



# Snow Leopard Population Assessment in India

Population Assessment of World's Snow Leopards (PAWS) for India





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##### **Cover and Book Design:**

Echostream Design Pvt. Ltd.

Opposite Dukhit Pan Dukaan, Bhanu Path Road, Gangtok-Sikkim 737101

[www.echostream.in](http://www.echostream.in)

### Suggested citation

MoEFCC (2019). SNOW LEOPARD POPULATION ASSESSMENT  
IN INDIA: Population Assessment of World's Snow Leopards. Ministry  
of Environment, Forest and Wildlife; Wildlife Institute of India; Nature  
Conservation Foundation-Snow Leopard Trust; and Global Snow Leopard  
and Ecosystem Protection Program-PAWS Advisory Panel. p59.



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प्रकाश जावडेकर  
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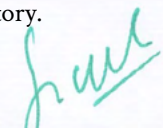
## FOREWORD

Snow leopard known as the “ghost of the mountains” are the most elusive carnivore found in the high altitude of the five states namely Jammu & Kashmir, Himachal Pradesh Uttarakhand, Sikkim and Arunachal Pradesh. It is the flagship species of conservation in the Indian Himalayas. The high-altitude ecosystem of the Himalayas provides fresh water and other services worth Rs. 288.25 billion annually to nearly one fifth of human population of the world. Despite such importance of snow leopard and its habitat, uniform protocol to assess its distribution and population was lacking. Ministry of Environment, Forest and Climate Change (MOEFCC), has taken leadership and with the help of Wildlife Institute of India, Dehradun, and Nature Conservation Foundation, Mysuru, have now prepared a National level protocol called the *Snow Leopard Population Assessment of India (SPAI)* consultation with the five snow leopard range States in India. Population enumeration of snow leopard is a management tool for the conservation biologist and Protected Area Managers. It also provides a platform for formulation of management strategies and is a unique feature of our snow leopard conservation efforts.

This protocol is evolved from the international efforts to develop a global protocol for the Population Assessment of World's Snow Leopards (PAWS) under the Global Snow Leopard Ecosystem Protection Program (GSLEP) of the twelve countries. Based on the SPAI protocol, through Government of India's existing initiatives, such as the Project Snow Leopard and Gol-GEF-UNDP's SECURE Himalaya, and international partnership on GSLEP the snow leopard range States will be able to estimate distribution and population of snow leopards and prey in a uniform manner to arrive at a National estimate for the first time. Since majority of snow leopard habitat in India lies along international boundary, partnership with other Ministries like the Ministry of Defence and local people of the bordering areas will be imperative.

I wish to congratulate all the Ministry Officials who have initiated it to fill a gap in the knowledge as well as Wildlife Institute of India, Nature Conservation Foundation, and the State Governments of Jammu & Kashmir, Himachal Pradesh, Uttarakhand Sikkim and Arunachal Pradesh on this achievement. The Nation will now eagerly await its first snow leopard and prey population estimates and will be a new chapter in our conservation history.

Date 24/07/2019

  
(Prakash Javadekar)



बाबुल सुप्रियो  
BABUL SUPRIYO




केंद्रीय मंत्री  
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय  
भारत सरकार  
MINISTER OF STATE  
MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE  
GOVERNMENT OF INDIA



## MESSAGE

Snow leopard is one of the most charismatic-species of Big-Cats. The unique nature of the snow leopard habitat is that wildlife is not restricted to protected areas. Snow leopards, its sympatric carnivores like wolves, brown bear and prey, namely, blue sheep and Asiatic ibex occur across vast landscapes of rugged mountains and undulating pastures, alongside local communities like Changpa, Pangwal, Lahauli, Spitian, Kinnaura, Pahadi, Bhotia, Monpa etc. keeping this unique natural history of snow leopard and associated wildlife in mind, the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, has embarked upon two National level initiatives focusing on landscape level participatory approach of conservation management, namely, The Project Snow Leopard and GoI-GEF-UNDP's SECURE Himalaya. India is also a partner country in the Global Snow Leopard Ecosystem Protection Program (GSLEP). Snow leopards are extremely difficult to be seen. Several attempts have been made using different approaches at different scales to estimate distribution and population of snow leopards. However, we are yet far from a very basic information: how many snow leopards are there in India? The Wildlife Division of the Ministry of Environment, Forest and Climate Change (MoEFCC), GoI, is pleased to present the Nation, the *Snow Leopard Population Assessment of India (SPAI)*. This National protocol has been developed jointly by the Wildlife Institute of India and Nature Conservation Foundation with inputs from the five Himalayan States. Namely Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. With the SPAI protocol, through the Project Snow Leopard, SECURE Himalaya and GSLEP, India will be able to assess and monitor distribution and population of snow leopards and prey in a systematic and uniform manner to deduce national estimates. The protocol will also serve as a guide to the other 11 range countries of snow leopard across Asia. We sincerely envisage collaboration with several other stakeholders in implementation of this protocol in India, namely, the Ministry of Defence, national and international NGO and local communities of the five Himalayan States. My sincere thanks and congratulations go to the MoEFCC Wildlife Institute of India and Nature Conservation Foundation for this achievement.

  
(Babul Supriyo)



सी. के. मिश्रा  
C.K. MISHRA



सचिव  
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## MESSAGE

Snow leopard is the apex predator of the mountain ecosystems across 12 countries in Central and South Asia, including India. Although snow leopards are widespread, they occur at naturally low densities. The main prey species of snow leopard, namely, bharal and Asiatic ibex, occur across snow leopard habitat, but in largely mutually exclusive areas. Research and surveys on snow leopard and its prey started back in the late 1980s and early 1990s. However, due to the elusive nature of snow leopards, rugged and remote habitat, carrying out distribution and population assessment surveys at large scale has been challenging. A holistic uniform approach to estimate their distribution and population at the National level has not yet emerged.

