habitat types and general habitat conditions. The geographical coordinates of the signs were also recorded for mapping purposes.

In addition to the area knowledge of the surveyors, the local people, specifically the yak herders, were consulted to achieve nearly pin-pointed searches for signs.

The surveyors were thoroughly trained by the resource persons from the Core Team on how to reliably identify snow leopard scats and tracks, and to distinguish between snow leopard signs and other sympatric carnivore signs. Quite often, surveyors mistook common leopard tracks for snow leopard tracks (Jackson et al. 2005) in areas where these two carnivores were sympatric. The surveyors were also confused between snow leopard scats and red fox (*Vulpes vulpes*) scats, especially when the scats were somewhat old and deteriorated. For example, Janecka et al. (2008) reported 54% of snow leopard scats were misidentified as those of red fox. One of the main reasons for such a confusion was that the length and number of segments in scats of snow leopards, wolves, and foxes were not statistically different (Anwar et al. 2011). Tips to avoid such misconceptions were imparted, particularly highlighting on the need to check the scat size and contents such as the hair contents and also on unique M-shaped lobes on the anterior portion of the snow leopard's pad (Oli 1994).

2.4.3. Computing sign encounter rates

The relative abundance index such as sign encounter rates were computed using the number of signs detected per kilometre of distance walked by the surveyors (Jackson et al. 2005). This index was computed for each survey area to be used for rapid monitoring of the changes in snow leopard abundance in times of limited budget and resources needed to conduct extensive surveys and camera trapping (Jackson & Hunter 1996).

2.4.4. Mapping snow leopard signs and identifying hotspots for camera trapping

The geographical coordinates of signs were plotted in ArcGIS to look at the sign distribution and were factored in MaxEnt model to identify good spots for stationing camera traps which are represented by areas with high probability of occurrence, often representing overlapping core areas of individuals (Ahlborn & Jackson 1988).

2.5. Prey base survey methods

2.5.1. General prey species of snow leopards

In its entire global distributional range, the snow leopard preys on a wide variety of ungulate species, including the domestic yaks, horses, sheep, and goat (Hemmer 1972). There is wide assortment of natural prey species in most of its range states, from wild goats and sheep to gazelles, musk deer, ibexes and pigs. However, the principal natural prey species differs from region to region, depending on their availability. In Mongolia, Siberian ibex (*Capra sibirica*) and argali sheep (*Ovis ammon*) are the principal prey of the snow leopard (Shehzad et al. 2012). Likewise, Siberian ibex and markhor (*Capra* *falconeri*) are the dominant natural preys in northern Pakistan (Anwar et al. 2011). In some parts of Nepal, Himalayan tahr (*Hemitragus jemlahicus*) and musk deer (*Moschus chrysogaster*) are the main diets of the snow leopard (Lovari et al. 2009). Their diet could also include small mammals such as pikas and hares and birds (Lyngdoh et al. 2014). The blue sheep forms the principal prey in four of its range states, such as China (Schaller et al. 1988; Xu et al. 2008), India (Fox et al. 1991; Bagchi & Mishra 2006), Nepal (Oli et al. 1993; Oli 1994; Wegge et al. 2012; Devkota et al. 2013), and Bhutan (Thinley et al. 2014; Shrestha & Tenzin 2015). In the Himalayas, marmots are also eaten as important food supplement (Schaller et al. 1988; Oli 1994).

2.5.2. Prey survey

Prey survey was conducted together with the snow leopard sign survey. Because it was too taxing for the surveyors to complete these two tasks concurrently, the preferred and robust double-observer survey method (Forsyth & Hickling 1997; Suryawanshi et al. 2012) could not be employed to estimate the abundance and density of the prey species. Instead, the simple sign survey was conducted for the blue sheep to understand its distribution pattern and habitat utilization. The sign locations (including those of sightings) and ancillary information of blue sheep were recorded in a separate format (Annexure IV). Readers are advised to refer to the recent estimation of blue sheep population in JDNP by Leki et al. (2016) for in-depth understanding of the application of double-observer method in Bhutan's context.

Himalayan Marmot *(Himalayana marmota)*

Blue sheep (*Pseudois nayaur*) herd in JDNP

The surveyors were issued with high power binoculars and spotting scopes to locate blue sheep and other prey species. They were also trained on sex and age classification of blue sheep based on the classification method employed by Wegge (1979) in Nepal.

2.6. Data analysis

2.6.1. Statistical Analyses

In order to know the habitat utilization and distribution of snow leopard and blue sheep signs along the environmental gradients of slope, elevation, aspect, and habitat types, descriptive statistics were first performed to see any unique patterns and marked differences. Kruskal-Wallis test with post-hoc analysis was performed to check if the differences in patterns were statistically significant. All statistical operations were conducted using Program R (R Core Team 2015).

2.6.2. Modelling species distribution using MaxEnt

2.6.2.1. Brief introduction of the MaxEnt model

The MaxEnt program (Phillips et al. 2006) was used to generate a map of snow leopard and blue sheep distribution in the country. The MaxEnt in an ecological sense is a computer program for modelling species distribution, using presence-only location data of the target species (and its signs) along with determinant environmental variables, to produce a surface which represents probability of occurrence of the species (Papeş & Gaubert 2007; Elith et al. 2010). Among many species distribution models, the MaxEnt was opted because the true absences of the target species could not be confirmed in the areas where they were deemed to be absent due to two reasons: 1) the sign survey was rapid, and there was no extended searches in the areas marked as absent; and 2) the survey was simply focussed on finding out signs of occurrences. Such a presence-only data without true absence lends itself well to MaxEnt mode of modelling species distribution. In fact, the model has been proven to work well even with a limited presence records (Phillips et al. 2004). The model has been applied to some carnivores such as dholes (Jenks et al. 2012).

2.6.2.2. Purposes of the MaxEnt model

The model was used with different purposes for the two focal species. The aim of the distribution model for the snow leopard was to spot areas with high likelihood of its occurrence, so that these areas could be selected for placement of camera traps to optimize capture probabilities. For the blue sheep, the model was used to predict its distributional range in the country.

2.6.2.3. Selection of environmental variables for the model

Based on an extensive literature review of the ecology of focal species (the snow leopard and blue sheep in this case), the environmental features that likely constrain their geographic distribution were selected: elevation, slope, vegetation cover, and distance from human settlement.

a) *Elevation*: It is one of the determining factors for the distribution of the snow leopard. In the Himalayan region, the species occupied a wider elevation range, whereas in the higher latitudes in the central Asia region and China, it occupied narrower elevation range. For example, the snow leopard was found between 3,000 and 5,000 m in Nepal's Sagarmatha (Mount Everest) National Park (Ale et al. 2007); 3,400 and 4,700 m in India's Hemis National Park (Chundawat 1990); and 3,000 and 5,000 in north-eastern and central portions of Hindu Kush range and Pamir valleys of Afghanistan (Adil 1997). In China's Beita Mountain, the snow leopard was known to prefer the altitude range of 2,000 to 2,200 m and avoid 2,600 to 3,000 m in Autumn (Feng et al. 2006). In south-western Mongolia, the snow leopard movements and activities were observed between 1,450 and 2,600 m (McCarthy et al. 2005).

   Generally, blue sheep in the Himalayas are known to occupy mountainous areas from 2,500 m to 5,500 m (Schaller 1977). In Nepal's Annapurna Conservation Area, blue sheep were recorded within the altitude range of 3,209 m and 5,498 (Aryal et al. 2014). In India's Gangotri National Park, situated in the western Himalaya region, blue sheep were observed to use areas within the elevation range of 3,000 – 4,000 m in all seasons (Bhardwaj et al. 2010). In Bhutan's Wangchuck Centennial National Park, blue sheep were recorded between 4,000 – 5,000 m (Shrestha et al. 2012).

b) Slope: The effect of slope to snow leopard seems to be variable in different areas. This elusive cat was observed to use all slope categories greater than 20o in south-western Mongolia (McCarthy et al. 2005). Wolf and Ale (2009) observed negative relationship between numbers of snow leopard sign encountered and slope in Nepal's Sagarmatha National Park, indicating the snow leopard's less preference for very steep areas. In contrast, Chundawat (1990) observed the species' strong preference for very steep slopes (>40^o) in India's Hemis National Park. Similarly, Jackson (1996) noted from the radio-telemetry study of the snow leopard's home range, movement, and habitat use in Nepal that the cat avoided gentle slopes (<40^o) and preferred slopes higher than 40^o.

As for the blue sheep, they were recorded more often in the gentle slopes. For instance, in Nepal's Annapurna Conservation Area, blue sheep evidences were mostly recorded between 16 – 30^o slopes in upper Mustang and Manang regions (Aryal et al. 2014). Bhardwaj et al. (2010) observed blue sheep in areas with medium steepness, ranging from 31 – 50^o slopes in Gangotri National Park.

c) *Aspect*: Snow leopards are known to select certain aspects. For instance, Jackson (1996) observed significant under-utilization of the northerly and easterly aspects (such as north, northwest and northeast) and over-utilization of southerly aspects by both sexes of snow leopards in Nepal.

In Upper Mustang area of Nepal, blue sheep were recorded in south, north, northeast, and west aspects (Chetri & Pokharel 2005). Bhardwaj et al. (2010) recorded blue sheep specializing in the southerly aspects.

d) *Land cover (or vegetation type)*: Among the biological parameters, vegetation or land cover types influenced the distribution of snow leopards. In Nepal, snow leopards were observed to utilize mixed shrubland and tree covers in excess of their availability while significantly under-utilizing the alpine meadows and barren lands (Jackson 1996). During a camera trap survey of snow leopard in Bhutan's Jigme Dorji National Park, Thinley et al. (2014) recorded 48% of snow leopard images from alpine rocky outcrops, 35% from alpine meadows, and 17% from sub-alpine or scrub forest.

Blue sheep were mostly recorded in the grassland habitats of Gangotri National Park in India (Bhardwaj et al. 2010). Similarly, Shrestha et al. (2012) observed blue sheep mostly occupying the alpine grasslands in Wangchuck Centennial National Park which is situated in north-central park of Bhutan.

e) Distance from human settlement: Humans are known to affect the distribution of animals. The potential social variables that strongly influence snow leopard distribution are the human disturbance factors, particularly poaching and retaliatory killing (Jackson & Wangchuk 2001).

As for the blue sheep, there is no study on how blue sheep are situated with varying distances from human settlement. However, they are known to come very close to the settlements, and are seen grazing together with the yaks (Personal Communication, Leki, Lingzhi Park Range, Jigme Dorji National Park).

f) *Distribution of prey*: This is relevant only for the snow leopard. Prey (inclusive of livestock) and their distribution is yet another important biological parameter that strongly determines any predator distribution. Prey density estimates are found to be strongly correlated with tiger density estimates in India (Karanth & Stith 1999; Karanth et al. 2004).

2.6.2.4. Developing the spatial layers for the environmental variables

All spatial layers for the environmental variables were prepared within the GIS (Geographic Information System) environment in raster (pixel) mode, using the program ArcGIS. For consistency, all layers were standardized and snapped to the layer with coarsest resolutions (i.e., with the smallest cell size). The layers were also standardized using the same projection (DrukRef in our case), coordinate system, and geographic extent (that of the potential snow leopard distribution; Fig. 2.2).

The elevation layer (Annexure V a) for the MaxEnt model was extracted by joining two Digital Elevation Model (DEM) layers that encompassed Bhutan and were created by Jarvis et al. (2006). The slope layer (Annexure V b) was extracted from the DEM using the *surface* function of the *spatial analysis tool* in ArcGIS. Likewise, the aspect layer (Annexure V c) was also derived from the DEM. The vegetation layer (Annexure V d) was sourced from the Land use Map of Bhutan 2010 prepared by the Policy and Planning Division of the Ministry of Agriculture and Forests. The layer depicting distance from human settlement (Annexure V e) was prepared by first clipping the settlement map of Bhutan 2006 (prepared from the Population and Housing Census of 2006) to the study area and rasterizing it using the Eucledian distance function in ArcGIS. As social factors such as hunting and retaliatory killing do not easily lend themselves to spatial geo-referencing, partly due to lack of adequate spatial points and data, they could only be factored into the model as (Eucledian) distances from human settlements. Finally, the blue sheep density layer (relevant only for the snow leopard distribution modelling) was created from the map of blue sheep distribution using density function in ArcGIS.

To make the layers readable in MaxEnt, all layers were converted from raster to ASCII format. The location files of the target species (snow leopard and blue sheep) in DRUKREF projection were first exported from ArcMap, and were then converted into files with comma separated values (.csv) format for readability in MaxEnt.

2.6.2.5. Model parameterization

The MaxEnt version 3.3.3k was downloaded from its official website belonging to Princeton University, USA: <https://www.cs.princeton.edu/~schapire/maxent/>. All the requisite inputs layers and points were brought into the model as shown in Figure 2.5.

The program's default settings of 5000 iterations with convergence threshold of 0.00001, regularization multiplier of 1, prevalence of 0.5, and maximum number of background points as 10,000 were used. The random test percentage was set at 25 (meaning 25% of the location points were set aside for testing) with 15 replicates. The output format was set as logistic with ASCII file type which can be imported into ArcGIS for better visualization.

2.6.2.6. Assessing model performance

The model performance was assessed using the area under the receiver-operating characteristics (ROC) curve (Area Under the Curve: AUC). The ROC plot is basically a plot of sensitivity values (true positive fraction) against 1 – specificity values (false positive fraction). The AUC values range from 0.5 to 1.0. Values closer to or equal to 0.5 indicate very poor fit while those closer to or equal to 1 indicate perfect fit (Fielding & Bell 1997). The model's in-built feature was enabled to jackknife the data for evaluating each environmental variable's influence on the predicted distributions of snow leopard and blue sheep, and to compute percent contribution of the variables to the model gains.

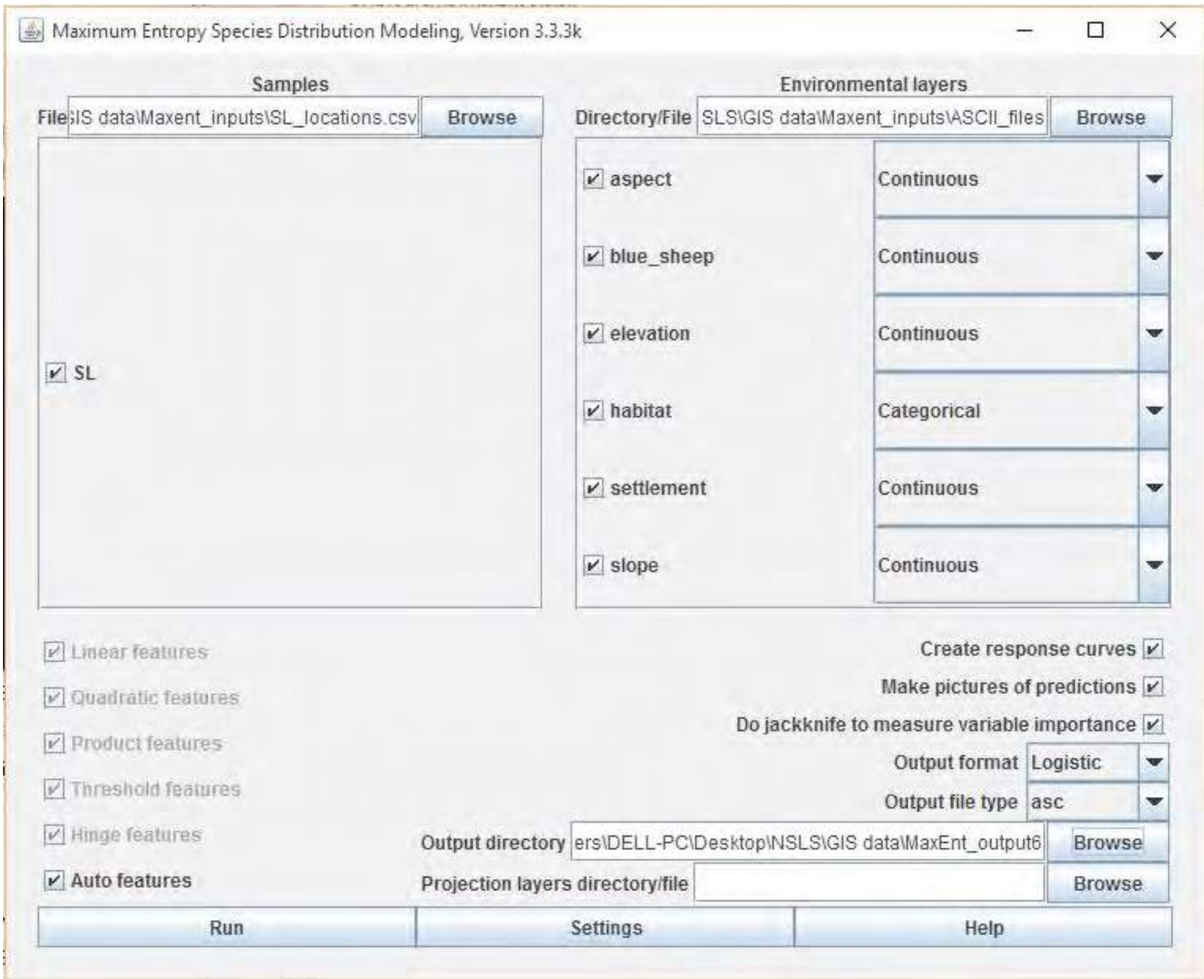


Figure 2.5: Reading the environmental variables and snow leopard location points in the MaxEnt model.