The Government of India is committed to landscape level conservation of snow leopard habitat through the Project Snow Leopard, GoI-GEF-UNDP SECURE Himalaya and the Global Snow Leopard Ecosystem Protection Program (GSLEP). The Wildlife Division of the MoEFCC, GoI, initiated the preparation of the *Snow Leopard Population Assessment in India (SPAI)* in 2018. The protocol was developed by the Wildlife Institute of India and Nature Conservation Foundation, in discussion with the five Himalayan States namely Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh.

With the guidance of the SPAI protocol the snow leopard range states in India will be able to estimate distribution and population of snow leopards and prey using uniform methodology, such that estimates from the different States are comparable and a national level estimate may be achieved. This protocol will inspire other range countries of snow leopard across Asia to develop their country specific protocols. Partnerships and collaboration with other stakeholders, such as the Ministry of Defence, national institutes, NGOs, local peoples and local institutions of the five Himalayan States will be important in implementation of the assessment. I sincerely thank and congratulate the MoEFCC, Wildlife Institute of India, Nature Conservation Foundation and the five State Governments for preparation of the SPAI protocol.

  
(C. K. Mishra)



वन महानिदेशक एवं विशेष सचिव  
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## MESSAGE

The ecological and cultural ambassador of the high-altitude ecosystem of Central and South Asia is the snow leopard. It is one of the rare wild cats globally, occurring across about 100,000 km<sup>2</sup> in the Indian Himalayas. Snow leopard habitat provides important ecosystem services like water, pastures, and plants of high medicinal values. Alongside snow leopards, the habitat also supports rare species like wild yak, Pallas's cat, Eurasian Lynx, black necked crane, Tibetan gazelle and Tibetan argali. Although several attempts to estimate distribution and abundance of snow leopards and its prey species have been made in the past, a consolidated uniform protocol was lacking. The Wildlife Division of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India (GoI), in partnership with the Wildlife Institute of India, Dehradun, and Nature Conservation Foundation, Mysuru, has developed the *Snow Leopard Population Assessment of India* (SPAI), in consultation with the State Governments of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. This protocol will now serve as the main guiding document for the snow leopard range States in India and other agencies interested in snow leopard distribution and abundance estimation.

The management of Protected Areas and snow leopard habitat will be greatly benefitted by the SPAI protocol. The Project Snow Leopard even though did not envisage development of this protocol in the initial stage, has now taken up this aspect in the right spirit. The thrust on having uniform protocol all over the country will be a way of demonstrating our seriousness in snow leopard conservation efforts.

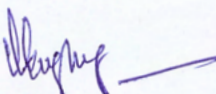
This was a long felt need in the management strategies for snow leopard conservation in the country and I congratulate the members of the Wildlife Division, Wildlife Institute of India, Nature Conservation Foundation and all the range States for coming out with this unique document. This will surely be emulated in other GSLEP range countries and I am sure India can lead the snow leopard conservation efforts in the world in the forthcoming years.

  
(Siddhanta Das)



## MESSAGE

Snow leopard is one of the most elusive species in the animal kingdom. Distributed across 12 countries in Asia, India has about 100,000 km<sup>2</sup> of snow leopard habitat. The snow leopard habitat is one of the important sources of fresh water, rangelands and medicinal plants. The cold-desert ecosystem of the Indian Trans-Himalaya also supports other unique wildlife, such as Pallas's cat, Eurasian lynx, black necked crane, Tibetan gazelle, Tibetan argali and kiang. Due to the large home range sizes of snow leopard, it's considered as the 'flagship' for conservation of the Indian Himalayas under the Government of India's Project Snow Leopard. Additionally, since snow leopards and prey occur in areas outside protected areas, the Project Snow Leopard adopted a landscape level participatory approach to snow leopard conservation, the first of its kind initiative for wildlife conservation in India. However, despite the importance of snow leopard and its habitat for the high-altitude and downstream ecosystems, little is known about its distribution and abundance at the national level. Several attempts to estimate distribution and abundance of snow leopards have been made in the past, but a consolidated uniform protocol was lacking. The Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India (GoI), in partnership with the Wildlife Institute of India, Dehradun, and Nature Conservation Foundation, Mysuru, has developed the *Snow Leopard Population Assessment of India* (SPAI), in consultation with the State Governments of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. This protocol will now serve as the main guiding document for the snow leopard range States in India and other agencies. I sincerely believe that the States will benefit from the protocol to implement State-wide occurrence and abundance estimation of snow leopard and prey in the near future to arrive at a national estimate. Thereafter, snow leopard and prey populations can be regularly monitored, and since based on this protocol repeated estimates will be achieved at national level, the year to year estimates will be comparable. This will provide crucial basis to design our management and conservation interventions and assess the effectiveness of the same in the long-term for better planning. I congratulate the MoEF&CC, the five snow leopard range States of India and partner institutions for this remarkable achievement.

  
(M.S. Negi)

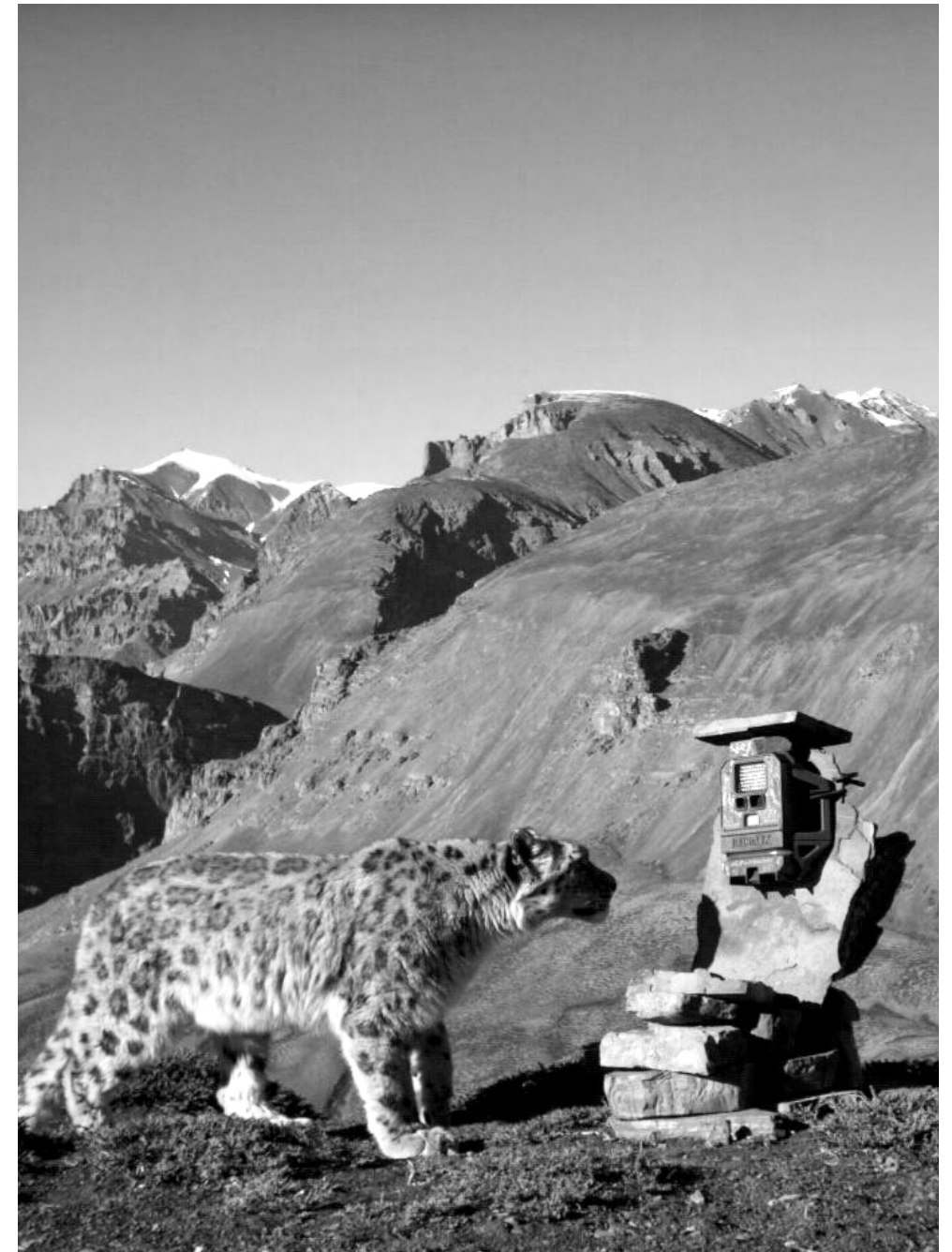




# Introduction

Snow leopard is the icon of high mountains of Asia. In India, they inhabit the higher Himalayan and Trans-Himalayan landscape in an altitudinal range between approximately 3,000 m to 5,400 m above MSL, spanning c. 100,000 km<sup>2</sup> in the five states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. This area contributes to about 5% of the global snow leopard range. Long term research and conservation efforts in India have made it one of the best researched snow leopard range countries in the world (e.g. Chundawat, 1990; Fox et al., 1991a; Mishra, 1997; Mishra et al., 2003; Mishra et al., 2017; Suryawanshi et al., 2017).

The high altitude snow leopard habitat in India is a source of local and regional ecosystem services (Murali et al. 2017) such as fresh water used by millions of people living downstream and in the plains, and sustains unique high-altitude cultures. In India, this species is threatened by prey depletion due to excessive livestock grazing, retribution killing, poaching, illegal trade, unregulated tourism, climate change, infrastructure development in the mountains and poor waste management practices leading to increase in free-ranging dog populations. Although India has been one of the leading countries in snow leopard science and conservation efforts, we still do not have a robust and accurate population estimate for the country, much like other range countries. In fact, scientifically robust population estimates for the species are available only for small study areas,



*Snow leopards are threatened with extinction. They are categorized as 'Vulnerable' by IUCN and in the Schedule I of the Indian Wildlife (Protection) Act 1972, and the J&K Wildlife (Protection) Act 1978. They are listed in Appendix I of the Convention on International Trade in Endangered Species (CITES) and the Convention on Migratory Species (CMS), affording the highest conservation status to the species, both globally and in India.*

which too are often biased in their sampling to only the best habitats. Barely 2% of snow leopard habitat globally, as well as in India (Bhatnagar et al. 2016), has been sampled for population abundance. Due to the biases and limitations in sampling, we still lack a scientifically robust global or national population estimate, which is a serious hindrance to effective conservation planning (Suryawanshi et al. 2019).

### **Population Assessment of the World's Snow Leopards (PAWS) and India's Role**

India has ratified and played an important role in the Global Snow Leopard and Ecosystem Protection Program (GSLEP), a high level inter-governmental alliance of all the 12 snow leopard range countries. These Governments have jointly initiated an effort to conduct Population Assessment of the World's Snow Leopards, or PAWS.

Recognizing the importance of understanding snow leopard occurrence and status for conservation planning, the Government of India has launched India's PAWS effort, referred to here as the 'Snow Leopard Population Assessment in India (SPAI)', which is expected to lead to scientifically robust national and state-wise population estimates of this endangered and elusive cat across its high altitude habitat, both inside and outside protected areas.

SPAI is also anticipated to generate substantial additional benefits including a reliable distribution map of snow leopards, spatial mapping of threats faced by the species across different parts of its range, identification of important population and biodiversity sites in need of greater protection, capacity building of young conservationists and local champions, and identification of potential refugia for snow leopards in response to various pressures such as global climate change.