CHAPTER 3: RESULTS AND DISCUSSIONS

3.1. Detection of snow leopard and blue sheep signs

A total of 345 snow leopard signs were encountered throughout its entire range in Bhutan. The signs were dominated by scats (n = 243) by huge margin, as compared to 63 tracks, 35 scrapes, 3 sightings, and only 1 scent mark (Fig. 3.1).

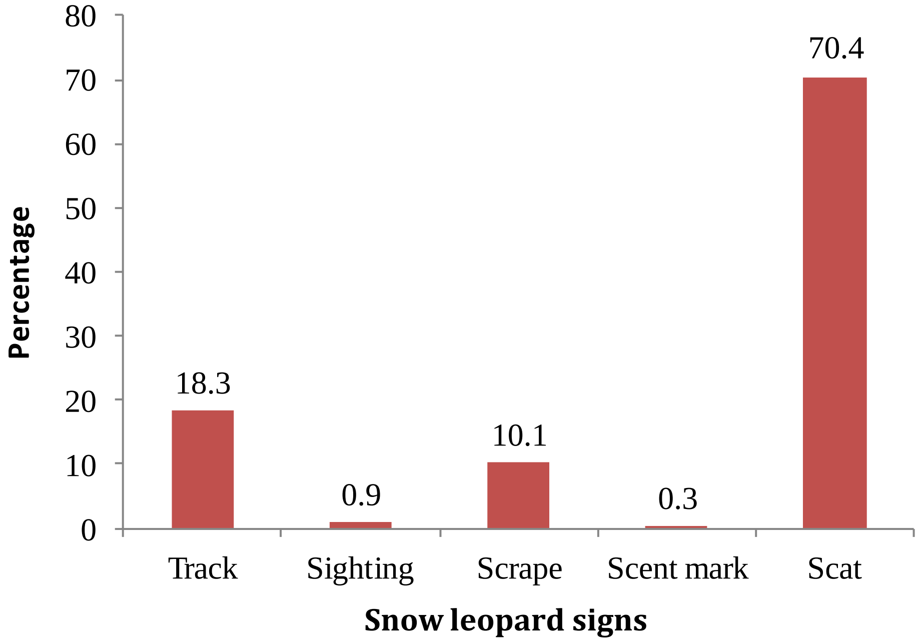
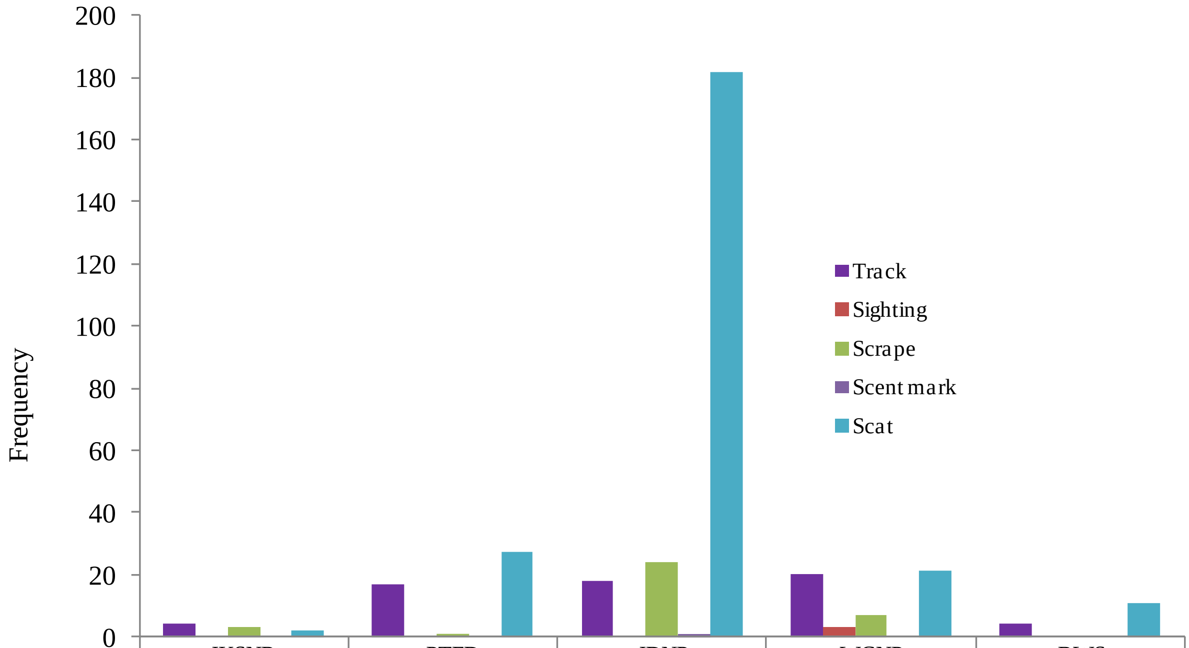


Figure 3.1: Locations of snow leopard signs in the range areas in Bhutan obtained during the Phase I of the National Snow Leopard Survey.

Majority of the signs (n = 225) were encountered in JDNP, followed by WCNP (n = 51), and PTFD (n = 45). Least number of signs were found in JKSNR (n = 9), while only 15 were found in BWS (Fig. 3.2). All sightings were recorded from WCNP.

The snow leopard signs were distributed differently in each range area (Fig. 3.3). Within JDNP, the signs locations were mostly gathered from Soe Park Range and Lingzhi Park Range, and only a few were collected from Ramina Park Range and Lunana Park Range. Compared to the latter two Park Ranges, the number of signs collected from Laya was higher, indicating decreasing trend in distribution from west to east in the park. Likewise, in WCNP the snow leopard signs were concentrated in the Western and Central Park Range while the Eastern Park Range had comparatively lesser number of signs. In contrast, the Paro Territorial Forest Division (PTFD) showed snow leopard signs in the northern portions of both Haa Range and Paro Range, whereas JKSNR showed snow leopard distribution outside of its jurisdictional boundary, way into the PTFD's Haa Range. This was because the JKSNR team covered some of the survey grids assigned to PTFD for ease of logistics arrangement.

As expected, only Dungzam Park Range and Khoma Park Range of BWS showed evidences of snow leopard presence, and there was none from SWS.



	JKSNR	PTFD	JDNP	WCNP	BWS
Track	4	17	18	20	4
Sighting	0	0	0	3	0
Scrape	3	1	24	7	0
Scent mark	0	0	1	0	0
Scat	2	27	182	21	11

Snow leopard range areas

Figure 3.2: The frequency of snow leopard signs encountered in each range area in Bhutan.

The pattern of blue sheep sign distribution is almost similar to that of the snow leopard sign distribution (Fig. 3.4). Here too, no evidences of blue sheep were recorded from SWS.

In comparison to the snow leopard signs, 426 blue sheep signs were recorded: 5 tracks; 169 sightings (indicating 169 different groups sighted); 243 droppings (or pellet groups); and 9 carcasses (Fig. 3.5). As it was in the case of the snow leopard signs, majority of the blue sheep signs were recorded from JDNP again (n = 228), followed by WCNP (n = 102) and PTFD (n = 52). Least frequency of evidences was gathered from BWS which had only 15 sign locations. JKSNR showed 29 evidences, despite its being smaller than BWS (Fig. 3.5).

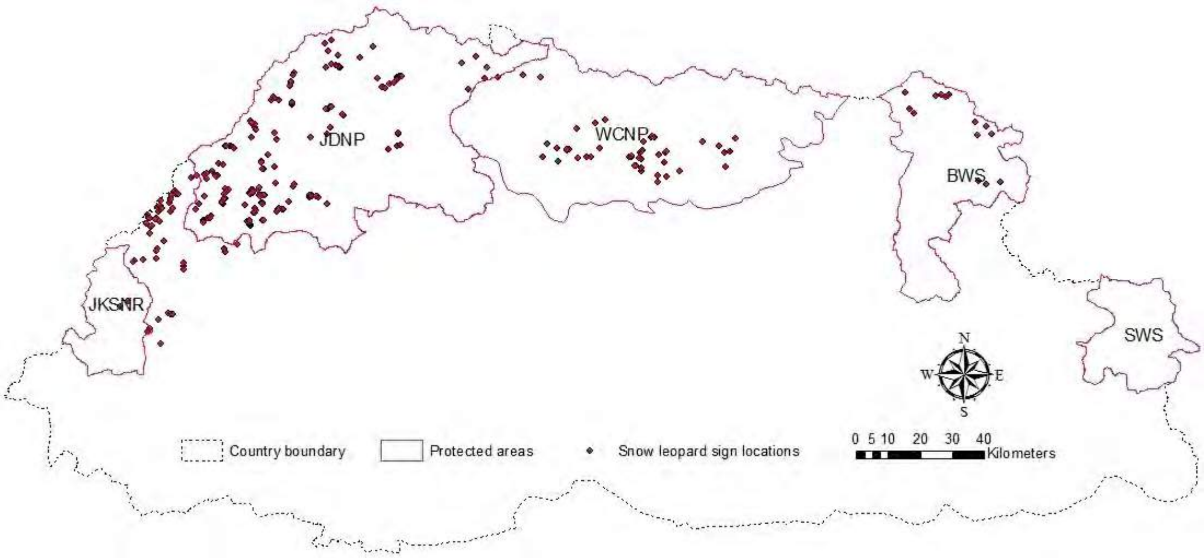


Figure 3.3: Locations of snow leopard signs in the range areas in Bhutan, obtained during the Phase I of the National Snow Leopard Survey.

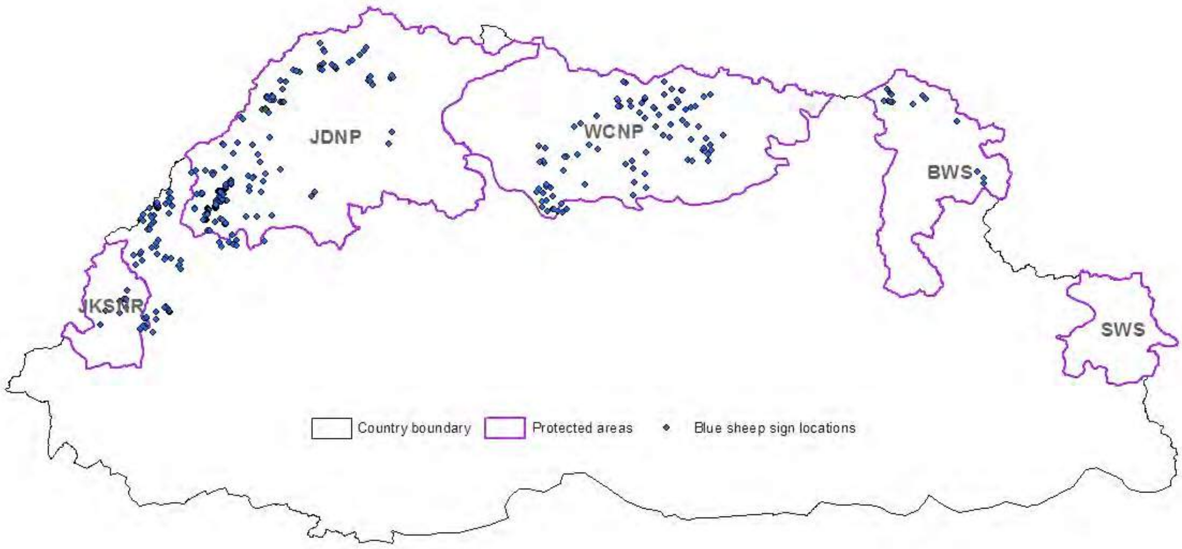
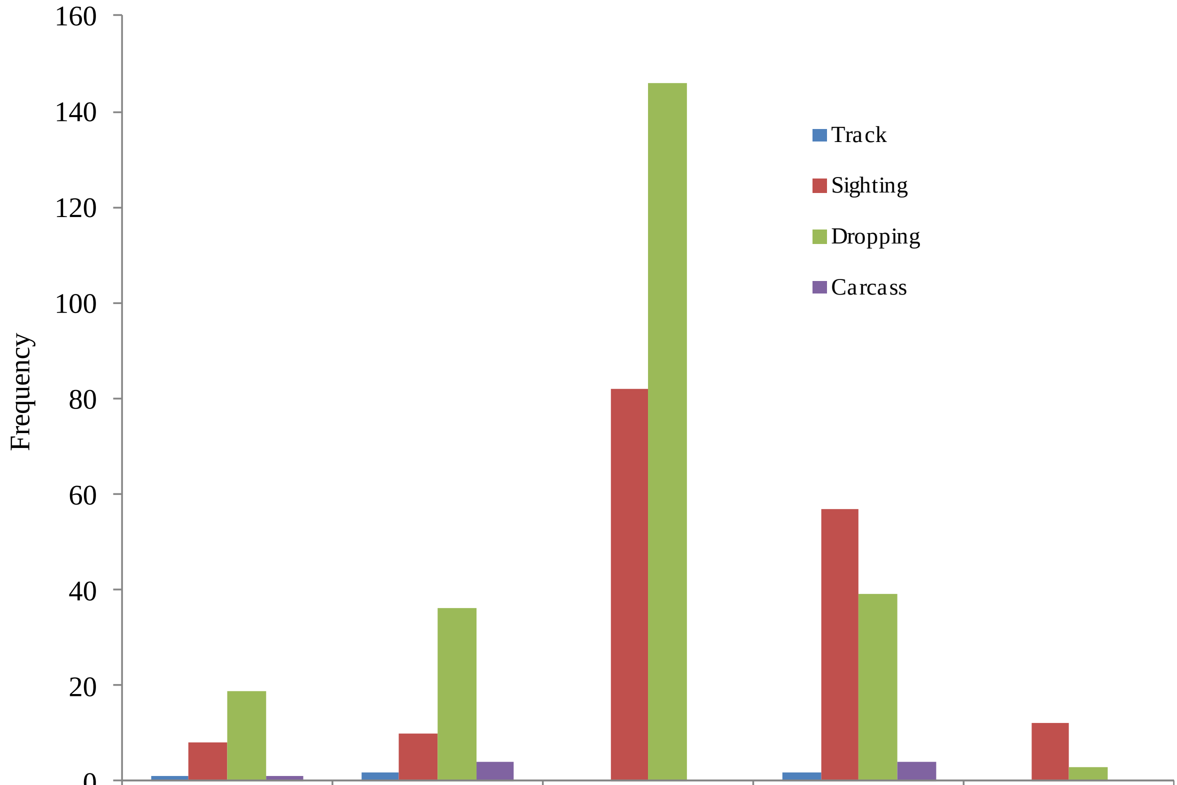


Figure 3.4: Location of blue sheep signs in Bhutan, obtained during the Phase I of the National Snow Leopard Survey.



	JKSNR	PTFD	JDNP	WCNP	BWS
Track	1	2	0	2	0
Sighting	8	10	82	57	12
Dropping	19	36	146	39	3
Carcass	1	4	0	4	0

Figure 3.5: The frequency of blue sheep signs encountered in each range area in Bhutan.

3.2. Habitat utilization by snow leopard

In the entire distributional range in Bhutan, majority of the snow leopard signs (56%; n = 194) were found in alpine meadow (Fig. 3.6). Next to alpine meadow, 25% of the signs were observed in alpine scree, and 12% in scrub forest. Signs were encountered sparingly in rocky outcrop and fir forest with only 3% and 4% respectively.

This result differs from the one obtained by Thinley et al. (2014) in JDNP during a camera trap survey of snow leopards in which 48% of the images were captured from rocky outcrop, 38% from alpine meadow, and 17% from scrub forest.

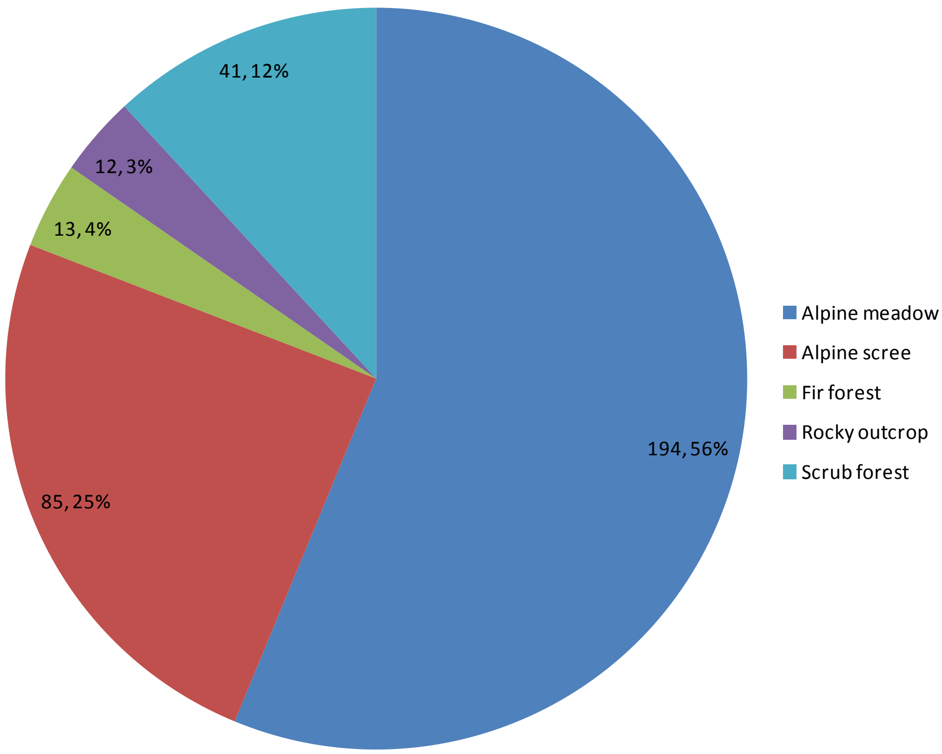


Figure 3.6: The percentage of snow leopard signs observed in different land cover types in Bhutan.

Among the signs encountered in alpine meadow, 142 were scats, 22 were scrapes, 29 were tracks, and 1 was sighting (Table 3.1). Scat was the most encountered sign in the alpine scree, and it was the only sign observed in rocky outcrop.

Table 3.1: Frequency of snow leopard signs observed in different land cover types in Bhutan.

Sign	Alpine meadow	Alpine scree	Fir forest	Rocky outcrop	Scrub forest	Total
Track	29	27	5	0	2	**63**
Sighting	1	2	0	0	0	**3**
Scrape	22	9	1	0	3	**35**
Scent mark	0	1	0	0	0	**1**
Scat	142	46	7	12	36	**243**
Total	**194**	**85**	**13**	**12**	**41**	**345**

By aspect, the frequency of snow leopard signs was the highest in the southeast aspect (n = 76), followed by northeast aspect (n = 74; Fig. 3.7). Least frequency of signs were observed in west (n = 24) and east (n = 30) aspects. Northwest and southwest aspects had somewhat same frequency of evidences. There was significant difference in the sign frequency among different aspects (Kruskal-Wallis chi-squared = 19.8238, df = 7, $p < 0.05$), but post hoc analysis showed no significant difference between any pair of aspects.

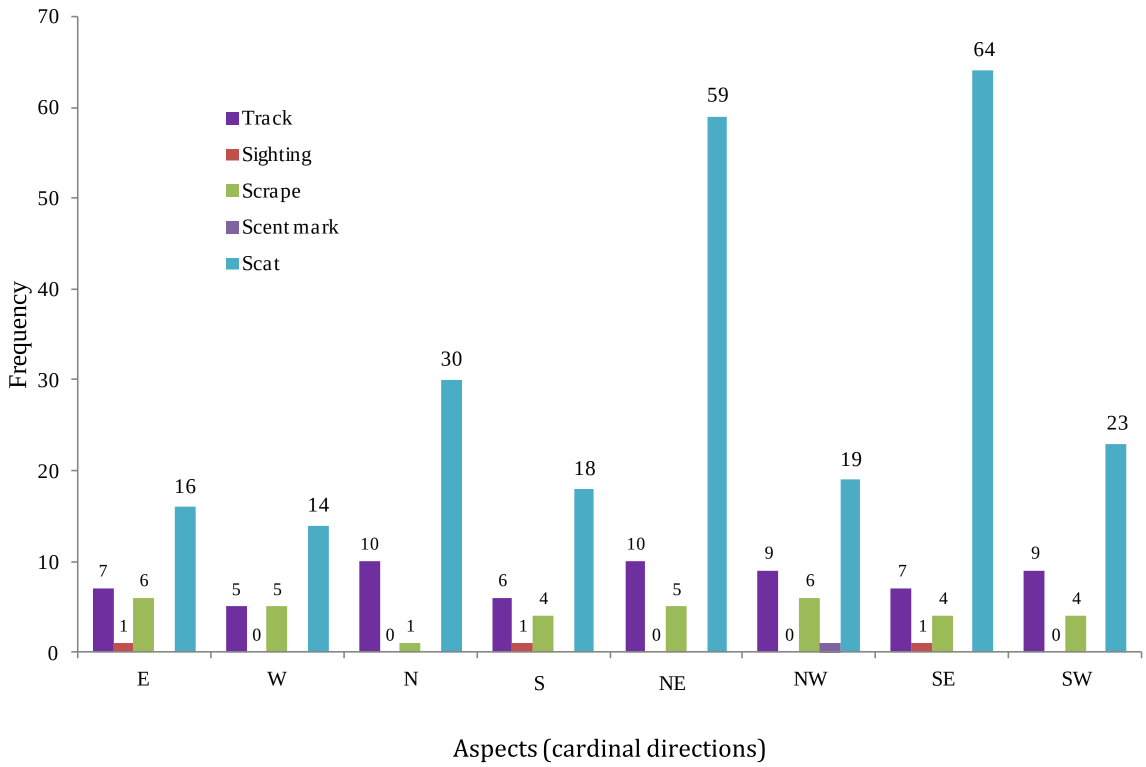


Figure 3.7: The frequency of snow leopard signs encountered in different aspects in the snow leopard range areas of Bhutan.

The snow leopard signs occurred between the slope range of 0° to 80° (Fig. 3.8); however, most of the evidences were gathered from slopes ranging from 11° to 50° with the highest number occurring within the slope class 31° to 40° (n = 53) followed by 21° to 30° (n = 50) and 41° to 50° (n = 48). The slope classes above 50° showed decreasing trend in the sign frequencies. This generally indicates snow leopards preference for gentle slopes to moderately steep areas.

With regards to elevation range, the snow leopard signs were found between 3,404 m and 5,186 m. Majority of the signs were encountered within the elevation range of 4,000 m to 4, 900 meters (Fig. 3.9). Highest number of evidences was gathered from the elevation class 4,300 m to 4,600 m (n = 114), while the lowest number was collected from the elevation class 3,400 m to 3,700 m (n = 8).

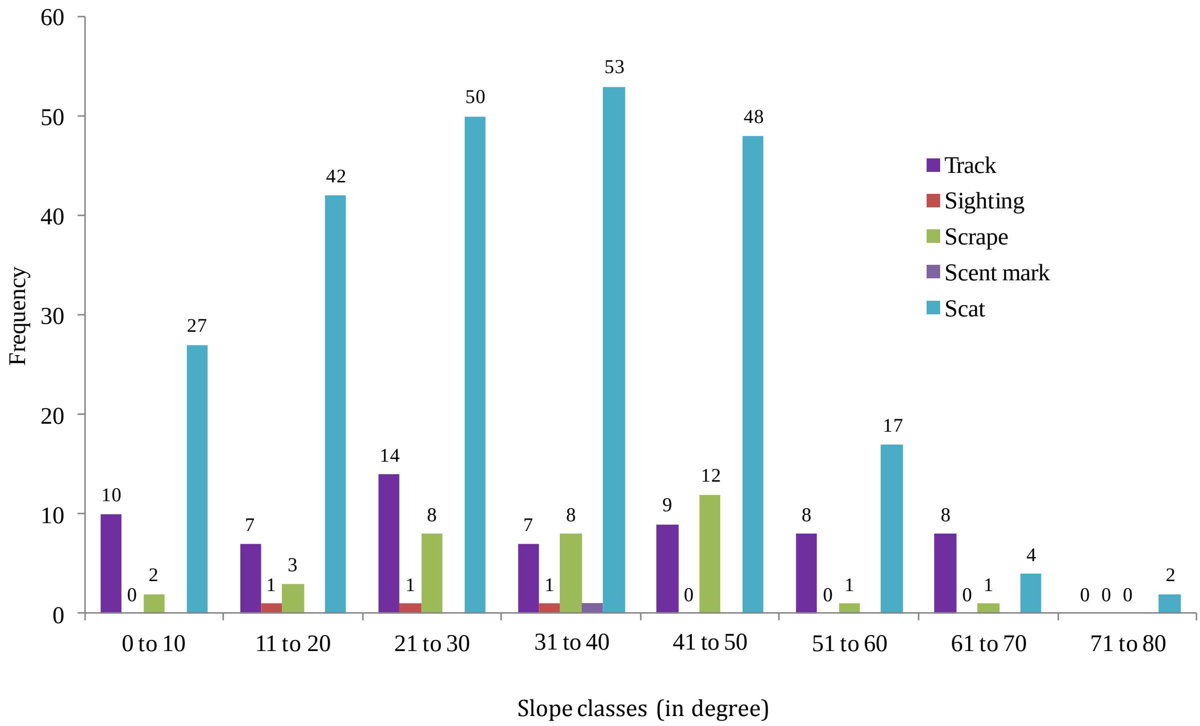


Figure 3.8: The frequency of snow leopard signs encountered in different slope classes in the snow leopard range areas of Bhutan.

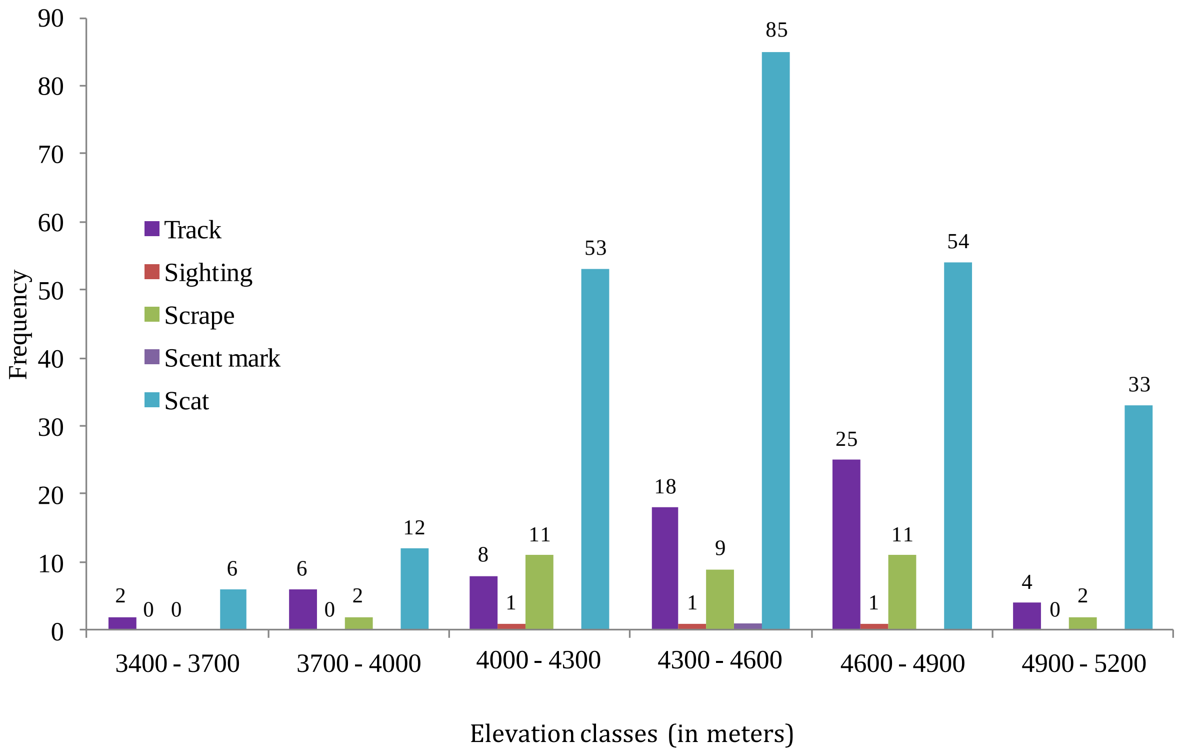


Figure 3.9: The frequency of snow leopard signs encountered in different elevation classes in the snow leopard range areas of Bhutan.

3.3. Habitat utilization by blue sheep

More than three-quarter of the blue sheep signs were found in alpine meadow, indicating its preference for such habitat type (Fig. 3.10). Only 12% of the signs were spotted in alpine scree, but readers are cautioned with this result. Blue sheep are known to escape to screes and rocky cliffs when threatened by a predator (Schaller 1973). They also retire to screes in the night. Such a small percentage in alpine scree may be because the surveys were conducted only during the day time. If surveys were done in the night, reverse scenario would have been obtained, because blue sheep do not forage in the night, and hence they may not be seen in the meadows. Blue sheep were also not seen much in the scrub forest, as indicated by a mere 7% of the signs encountered. Expectedly, blue sheep signs were scantily seen in fir forest too. They seldom venture into the tree line which seems to be their lowest distributional limit in the Bhutanese trans-Himalaya.