Estimation of snow leopard population for the entire Himalayan range in India is a mammoth task. Snow Leopards are not restricted to protected areas but spread across the high elevations Himalayan and Trans-Himalayan regions. Reliable estimates of snow leopard population across such a large landscape will require the latest scientific techniques and a statistically robust stratified sampling strategy that is also practical for its application in the field.

These guidelines are created for guiding SPAI, or national population assessment of snow leopards in India. It brings together the best practices from various resources, including guidelines prepared by Wildlife Institute of India (WII), Nature Conservation Foundation (NCF), PAWS Technical Support Committee of GSLEP, GTI Council, WWF, World Bank Group, Wildlife Conservation Trust and the Global Tiger Forum.

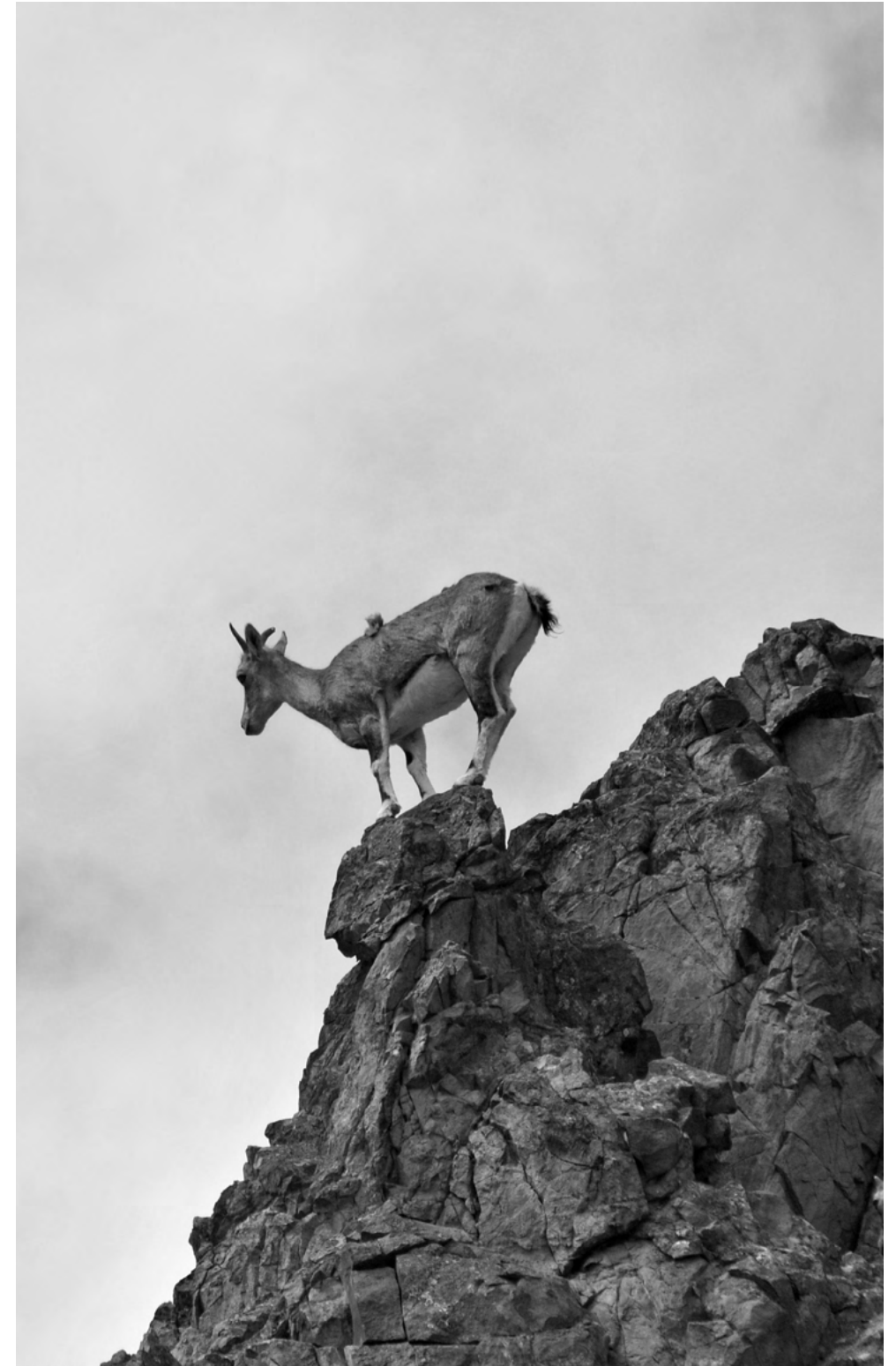
# Challenge

Snow leopards occur over a vast, relatively remote and difficult to access mountainous area. Together with their elusive nature, this makes a complete population census of snow leopards an unfeasible goal. Even their distribution remains unclear. For example, recent surveys show that they do not occur in 25 % of the area that was thought to be their range in the state of Himachal Pradesh (Ghoshal et al., 2017).

Their density is expected to be variable in space, dependent on several factors such as habitat suitability, prey availability, disturbance and connectivity (Sharma et al. 2015; Suryawanshi et al., 2017). Variation in density across space also poses the risk of biased sampling, and, indeed, most of the snow leopard population assessments conducted so far across the world are biased towards the best habitats (Suryawanshi et al. 2019). This makes it critically important that any national or state-level effort to assess their population is based on a rigorous and stratified sampling design.

A recent study using camera trap photo histories of known snow leopards points to potential errors in identification of individuals from camera trap data, that can lead to inflated population estimation (Johansson et al. in review). Finally, the large volumes of data generated in the form of camera trap images or genetic sequences require significant inputs into data collation and management and high computing power.