Statistically, there is a significant difference in blue sheep's utilization of different land cover types (Kruskal-Wallis chi-squared = 36.7164, df = 3, $p < 0.05$), particularly between alpine meadow and alpine scree, and between alpine scree and scrub forest.

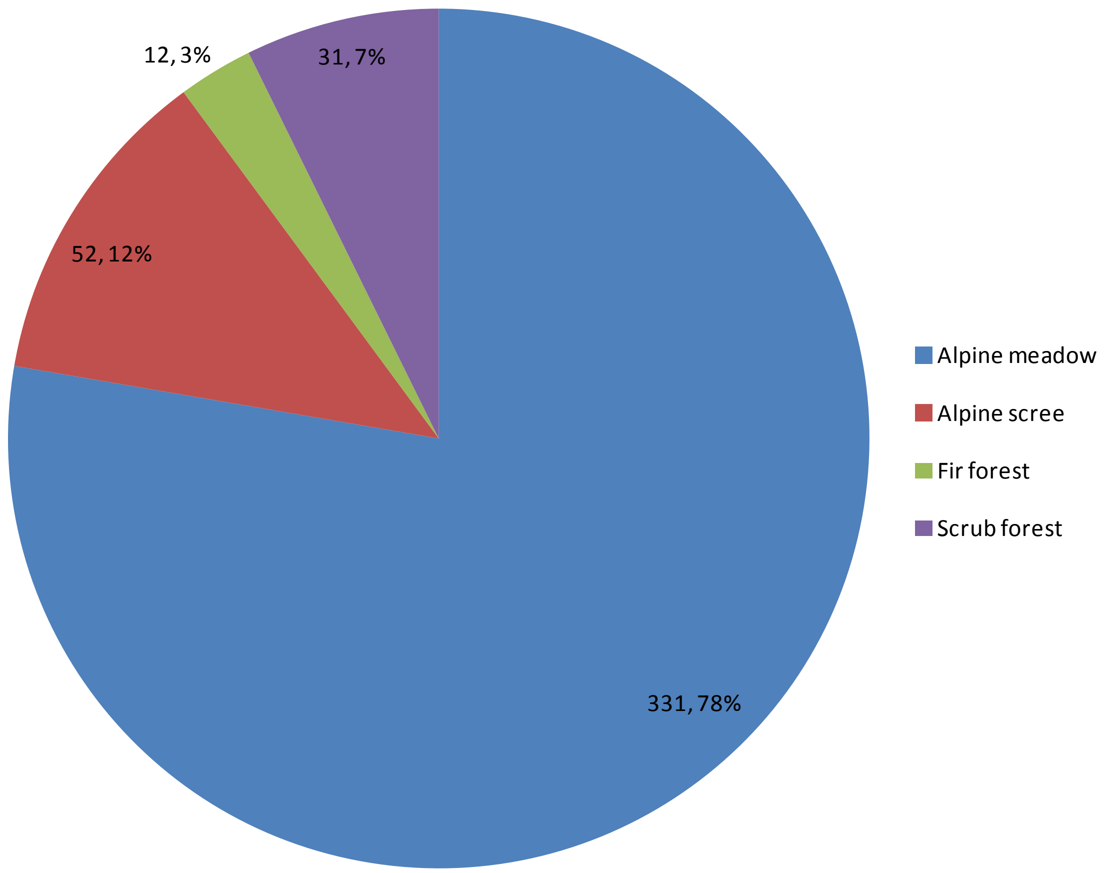


Figure 3.10: The percentage of blue sheep signs observed in different land cover types in Bhutan.

Blue sheep were seen in all the aspects (Fig. 3.11), but they seemed to favour northeast aspect where the highest number of signs was observed (n = 96). They were seen almost equally in southwest and north aspects with 66 and 68 signs respectively. Similarly, equal number of signs (n = 43) were observed in east and south aspects, and slightly lower numbers were observed in southeast (n = 41) and northwest (n = 39) aspects. The lowest number of signs (n = 30) were observed in west aspect. However, there was no statistically significant difference in the utilization of different aspects (Kruskal-Wallis chi-squared = 7.7181, df = 7, p = 0.3581).

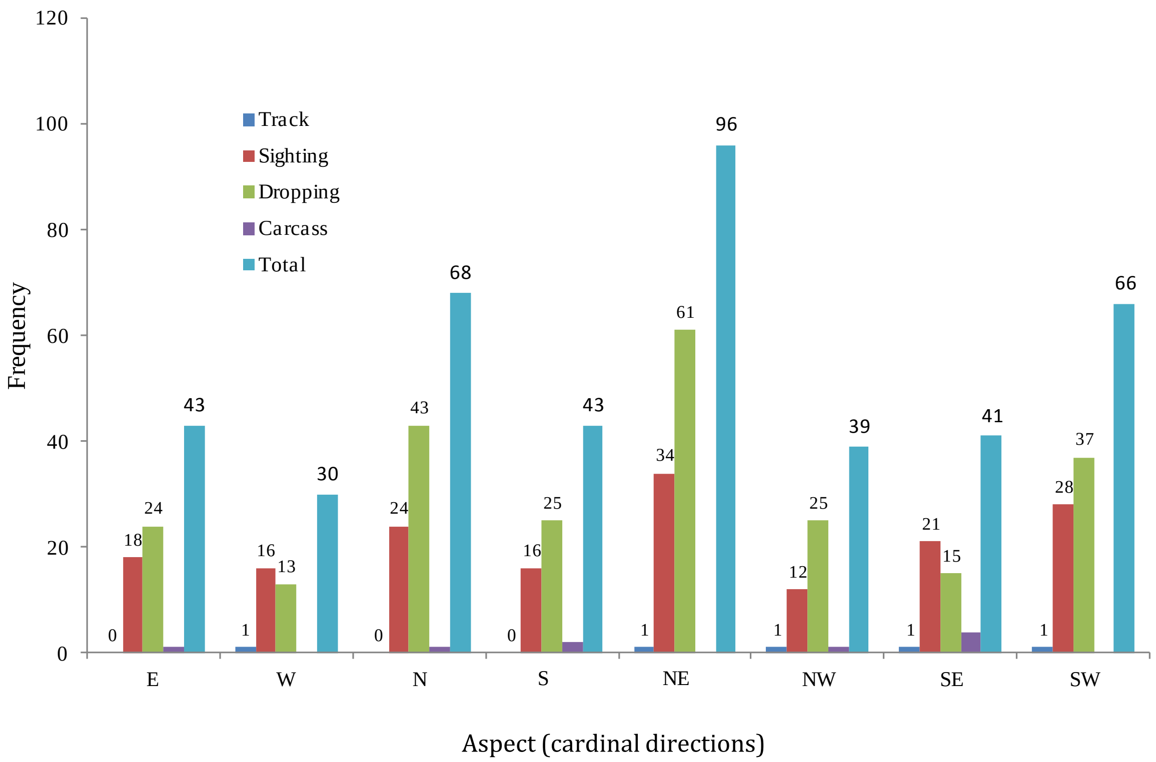


Figure 3.11: The frequency of blue sheep signs encountered in different aspects in Bhutan.

As in the case of snow leopard, blue sheep signs were observed between 0^{o} to 80^{o} slopes (Fig. 3.12) with vast majority of the signs occurring between 0^{o} to 30^{o}. Fair number of signs was also observed between 31^{o} to 50^{o} above which the sign frequency steadily decreased, indicating the blue sheep's less preference for steep areas.

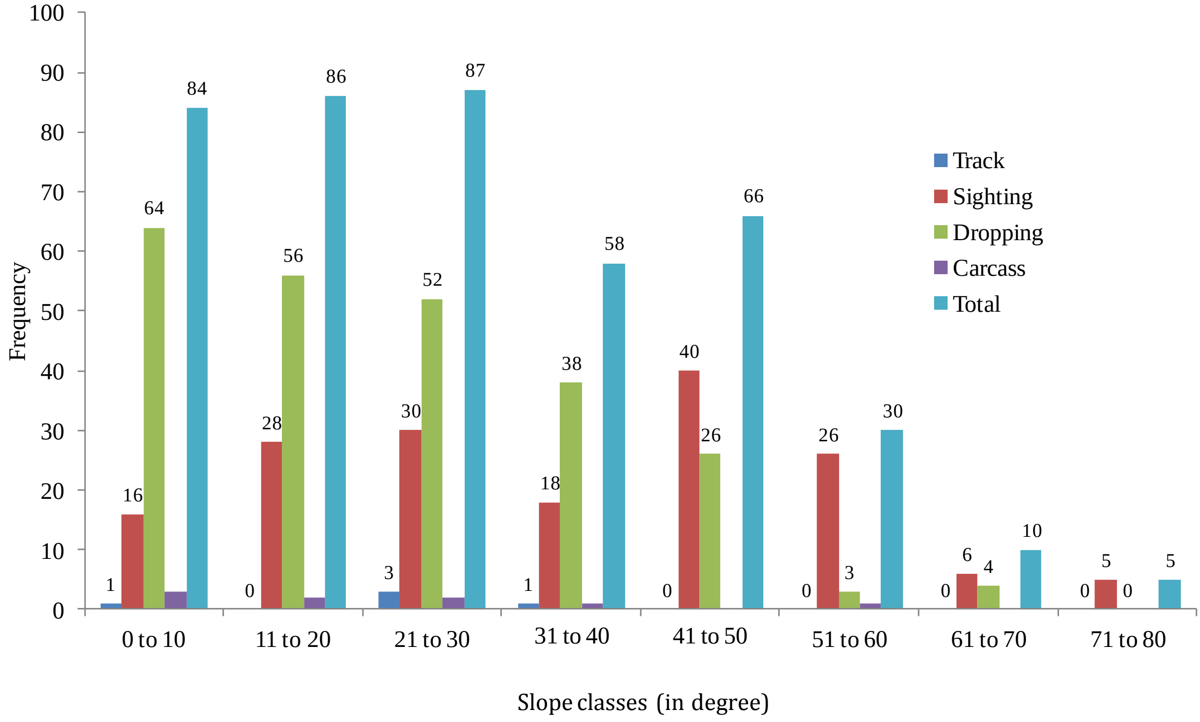


Figure 3.12: The frequency of blue sheep signs encountered in different slope classes in Bhutan.

Elevation wise, blue sheep signs were observed between 3,528 m and 5,209 m. They hardly came down to areas below 3,700 m, as shown by mere six signs seen in the elevation class 3,400 m – 3,700 m (Fig. 3.13). Majority of the signs were observed between 4000 m and 4,900 m. Blue sheep went up to areas above 4,900 m also, as indicated by 32 signs observed in the elevation class 4,900 m – 5,210 m.

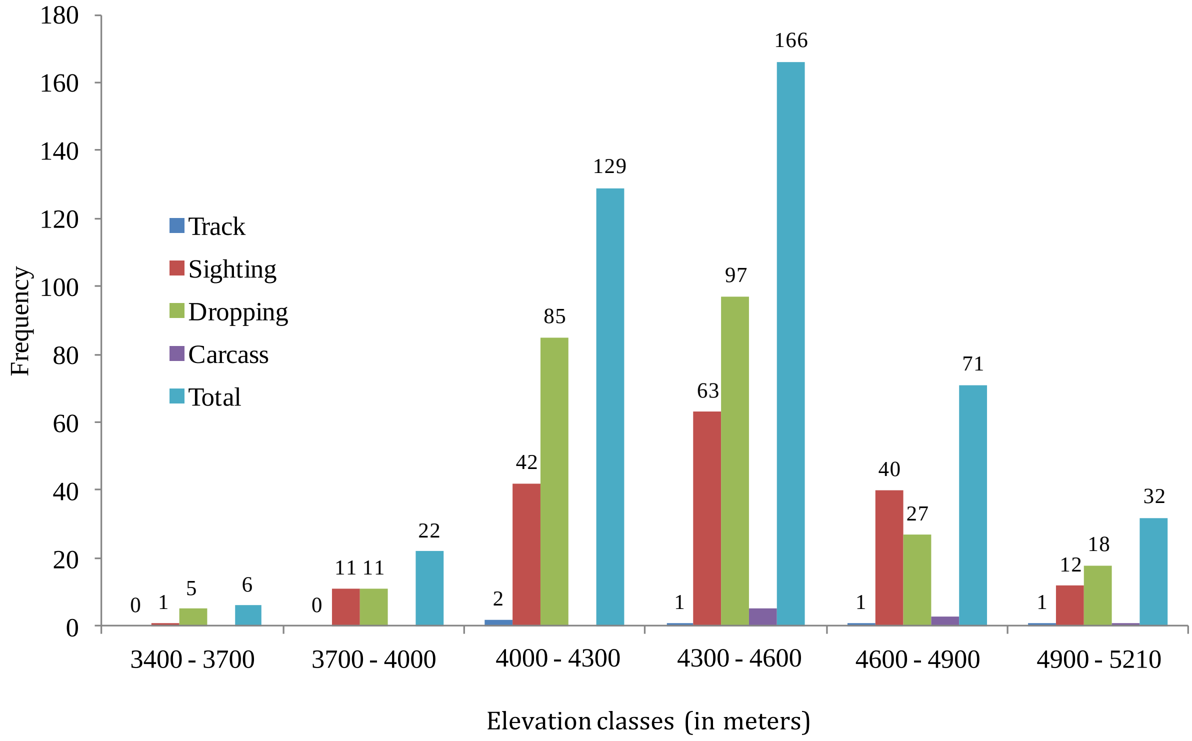


Figure 3.13: The frequency of blue sheep signs encountered in different elevation classes in Bhutan.

3.4. Distribution of snow leopard

3.4.1. MaxEnt model output

Snow leopard distribution (Fig. 3.14), resulting from MaxEnt modelling, showed high probability of occurrence (as indicated by red colour in the map which could also mean high suitability for snow leopard) in central part of JKSNR, northern part of PTFD, northern and western parts of JDNP (particularly Soe, Lingzhi, and Laya Range), Western and Central Range of WCNP, and northern part of BWS's Dungzam Range. Coincidentally, these areas were also marked as high density blue sheep areas (Annexure V f), indicating that the snow leopard distribution was most influenced by the prey density layer among the six environmental layers used in the MaxEnt model.

SWS showed moderately low probability of occurrence, mainly because of the absence of blue sheep there. However, if blue sheep were introduced in the sanctuary the probability could go up.

The snow leopard distribution map shows a clear declining probability of occurrence from west to east part of the country. Similar pattern was also observed by a researcher (Personal Communication, Mr. Tshewang R. Wangchuk, Bhutan Foundation) during his non-invasive genetic sampling of snow leopard populations.

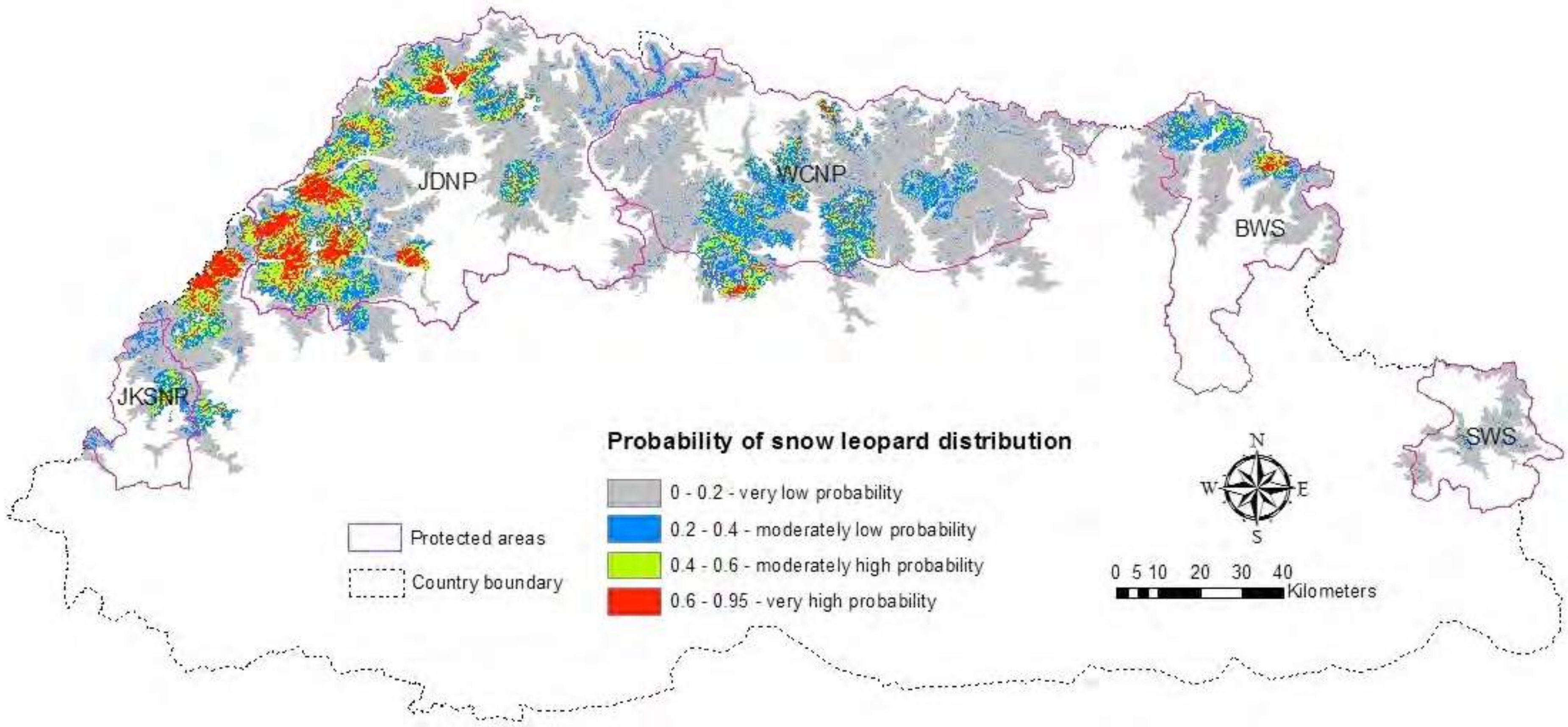


Figure 3.14: Distribution of snow leopard in Bhutan, indicating different probabilities of occurrences ranging from very low to very high.

In order to maximize the detection probability of snow leopards on the detectors during camera trap survey in the Phase II of the NSLSB, the field surveyors could station their cameras on areas corresponding to very high probability (red) and moderately high probability (yellowish green) areas on the map.

3.4.2. Contributions of the environmental variables to the model

Strong influence of prey distribution on snow leopard distribution was also corroborated by the variable contribution table (Table 3.2), which showed that the variable 'blue sheep density' contributed 63.7% to the model. The next highest contribution of 13.9% was made by the variable 'distance from human settlement', but this percentage was not large enough to reasonably conclude that the variable had considerable effect on the model. Moreover, areas with high probability of snow leopard occurrence were situated far away from human settlements. In contrast to normal expectations, the 'land cover type' contributed the least (2.9%) to the model. Among the geophysical variables, slope had the highest influence on the model with 8.8% contribution.

Table 3.2: Estimates of relative contributions of the environmental variables to the MaxEnt model of snow leopard distribution in Bhutan.

Variable	Percent contribution
Blue sheep density	63.7
Distance from human	13.9
settlement Slope	8.8
Aspect	5.5
Elevation	5.4
Land cover type	2.9

Even the jackknife test revealed the highest contribution of the 'blue sheep density' variable. The jackknife plot of regularized training gain for snow leopard distribution (Fig. 3.15) showed that if 'blue sheep density' variable was used, it would have allowed a reasonable good fit to the training data, whereas the variables such as 'aspect' and 'slope' by themselves would not have contributed much for estimating the distribution of snow leopard.

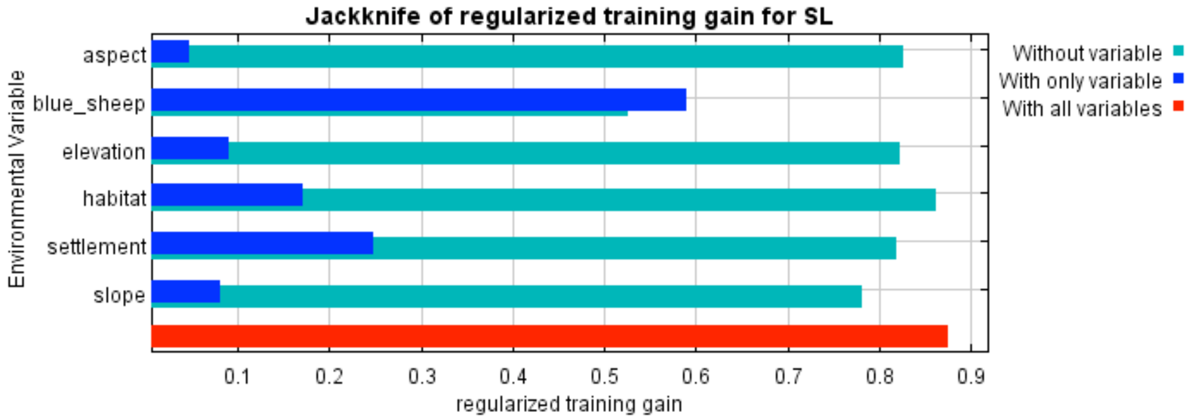


Figure 3.15: Results of the jackknife test of variable importance using 25% training data. The 'blue_sheep' refers to density of blue sheep, 'habitat' refers to land cover type and 'settlement' refers to distance from human settlement.

The AUC plot on test data (Fig. 3.16) also showed that the 'blue sheep density' is the single most effective variable for predicting the occurrence of snow leopard. None of the variable showed light blue bars that are longer than the red bar, which indicated that their use in the model would not have reduced the model's predictive performance.

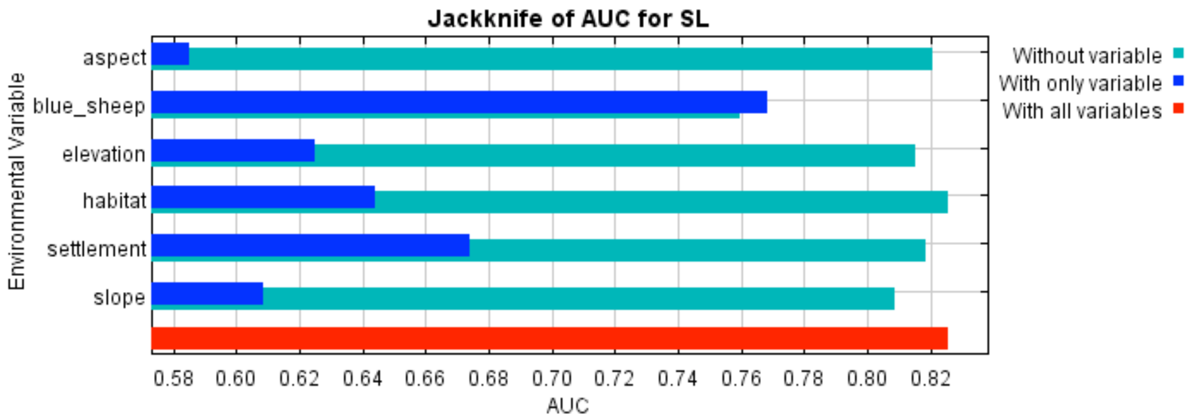


Figure 3.16: Results of the jackknife test of variable importance using AUC on test data. The 'blue_sheep' refers to density of blue sheep, 'habitat' refers to land cover type and 'settlement' refers to distance from human settlement.

3.4.3. Model performance

The MaxEnt model performed well on the snow leopard occurrence data and appropriately predicted the distribution of snow leopards, as indicated by the mean AUC curve of 0.826 (Fig. 3.17) which means that 82.6% of the time a random selection from the positive group will have a score greater than a random selection from the negative class (Fielding & Bell 1997).

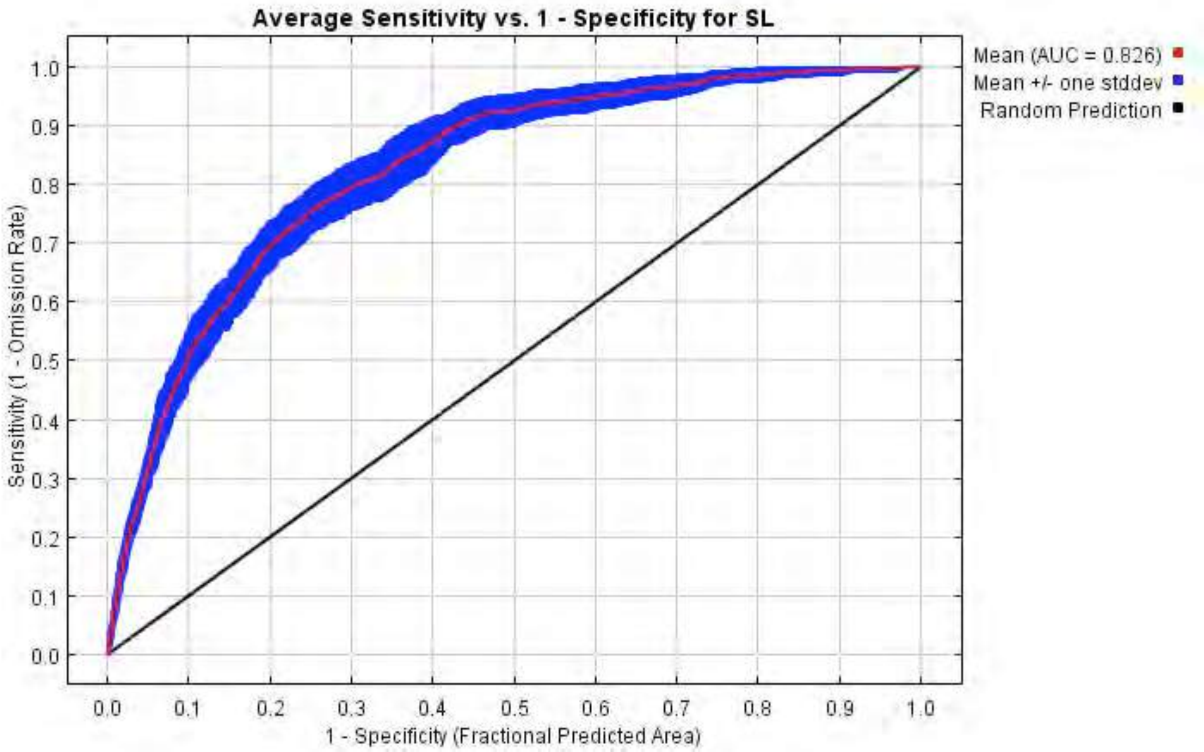


Figure 3.17: The Receiver Operating (ROC) curve for snow leopard sign locations showing area under the curve (AUC) averaged for all 12 replicates.

3.5. Distribution of blue sheep

3.5.1. MaxEnt model output

Judging from the locations of signs (Fig. 3.3) and the MaxEnt model output (Fig. 3.18), the highest probability of blue sheep occurrence were found in most of JDNP, northern part of PTFD, central part of JKSNR, lower half of WCNP, and upper right portion of BWS. The model output showed moderately and highly probable areas even in some parts of SWS, although no evidences were found there. This indicates that blue sheep could be reintroduced in the sanctuary in the near future. Overall, the pattern and extent of probable blue sheep distribution looks very promising with many areas of moderately and very high probable areas of occurrence from north-western to north-eastern stretch of the country.

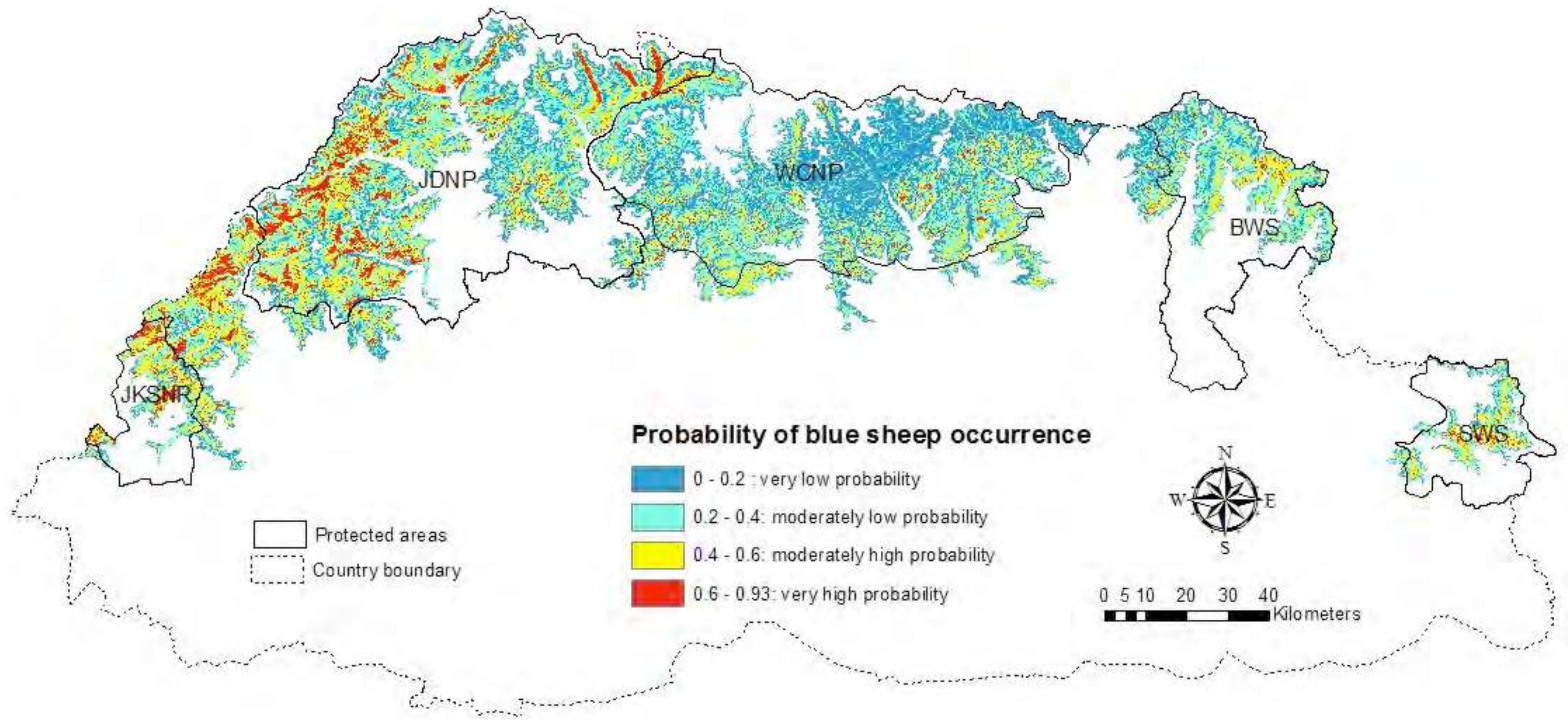


Figure 3.18: Distribution of blue sheep in Bhutan, indicating different probabilities of occurrences ranging from very low to very high.