It is therefore important to use standardized methodologies, appropriate training, uniform sized



## Challenge

sampling units, careful stratification, and robust data management and analyses in order to determine true population status of the snow leopards and to arrive at a scientifically valid national level population figure.

The tasks of conducting primary field work for proposed occupancy survey, camera trapping and genetic sample collection, prey abundance and threats assessment need substantial coordination among the Forest/Wildlife Department staff, nodal institutions WII and NCF, NGO partners and volunteers, and partner universities and institutions. This coordination is especially essential from the initial planning and training phases.

## Opportunity

India's Project Snow Leopard (PSL) promotes an inclusive and participatory approach to conservation that fully involves local communities, conservationists, conservation scientists, and the civil society. PSL can provide the much-needed support to the wildlife managers of the snow leopard range, particularly for landscape level planning and management, and to undertake SPAI.

The "Securing livelihoods, conservation, sustainable use and restoration of high range Himalayan ecosystems" (SECURE Himalaya) with support from GEF-UNDP is an ongoing project on conservation of high altitude biodiversity and reducing dependency of local communities on natural ecosystem. This project is now operational in four snow leopard range states, namely, Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Sikkim. There are significant resources available under this programme to be able to support SPAI, in particular the aspects of training and capacity development.

Jointly, WII and NCF have considerable experience in snow leopard population surveys in India and elsewhere. NCF is nearly completing state level snow leopard surveys in Himachal Pradesh in collaboration with the state forest department, and WII has made similar efforts in Uttarakhand and Sikkim. Their Scientists have (i) published research on snow leopards, their prey, status, and population assessments in top international journals including the first-ever paper on snow leopard



demography, (ii) have been assisting Government of India and the GSLEP Secretariat in designing and implementing conservation and monitoring efforts, and are represented in Government appointed committees including PSL and the Technical Oversight Committee of PAWS.

Both organizations also have a history of implementing collaborative projects with different State forest departments, have undertaken capacity enhancement programmes, and also worked closely and collaboratively with other organizations such as WWF, WTI, and various universities and local institutions.

The Wildlife Division of the MoEF&CC provides technical and financial support to all states for the conservation and management of wildlife and their habitats in the country.

The CSS-Integrated Development of Wildlife Habitats provides 100% funding for management of wildlife protected areas (PA) as well as areas outside PAs.

Monitoring of snow leopard population in high altitudes of the Himalaya requires trained manpower. Currently, the required manpower is available in the form of field staff of State Forest/Wildlife Departments. However, with a few exceptions, they are not trained in using protocols that can match the scientific rigor expected from this country-wide snow leopard survey. This exercise will enable large number of department staff, specifically from the high-altitude forest divisions, to