3.5.2. Contributions of the environmental variables

'Land cover type' contributed the most (32.3%) to the MaxEnt model of blue sheep distribution in Bhutan (Table 3.3). Trailing the 'land cover type' were 'elevation' and 'slope' variables, which contributed 24.6% and 23% to the model. 'Aspect' and 'distance from settlement' variables contributed almost equally, with 10.5% and 9.6%, but they were the least contributors. In the case of blue sheep too, the highly probable areas of occurrence were situated far away from human settlements.

Table 3.3: Estimates of relative contributions of the environmental variables to the MaxEnt model of blue sheep distribution in Bhutan.

Variable	Percent contribution
Land cover type	32.3
Elevation	24.6
Slope	23
Aspect	10.5
Distance from settlement	9.6

The 'land cover type' (shown as habitat in Fig. 3.19) had the highest gain when used singly in the model; thus, it appeared to have the most useful information by itself. In contrast, slope was the variable that decreased the model gain the most when omitted from the model. It, therefore, appeared to have the most information that was not present in other variables.

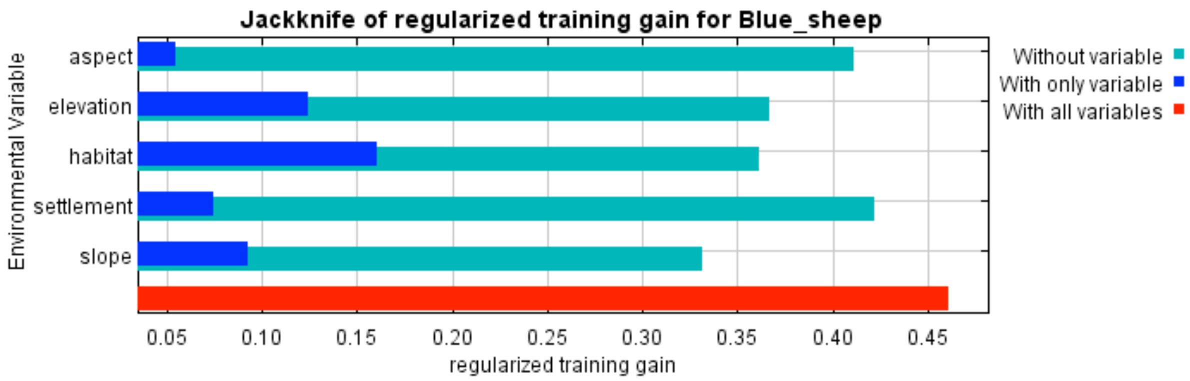


Figure 3.19: Results of the jackknife test of variable importance using 25% training data. The 'habitat' refers to land cover type and 'settlement' refers to distance from human settlement.

Even the results of the jackknife test on model gain using test data (Fig. 3.20) showed similar results, except that the light blue bar of the "distance from settlement' variable was longer than the red bar, indicating that the model's predictive performance would improve if it is omitted.

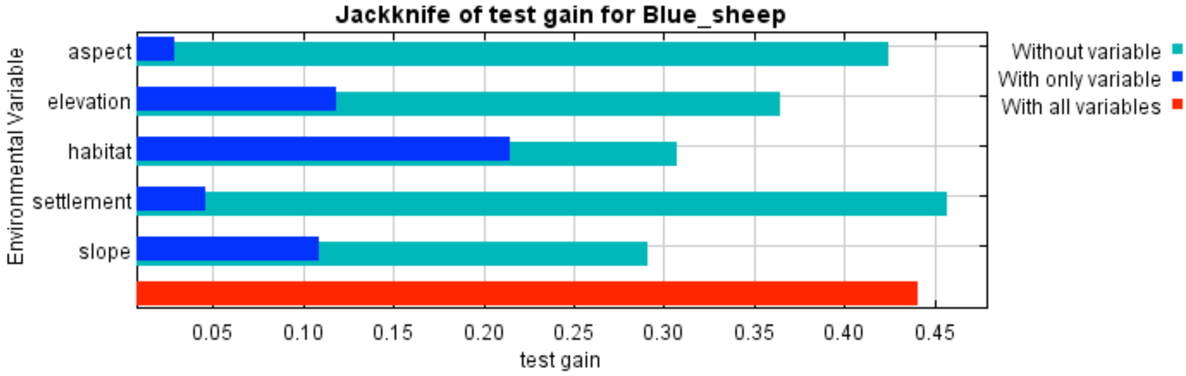


Figure 3.20: Results of the jackknife test of variable importance using test data. The 'habitat' refers to land cover type and 'settlement' refers to distance from human settlement.

Finally, the jackknife test using AUC on test data (Fig. 3.21) showed that the 'slope' was the most effective single variable for predicting the distribution of blue sheep occurrence data that was set aside for testing, even though it was sparingly used in the model when all variables were considered. Next to the 'slope' variable was the 'land cover type' variable which showed effectiveness in model prediction when used alone. This is plausible, because blue sheep are herbivores, and they would always follow optimal foraging areas with lush cover of grasses.

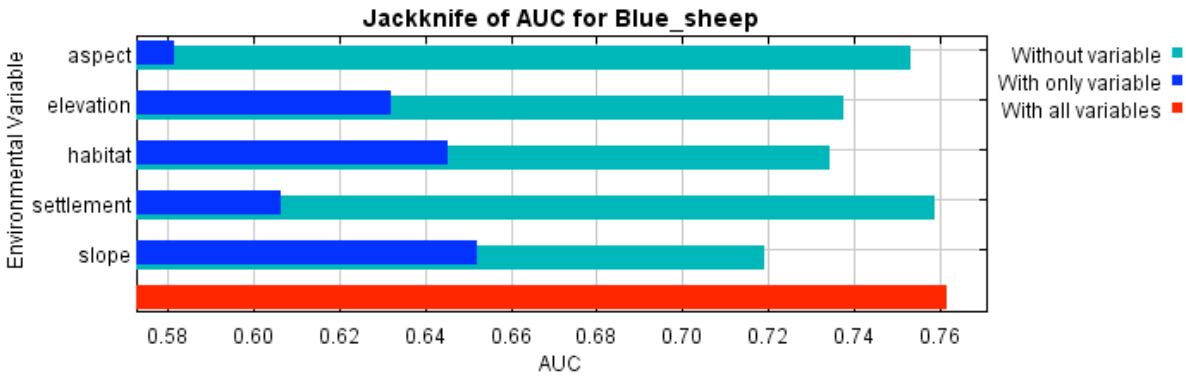


Figure 3.21: Results of the jackknife test of variable importance using AUC on test data. The 'habitat' refers to land cover type and 'settlement' refers to distance from human settlement.

3.5.3. Model performance

The MaxEnt model for blue sheep distribution performed well to reliably project the probable areas of occurrence, as proven by the mean AUC curve of 0.761 (Fig. 3.22) .

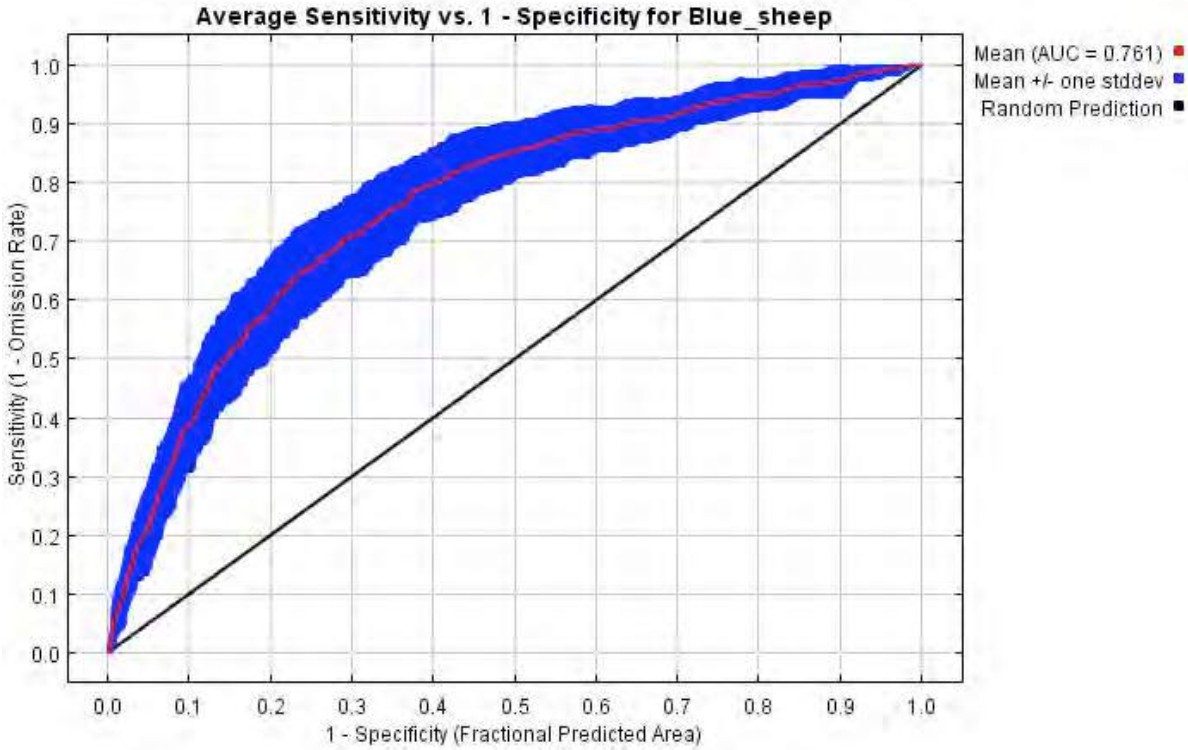


Figure 3.22: The Receiver Operating (ROC) curve for blue sheep sign locations showing area under the curve (AUC) averaged for all 12 replicates.

3.6 Threats to snow leopard and blue sheep noted by the surveyors

The field surveyors noted some of the key threats to snow leopard and blue sheep:

a) Stray dogs were observed killing blue sheep (particularly in JDNP and JKSNR) and thus, potentially competing with snow leopard and also increasing the risk of disease transmission.

b) Evidences of retaliatory killing of snow leopards by the local communities were recorded from JDNP.

c) Poaching of blue sheep by cordyceps collectors and armed forces were documented in some of the protected areas.

d) Cordyceps collectors caused disturbances to snow leopard and blue sheep habitats.

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CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

4.1. Summary of the key findings

Bhutan appears to have vast swathe of suitable areas with high probability of occurrence for snow leopard and blue sheep, based on the findings of the sign surveys for both these predator and prey. The snow leopard distribution is largely dependent upon the density and distribution of blue sheep, underscoring the need to preserve a good stock of this important prey species for longevity of the endangered predator. The blue sheep distribution on the other hand is heavily influenced by land cover type, especially the alpine meadows, by virtue of its being a herbivore.

Among the protected areas, JKSNR, JDNP, WCNP, and BWS are important for snow leopard and blue sheep conservation. Among the areas outside the protected areas, particularly the territorial forest division, PTFD is the most important area for the conservation of these two species. On account of the presence of large suitable areas, SWS holds potentials for re-introduction of blue sheep and subsequently snow leopard in the near future.

4.2. Field constraints and challenges

It is essential to understand the challenges faced by the frontline staff while conducting such a survey. Following constraints were faced by our frontline staff during Bhutan's first national level sign and prey base survey for the snow leopard:

1. Correct identification of sign was one of the most difficult tasks while in the field due to short life and quick deterioration of signs.
2. Thick snow cover impeded the survey team to conduct sign surveys in some areas which were otherwise ideal for sign survey.
3. Remote, hostile and rugged terrains in most of the survey areas severely constrained the surveyors, often threatening their lives.
4. Lack of appropriate and adequate field gears and first aid kits limited the productivity of the survey team members.

4.3. Management recommendations

In order to ensure the long-term viability of snow leopards and blue sheep in Bhutan and in the region, the following recommendations are offered:

1) Protect and maintain the alpine meadows using the sound principles of integrated rangeland management, including proper livestock management.

2) Maintain habitat connectivity between the snow leopard and blue sheep range areas. Realign the existing biological corridor between JKSNR and JDNP to include potential habitats along the northern parts of PTFD.
3) Subsume or incorporate some of the potential snow leopard areas into the existing protected areas boundaries wherever deemed necessary.
4) Periodically monitor snow leopard and blue sheep populations using the method in this sign survey which is rapid and less expensive.
5) Use the results of the sign survey as inputs to the snow leopard conservation plan.
6) Encourage ecological studies on blue sheep and snow leopard with strong emphasis on the impacts of anthropogenic activities (such as livestock grazing, medicinal plant collection, and tourism) on their habitats.
7) Study the impact of stray dogs on snow leopard and blue sheep populations and devise appropriate mitigation strategies
8) Study the impact of medicinal plants collection on blue sheep population and propose relevant interventions
9) Study the extent of retaliatory killing of snow leopard by the local communities and frame appropriate mitigation measures.
10) Institute regular patrolling and enforcement strategies to prevent poaching of snow leopard and its prey, including musk deer.
11) Given the uncertainty of snow leopard populations in BWS, it is important to maintain and enhance connectivity between Eastern Range of WCNP and BWS via Kurichu.
12) Strengthen the capacity of the frontline staff and/or surveyors on the survey methodology, particularly field data collection and the monitoring protocols to obtain reliable data.
13) Equip the frontline staff with adequate and appropriate field gears, and provide first aid kit to ensure staff safety.
14) Initiate a life insurance programme for all staff involved in such surveys for at least during the survey period.

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Annexure Table I: Name list of Field Focal Persons from the respective survey areas

Name	Designation	Survey area
Bhakta Bdr. Ghalley	Forest Ranger I	Jigme Khesar Strict Nature Reserve
Sonam Dorji	Sr. Forest Ranger	Paro Territorial Forest Division
Rinzin Dorji	Forest Officer	Jigme Dorji National Park
Tenzin	Sr. Forest Ranger II	Wangchuck Centennial National Park
Tshering Dhendup	Forest Officer	Bumdeling Wildlife Sanctuary
Kumbu Dorji	Forest Officer	Sakteng Wildlife Sanctuary

Snow leopard planning and training workshop attended by field focals and range focals at Lobesa, Wangdi in September 2015

Annexure Table II: Name of Core Team members for the National Snow Leopard Survey

Name	Designation	Office	Role
Sonam Wangchuk	Chief	Wildlife Conservation Division	Project Manager/resource person
Dr. Phuntsho Thinley	Principal Research Officer	RNR-Research and Development Centre at Yusipang	Scientific advisor and co-principal investigator
Dechen Lham	Senior Biodiversity Officer	Wildlife Conservation Division	National Focal Person/ project coordinator and co-principal investigator
Lhendup Tharchen	Park Manager	Jigme Dorji National Park	Member / resource person
Namgay Wangchuk	Park Manager	Jigme Khesar Strict Nature Reserve	Member/resource person
Phuntsho	Research Officer	Ugyen Wangchuck Institute of Conservation and Environment	Member/GIS focal person
Tenzin	Forest Officer	Wangchuck Centennial National Park	Member/resource person
Kinzang Lham	Sr. Forest Ranger	Wildlife Conservation Division	National Data Manager/resource person for scat analysis
Tandin Namgay	Sr. Forest Ranger	Wildlife Conservation Division	Equipment custodian / resource person for survey equipment handling and care

Annexure Table III: Data form for snow leopard sign survey

Date : ……………………………………… Weather……………………

Start Time………………………………… End Time…………………

Start Location……………………………… End Location……………

GPS Reading starting: Lat………………… Longitude………………… Elevation……………Aspect………..

GPS Reading ending: Lat…………………… Longitude………………… Elevation………………Aspect…………..

Grid #:……………………………Name of Trail/ Transect No………………… Approximate length of transect…………………….

Habitat type……………………………… Surveyor/s…………………………………Contact #:………………………………………………

Location	GPS Reading				Type of Sign	Age of sign	Sign Measurement	Dominant landscape	Range land use	Land Form ruggedness	Remarks
	Latitude	Longitude	Altitude	aspect							

Codes for the sign survey form:

1. Grid number - Number grid consecutively

2. Location – Name of the area

3. Elevation –Take from Altimeter/GPS (in meters)

4. Aspect of site - Record the direction of the site containing the sign (in degrees)

5. Type of sign present at site.

Scrape	SC	Scrape made by a Snow leopard.
Scratch	SR	Scratch made on tree trunk or bushes.
Faeces	FE	Scat or dropping.
(Scat) Scent	SS	Scent mark
spray Urine	UR	Urination mark.
Claw rake	CL	Claw mark made on a tree trunk or rock face.
Pugmark	PU	Footprint impression or track.

6. Age of sign or visibility (by type of sign present)

Scrape

Very old	0	Extensive weathering and disintegration, Scrape features poorly defined, often with vegetation growth in the depression and on the pile (age = at least 3 to 6 months)
Old	1	Moderate Weathering and disintegration, with then scrape Showing a rounded form, occasionally with vegetation in the depression or on the pile (age=several months or more)
Fresh	2	Slight weathering, Scrape has a well-defined form with "Sharp" edges, is easily recognizable and has no new vegetation growing in the scrape depression or pile (age = 1 to 4 weeks)
Very fresh	3	Little or no weathering has not occurred, so that the scrap"has a very sharp and "clean" form, is very easily recognizable, and has no vegetation in its depression or pile. Sand or gravely materials may cover some vegetation, causing it to "bend down". Other ephemeral sign such as tracks or urine may be observed, while scats deposited at the same time are obviously still fresh or very fresh (age = less than 1 week)

Pugmark

Old	0	Pugmark is very poorly defined, with an obviously "weathered" appearance (more than 2 weeks old)
Fresh	1	Pugmark has sharply defined edges and shape (several days, but less than one week old)
Very fresh	2	Pugmark is very fresh, showing fine surface details and having a very sharp edge (made less than 24 hours previously).

Feces

Old	0	Scat is mottled and cracked, with a hard, dull surface and dry interior (several weeks to several months of age)
Fresh	1	Scat is odoriferous and “fresh looking”, with a glossy, sheen inside (more than 2 days but less than 10 days of age)
Very fresh	2	Scat is still wet outside and moist inside (no older than 2 days)

Scent Sprayed Rock

None	0	No detectable odour (more than 3 months)
Slight	1	Odour is just detectable.
Moderate	2	Odour is readily detectable.
Strong	3	Odour is unmistakable.
Very strong	4	Odour is very strong (can be detected from 25cm or more away; less than several weeks old)

Claw or tree rake (living tree only)

Very old	0	Bark has fully covered the claw scars, completely healing the wound.
Old	1	Claw scar present on the bark but the scar has clearly started to heal.
Fresh	2	Claw mark still very evident and sap may still be exuding from the wound, with other sign such as mud on the bark or pugmark nearby.

7. Dominant topographic feature (local feature which best describe the site.

Cliff	CLF	Terrain at site is very precipitous (slope more than 50 degree)
Ridgeline	RID	Narrow crest of land sloping down on either side.
Hill-slope	HIL	Side or slope of a hill.
Valley floor	VAL	Valley floor or adjacent slope.
Basin or bowl	BOW	Bowl-like depression.
Saddle	SAD	well defined low spot along a ridgeline.
Pass	PAS	Well defined mountain pass.
Stream bed	STR	Site with seasonal or permanent water flowing drainage through it.
Boulder field	BOU	Outcropping of large boulders.
Talus or scree slope	TAL	Accumulation of rocks and pebbles at base of steep slope.
Rock fall or landslide	ROC	The mass of rocks at the base of cliff.
Bluff	BLU	Steep slope bordering the stream or river.
Terrace	TER	Level raised area bordering a stream or river.
Glacier	GLA	Permanent ice field.

8. Rangeland use.

None	NON	Area receives no human use.
Seasonal grazing	SGR	Area grazed seasonally by Livestock.
Year round grazing.	YRG	Area grazed throughout the year by L/stock.
Other type of land use.	OTH	(Describe)

9. Land form or land surface ruggedness.

Cliff	CLF	Terrain at site is very precipitous (slope more than 50 degree)
Broken	BR	Terrain is broken by cliffs, rocky outcrops, ravines and gullies.
Very broken	VBR	Terrain heavily broken by cliffs, rocky outcrops, ravines and gullies.
Rolling	ROL	Terrain has a relatively smooth land surface (eg, rolling hills or alluvial fan)
Flat	FLA	Terrain forms a level surface (e.g, plain).

10. Habitat type

1. Alpine scree
2. Alpine grassland
3. Alpine scrub forest
4. Fir Forest

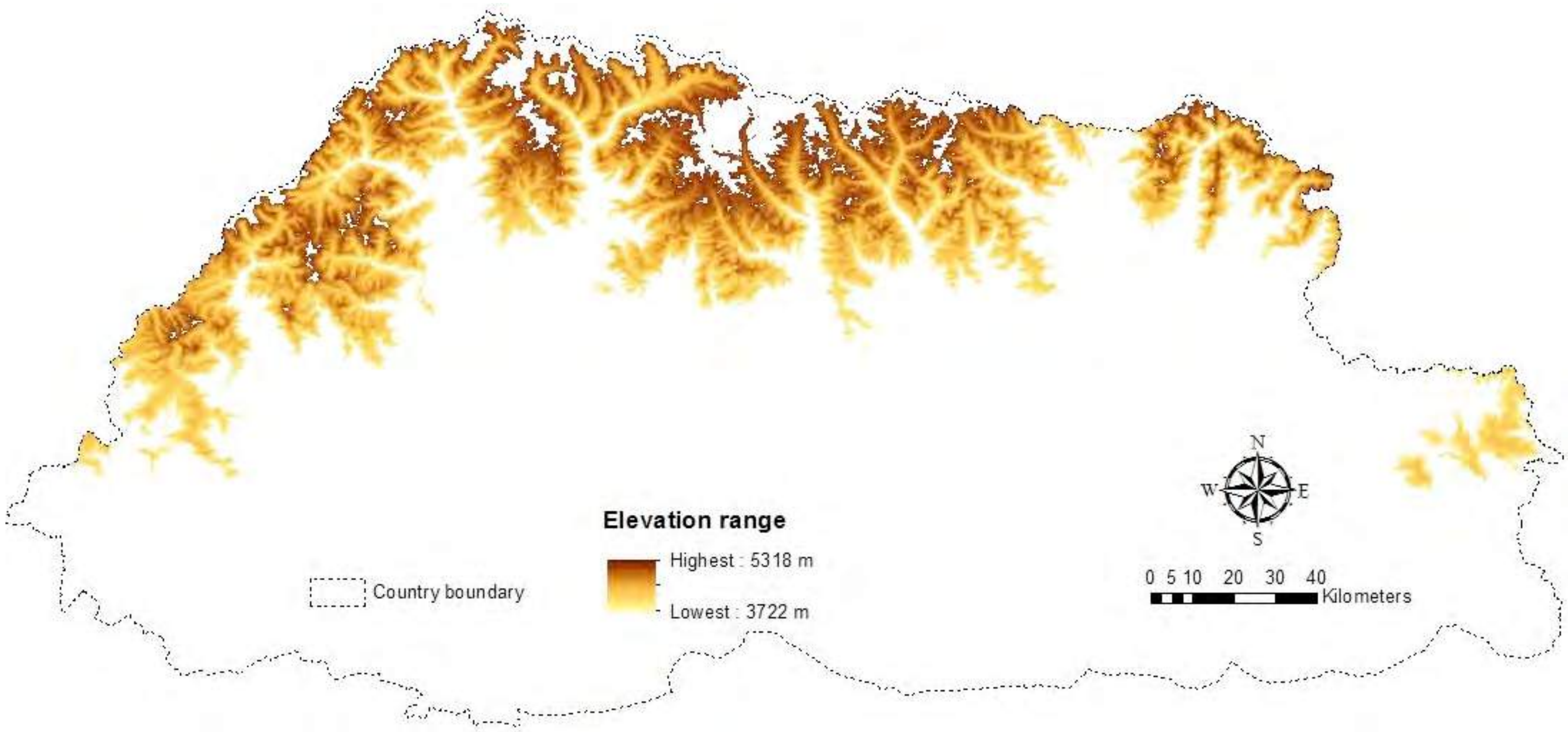
Annexure Table IV: Data form for survey of snow leopard prey base

Name of Park/Division: **Name of range:** **Dates of survey: start................end......................**

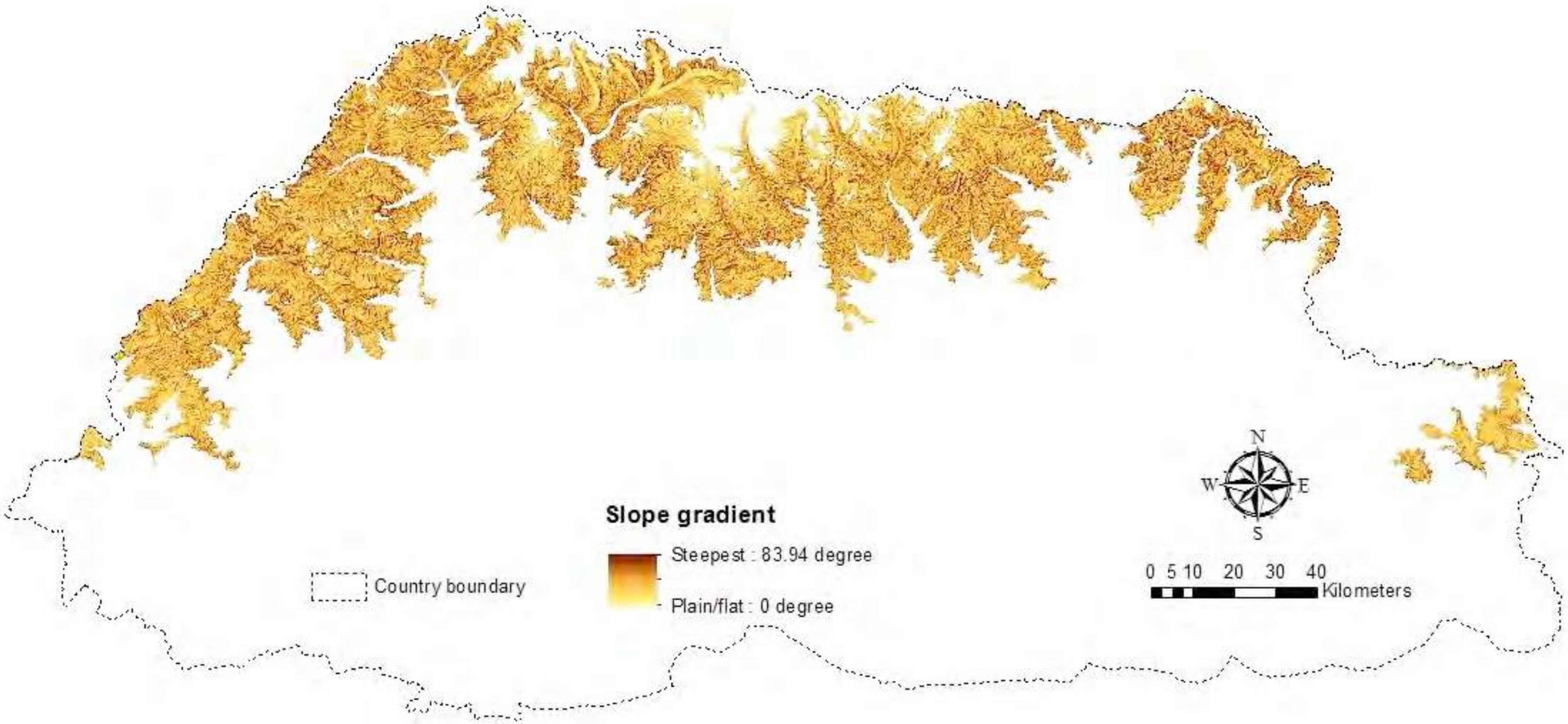
Grid #	Transect #	Observation point #	Species	Date	Time	Weather	Count						Latitude			Longitude			Altitude (m)	Aspect (deg)	Slope (deg)	Habitat	Locality	Land features	Surface ruggedness	Rangeland used	Observer	Remarks
							M	F	Lamb	Yearling	Unknown	Total	dd	mm	ss.ss	dd	mm	ss.ss										

Annexure Figure I: Spatial layers representing the environmental variables in MaxEnt model