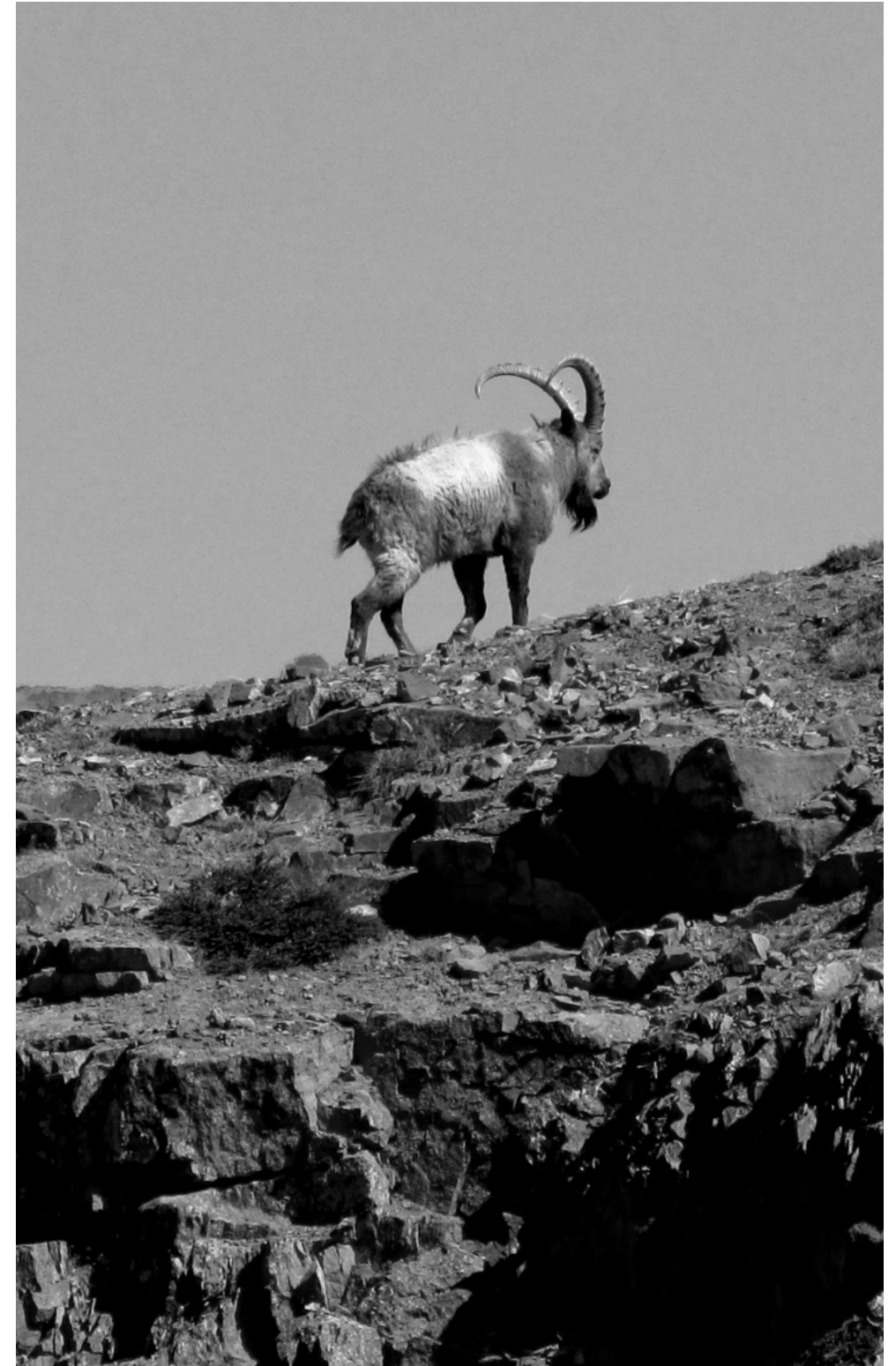
## Opportunity

get proper scientific training on conducting systematic surveys to assess the populations of snow leopard and associated species in the rugged mountainous terrain.

SPAI also presents an opportunity to engage and build long term collaborative relationships with the local communities as well as to identify local champions motivated towards conservation of the high-altitude landscape.

Since a large proportion of the snow leopard landscape falls within sensitive border areas, military and paramilitary forces are also a major presence in the landscape. Collaboration and assistance on this project from them can also help sensitize and engage these personnel in the monitoring.

All along the Indian Himalayan Region and particularly in the snow leopard range States, there are many local, national or international NGOs working in different sectors, and there is an opportunity to train this manpower and involve them in achieving the desired goals. Apart from the NGOs, educational Institutions such as Universities and Colleges, especially local ones, can provide support through students available for short-term assignments.



# Sampling Strategy for SPAI

(also see Appendix I [page 39]):

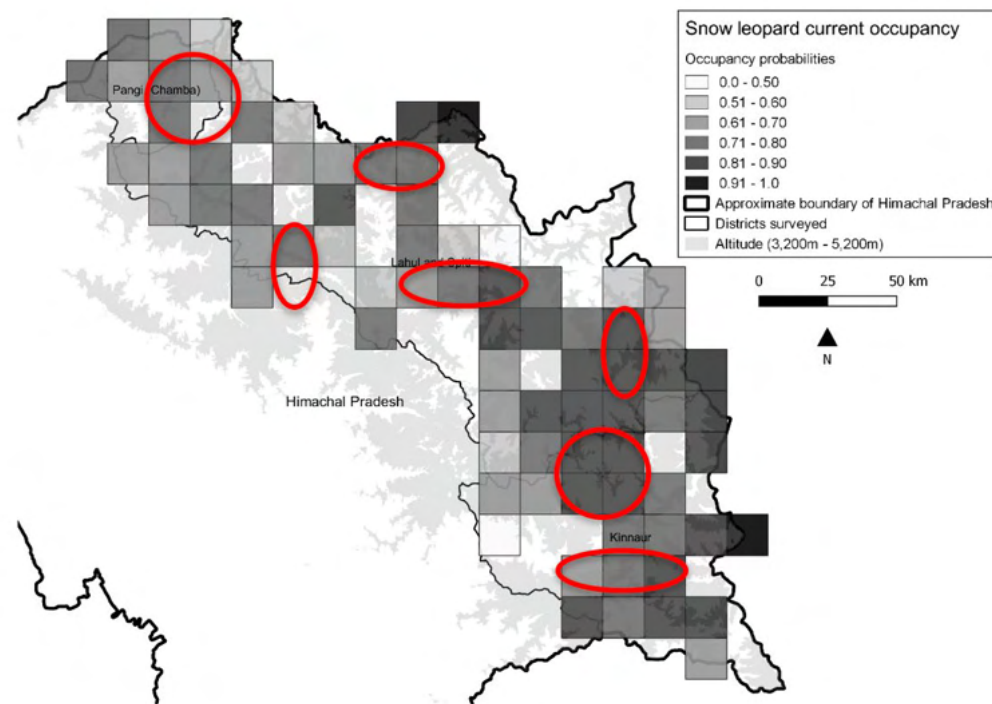


Fig. 1: Probability of site-use by snow leopards from across the Himachal Pradesh State (Ghoshal et al. 2014) used to stratify and determine sampling effort. Red ellipses represent sampling blocks for the stratified sampling based on 4 'probability zones' of site use (high, moderate, low and very low).

## a. Two-step field surveys for snow leopard population assessment to be planned at the state level

SPAI will follow a two-step process to be implemented simultaneously, even as the results from the first would inform and help improve the design of the second. The first step is to systematically assess the spatial distribution of snow leopards (as a function of habitat covariates). This occupancy-based approach based on data on sign and interview surveys and field and geospatial mapping would lead to a refined snow leopard distribution map, and a layer of base data that will help in stratification for snow leopard population sampling (e.g. Fig 1). In the second step, snow leopard abundance can be estimated through camera trapping and genetics in habitat patches (> 500 sq. km) of low and high quality (as identified in step 1), as a function of heterogeneous density across space. Both of these steps involve various activities including training and capacity building workshops, periodic interaction with specialist supervising the effort, procurement of equipment, field surveys, analyses of data, etc. A continuous review and feedback mechanism is engrained in the entire initiative to facilitate learning exchange and course correction.

Intensive sampling using camera traps (or genetic surveys) will be done from randomly selected sites within each state that represent different snow leopard



habitats in the state that are able to capture potential spatial variation in snow leopard density. The results of occupancy surveys will help identify the different strata that can be used to define probability of site use by snow leopard. This stratification will then help prioritize intensive camera trapping (or genetic sampling) using objective methods such as Halton's Iterative Partitioning to represent all available strata.

All field sampling is to be preceded by a period of intensive training of field personnel, supervised jointly by WII and NCF.

### **Step 1: Occupancy based assessment of snow leopard distribution**

The first step towards conducting any survey is that of identifying the study area. Given that the objective of SPAI is to estimate snow leopard population abundance in its entire range in India, as a first step, one needs to obtain a thorough understanding of the species' distribution. A thorough review of literature and information from key informants in the field can help determine potential snow leopard distribution across the country. A uniform grid of sampling units can be used for assessing the actual presence of snow leopards (and other species of interest). Since occupancy is a size dependent parameter, it is important to define uniformly sized sampling unit (grid size).

Occupancy is a species level indicator where the same individual can quite easily extend beyond a grid cell. Here we intend to try and measure utilization rather than strictly occupancy, that, in turn can provide valuable information about designing intensive spatial capture recapture studies.

On the one hand, the grids need to be large enough so that a representative number of these cells can be sampled over a relatively short period of time. However, the size cannot be too large either, considering the heterogeneity of habitats and the possibility that often one may end up sampling only a small portion of the unit, making fairly large assumption about the rest. On the other hand, very small sampling units may produce high resolution data, but will require proportionately large effort that may make the entire exercise prohibitory. Given the flexibility allowed by occupancy analysis framework to choose the size of the sampling unit as long as the estimates are interpreted correctly; the scale at which intensive sampling can be done with a limited number of resources; and timelines in question; it is recommended that a grid cell be defined as a square of 15x15km.

Typically, surveys based on interviews produce useful information about sites being used by the species of interest. It is however likely that in some areas of interest there may not be a sufficient number of respondents or the quality of information from respondents may not

be reliable. In this case it is advisable to supplement it with data based on sign surveys or even camera traps.

Interview based data are best collected by first creating a map of the entire area of interest and then identifying places where key informants can be met with and interviewed in a relaxed environment. Each interview data can be collected on a form with clearly marked sampling units that the interviewee can recognize as his/her area of knowledge. Conversations about the sighting of snow leopard or its evidence often reveal the accuracy of the observation. Verification kits such as images of snow leopards, their pugmarks, scrapes and kills can be used to ascertain the ability of the interviewee to identify and report the presence accurately. It is important to collect information from more than one informer for each sampled unit (grid cell or watershed).

To conduct sign surveys, a grid based map of the entire area can be created and specific locations (potential marking sites) within these can be surveyed for snow leopard signs. Sign surveys can be conducted by walking across transects looking for snow leopard signs, or looking for snow leopard signs of presence at specific marking sites such as overhanging rocks, cliffs, ridgeline saddles etc. Information about the weather conditions, length of transects (if used) substrate (if doing sign surveys), topography, terrain and presence of humans/livestock can be recorded as these are likely to affect the probability of detecting snow leopard signs.

Each report of snow leopard presence can be recorded as detection of the species, whereas lack of reports do not necessarily indicate absence, and hence must only be treated as non-detections, not absences. In case of interviews, this information may be collected for the current period, and also for a certain number of years in the past, as long as the time period is clearly annotated in the data. Details about each interviewee, such as their experience, profession, age and familiarity with the sampling unit that they report about must be recorded so it can be used to model the variation in detection probability. The information collected can then be reorganized into uniform sampling units where each interview or sign survey provides reasonable representation of detection or non-detection of the animal of interest in the entire sampling unit.

It is strongly recommended that time periods being recalled are fairly recent, and time period associated with memories is recorded so that at least one analysis can be based on only recent detections. Most often evidence of direct sighting or fresh kills by the species of interest can be sought in the reports of sightings by interviewees. In case of indirect evidences (e.g. signs or scrapes), respondents are requested to provide latest signs, even though in case of snow leopards signs of presence typically degrade quite rapidly.

Multiple ways of dealing with non-independence have been developed under different designs. In the case of interviews, each interview is treated as a sampling

occasion, such that variation among sample units in number of interviews is readily handled as varying numbers of occasions. Interviews in this case will focus on actual detections by the person being interviewed within some tight time frame, as opposed to personal “knowledge” (sometimes obtained from others) of whether a species is found in an area or not. The interview will also ask about the area sampled during this period (i.e., where did the person travel while paying attention to sign; often assessed by letting person draw area on map OR by mentioning specific site(s) with reference to a prominent land mark (mountain peak, ridge, cliff, nullah, grazing camp etc.

Occupancy models are flexible enough to account for non-constant detection probability through a range of options, but predominantly with the use of covariates. Survey method (e.g., sign, photo captures and questionnaire) could be easily used as a covariate in the analysis to estimate occupancy. Occupancy models are well suited for the incorporation of multiple detection types, including ‘surveys’ (see Miller et al 2011, and Crum et al. 2017). Moreover, multi-method occupancy frameworks (Nichols et al. 2008) can help integrate datasets collected using not only multiple methods, but also multiple scales, should the latter be required in special cases. While interview based data collection is valuable in its ability to be conducted rapidly across large spatial scales, it can be complemented where possible with primary sign based or camera trapping surveys.

Data from multiple interviewees, transects or camera traps can be analyzed in the occupancy framework by modeling the variation in each sampling unit being used by snow leopards as a function of habitat types or other covariates. Since occupancy methods corrects for imperfect detection, they help generate reliable maps that represent differential probability of use by snow leopards across the entire survey region for each sampled unit. These probabilities of site use can be used to generate refined distribution maps of snow leopards, and identify strata that can then be used to choose sampling units for intensive sampling under step 2.

## Step 2: Snow leopard population sampling for regional density estimation

(See Appendix II [page 43] for camera trapping and genetics data collection protocols)

Camera trapping for snow leopards is being conducted widely by various individuals and organizations for years. There is also some genetics based sampling that has been undertaken. While many of these are published, several such datasets are unpublished either due to lack of resources or inadequate support for analysis. A thorough review and an online voluntary engagement tool can be used to generate maps with information about locations that have either already been sampled with camera traps or are currently being surveyed. All

datasets will be reviewed through a quality assurance checklist to evaluate their usability for understanding snow leopard distribution or density.