a. Elevation

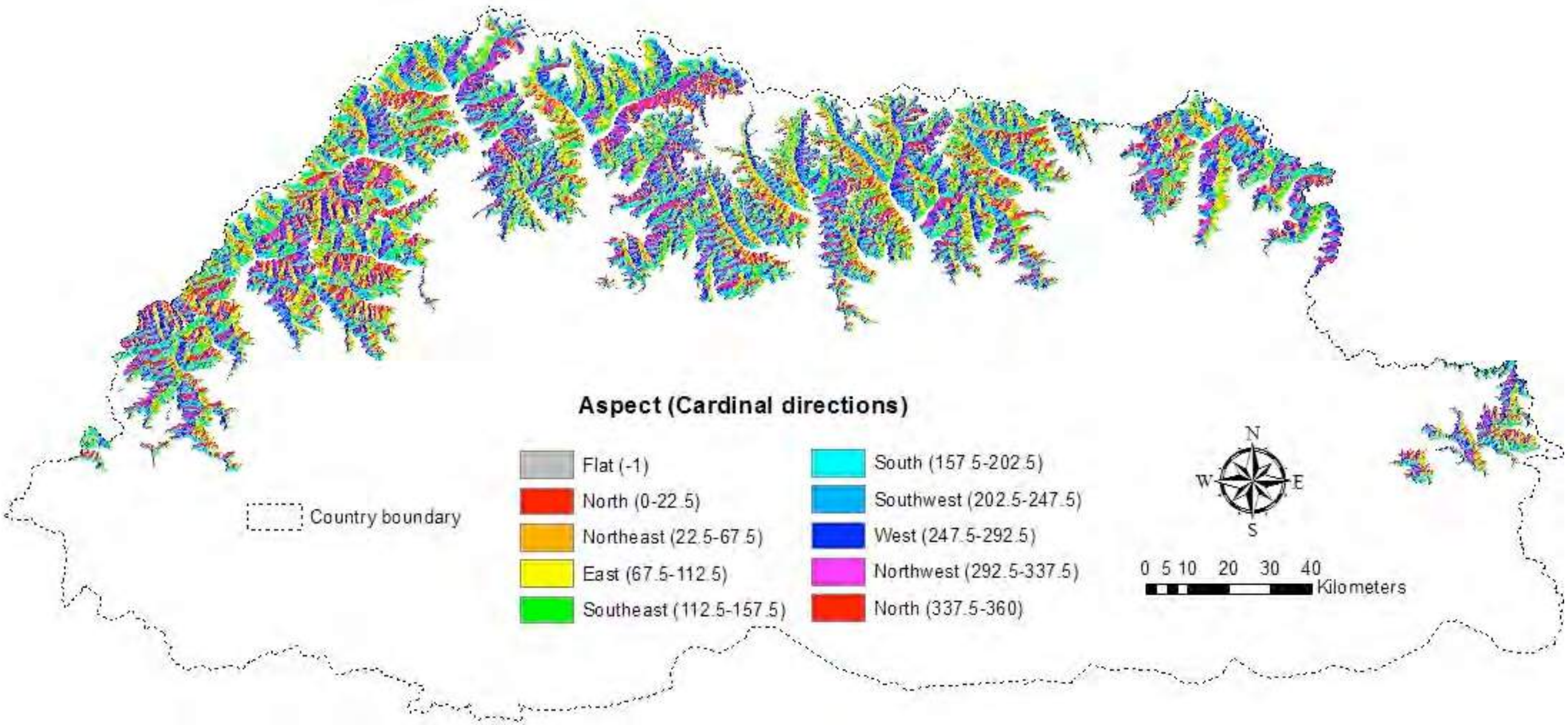


b. Slope

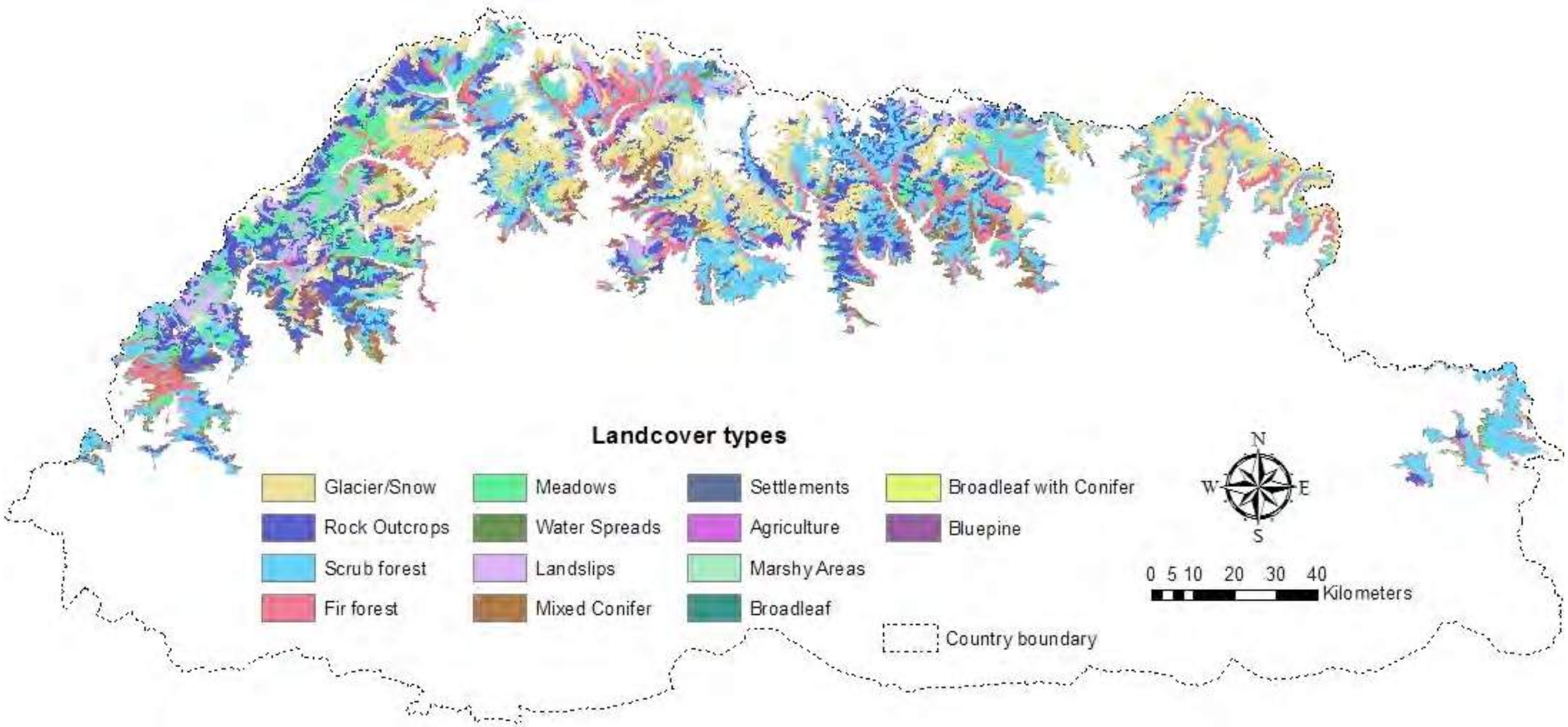


Slope gradient
Steepest : 83.94 degree
Plain/flat : 0 degree
Country boundary
N
W
E
S
0 5 10 20 30 40
Kilometers

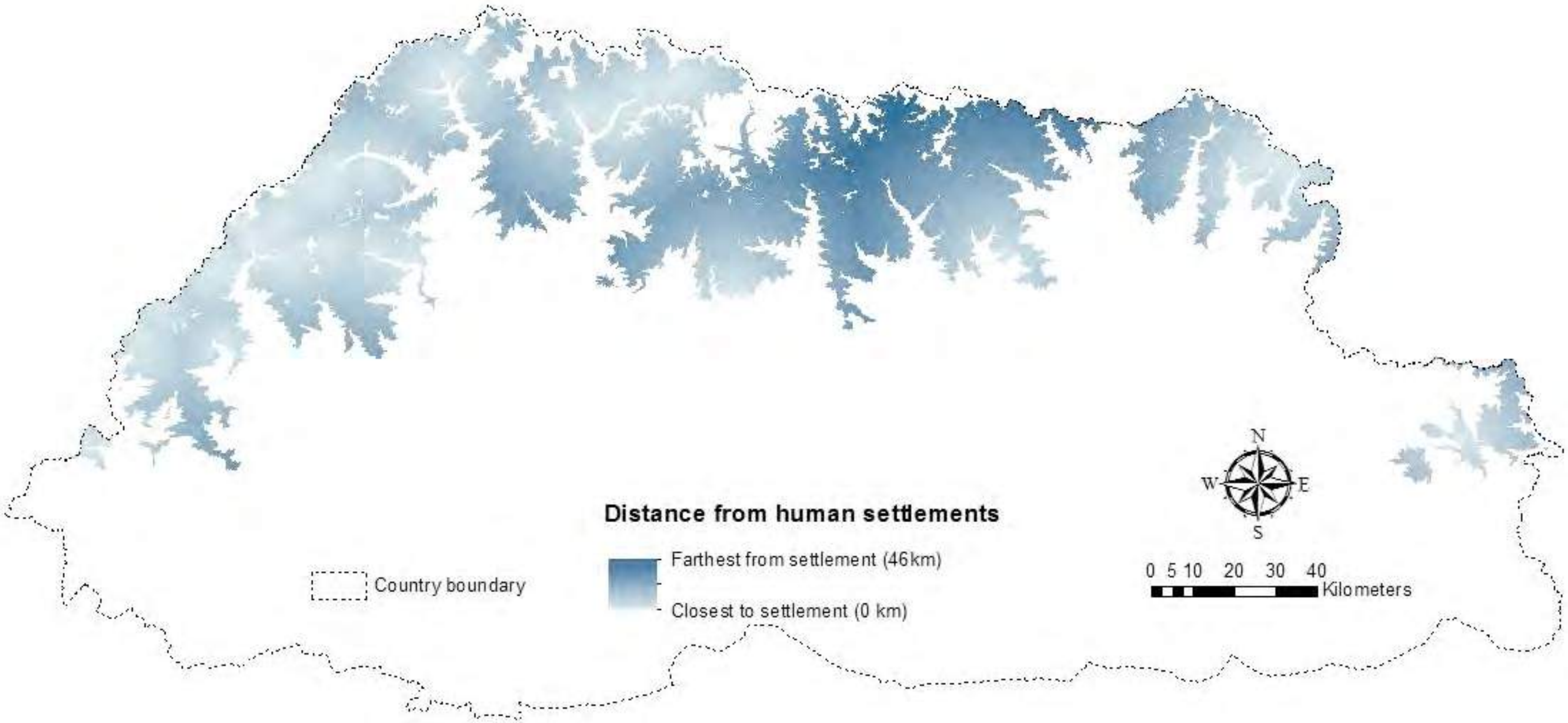
c. Aspect


Aspect (Cardinal directions)
Flat (-1)
North (0-22.5)
Northeast (22.5-67.5)
East (67.5-112.5)
Southeast (112.5-157.5)
South (157.5-202.5)
Southwest (202.5-247.5)
West (247.5-292.5)
Northwest (292.5-337.5)
North (337.5-360)
Country boundary
N
W
E
S
0 5 10 20 30 40
Kilometers

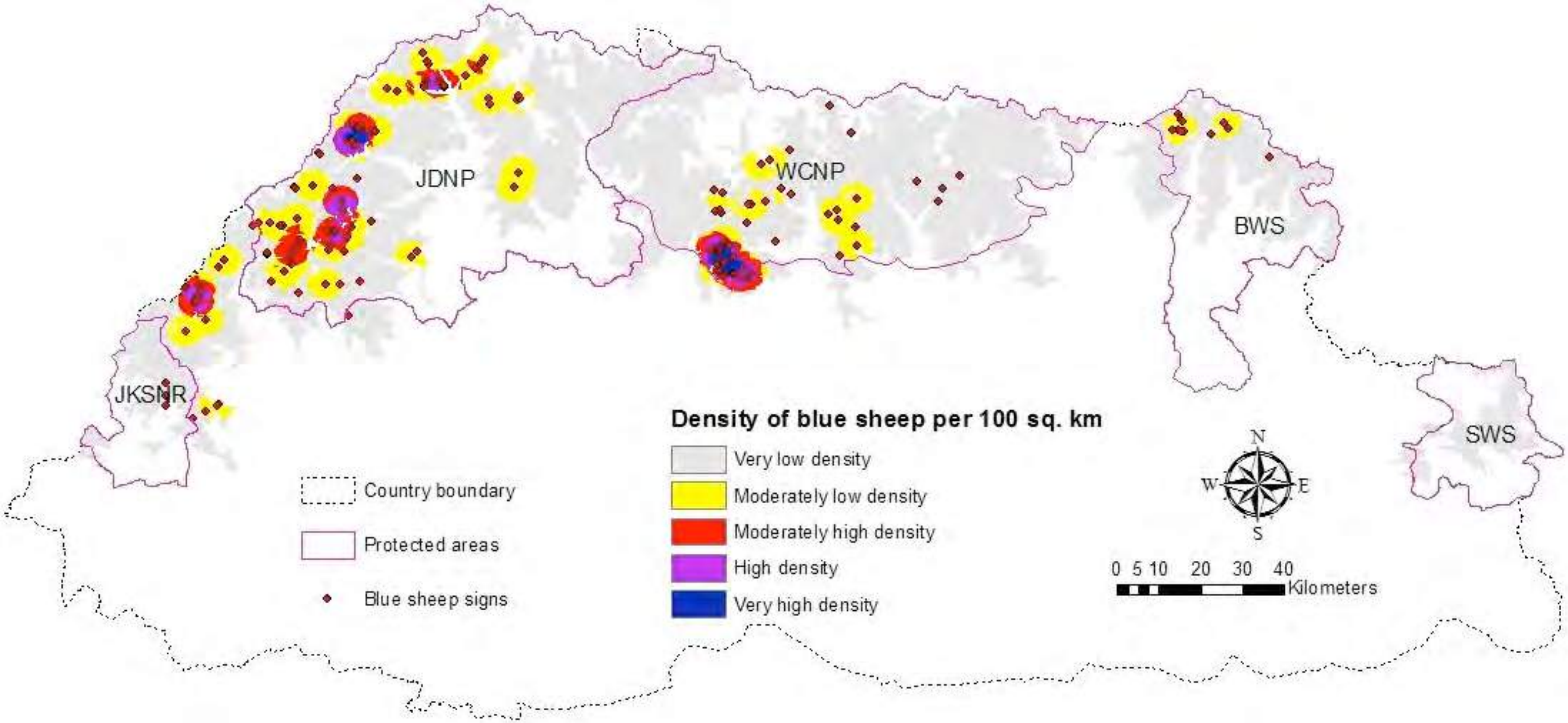
d. Land cover or vegetation type



e. Distance from human settlement



f. Blue sheep density

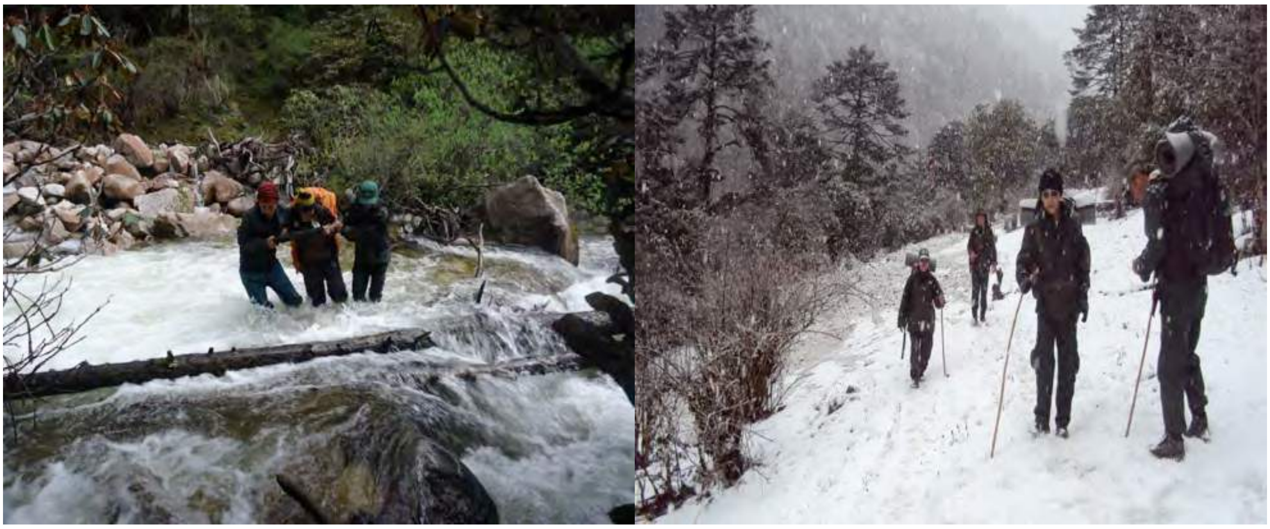


Annexure Figure II: Photographs of sign surveys in the snow leopard range areas in Bhutan.

JKSNR Survey members being de-briefed before commencing field work

JDNP Survey members noting field evidences

Survey members communicating and struggling in the snow and traversing the steep terrains



Survey members risking lives crossing fast flowing rivers and bearing the extreme cold

Survey members discussing and preparing areas for survey before venturing in the field

Survey members in JKSNR (left) and BWS (right) recording and noting signs and GPS coordinates

Survey members following ridgeline and valley bottoms in search of signs and evidences

Team members identifying snow leopard scat (left) and scrape (right)

Survey teams from JKSNR (left) and SWS (right)

JDNP Survey team members: Lingshi range (left & right) and Gasa range (middle)

Haa range survey members under Paro Territorial Division (left) and WCNP survey members (right)

Annexure Figure III: Photographs of snow leopard and blue sheep signs.

Snow leopard pug mark observed in Lingshi range, JDNP (left) and JKSNR (right)

Snow leopard scrapes observed in Lingshi range, JDNP (left) and WCNP (right)

Blue sheep hooves mark in snow (left) and sand (right) observed in JKSNR

Snow leopard old scat observed in JKSNR (left) and Lingshi range, JDNP (right)

Snow leopard fresh scat found in Naro, Lingshi range, JDNP

Blue sheep droppings observed in JDNP (left) and JKSNR (right)

Blue sheep in JKSNR (top) and JDNP (bottom)

Evidence of domestic yak depredation by predator snow leopard (WCNP) and Himalayan marmot sighted in JKSNR

Adult male blue sheep in JKSNR

Near Jomolhari base camp, JDNP

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