Spatial capture recapture methods require animals to be sampled for a period long-enough so that it provides sufficient opportunity to be encountered at more than one location within the study area. At the same time, the method requires populations to be closed to changes, thus making it essential for the sampling to be done over a period that is short enough to assume closure (no individuals being lost or added to the population during the sampling period). The spatial capture recapture methods are founded on the principle that space use by animals is heterogeneous, with more time spent in or near the activity centers, and a gradual or sudden decline in space use as we move away from the activity center. This in turn implies a greater probability of individual animals being captured (or photographed or detected in genetic samples) close to the centers of their activity ranges as opposed to their fringes. The spatial data on animals encountered multiple times at different locations during the sampling effort provide the required data to develop the detection function, and ultimately estimate the number of animals that may not get captured (hence enumerated) during a sampling exercise.

Intensive sampling in areas larger than 2000 km<sup>2</sup> has rarely been achieved, primarily owing to logistical and equipment related constraints. Ideally, an area

greater than 10,000 km<sup>2</sup> can be sampled by randomly (or systematically, with random start) choosing several smaller study areas within, that can then be intensively sampled to provide design based inference about the overall snow leopard abundance from the larger region of interest. To improve precision, the larger region can be stratified into more than one stratum and, to reduce variance more sampling effort can be put in areas that are likely to have greater density but still ensure at least some effort (sampling) in the low density areas.

This however can only be achieved if we have reliable knowledge of which areas are occupied by snow leopards (and ideally, which areas have higher and lower density). Estimates of occupancy, obtained by conducting preliminary surveys, using interview or sign based occupancy methods (Step 1) can help develop these stratifications. Locations for intensive sampling can be identified based on stratification using occupancy data. Specific placement of locations for intensive sampling will be done using objective methods such as the Halton's Iterative Partitioning that allow additional survey points to be added whenever desired, or infeasible locations can be removed without compromising the key properties of the design. The specific placement of these study areas will be stratified across the utilization/occupancy gradient identified by the occupancy analyses.

Areas between 500 km<sup>2</sup> to 2,000 km<sup>2</sup> can typically be sampled with 30-50 camera traps or surveyed for

collection of genetic data. Conventionally, the study areas were expected to be many times bigger than the home range size and have no holes (areas with snow leopards but no sampling). These assumptions have been relaxed considerably in the spatial capture recapture framework as long as certain other assumptions are met with. Typically, a camera array needs to be larger than a home range, whereas cameras need to be spaced such that there is a high probability of individual animals to be detected on more than one camera. For details, see Appendix II [page 43]. Data collection protocols for camera trapping and genetic sampling.

To begin with, sites to be intensively sampled can be chosen on the basis of ongoing programmatic priorities, though emphasis can be on areas that have not been sampled in the current window of time starting 2017, especially those that are in relatively poor snow leopard habitats. To sample in new areas, one may either randomly choose locations that are never sampled before, or use stratification data generated from occupancy surveys to prioritize representative sampling from selected strata.

## b. Other data to be collected

Surveying for snow leopards across their entire range spread in 5 States will provide an unprecedented opportunity to understand aspects related to human activities, threats, and prey populations. With little

additional effort, a substantial improvement can be made in our knowledge about the entire ecosystem, which can in turn help prioritize resource mobilization and policy level intervention. Specifically, we hope to be able to improve our understanding of conservation situation on ground, prey abundance, and threats from the snow leopard range in the country.

## Prey population estimation

(see Appendix IV [page 65] for details)

An important determinant of snow leopard abundance is the abundance of their wild ungulate prey (Suryawanshi et al. 2017). Estimating and monitoring the population of wild ungulates such as blue sheep *Pseudois nayaur*, ibex *Capra sibirica*, argali *Ovis ammon* and others is important for snow leopards, and most of these species are themselves categorized in Schedule I of the Indian Wildlife (Protection) Act, 1972.

Under SPAI, assessments of the abundance of wild prey species will also be undertaken in specific locations, based on probabilistic survey techniques such as the double observer surveys that have been developed for estimating the abundance of snow leopard prey (Suryawanshi et al. 2012). In areas where double observer surveys are not feasible, methods such as scan counts from vantage points and distance based camera trapping will be undertaken.

## Situation Description and Assessment of Threats

Some of the five snow leopard range States in India have already initiated steps towards snow leopard population assessment with the help of Governmental and Non-Governmental agencies working collaboratively. All these ongoing or completed efforts need to be reviewed for their alignment with the proposed data collection, management and analysis protocols.

Depending on the stage at which these efforts are (e.g. planning, data collection, data organization and management, data analysis, or publication), their potential use in SPAI can be assessed. Detailed assessment of the ongoing works will also help identify the areas where no survey has been conducted, areas where no trained manpower is available to conduct any survey, or areas where no funds are available from any existing source to conduct the survey.

The survey across the snow leopard range in India will also help us identify and map threats reportedly being faced by snow leopards and other wildlife across the high mountains of the five snow leopard states in the country. A reliable heat map of threats to biodiversity across the snow leopard range in India will provide valuable guidance to prioritize conservation action and resource allocation. Additionally, these threat maps can become useful monitoring and evaluation benchmarks

to gauge the performance of State or organization run conservation programs.

## Workflows for Data organization and management

(See Appendix III [page 55] for detailed workflows for different types of data)

Multiple methods can be employed to facilitate easy management and sharing of data in this effort that can be handled by dedicated staff at WII and NCF. All the raw and processed data should ideally be uploaded onto a cloud server with appropriate information about survey region, period, method and organization retained. Broadly, three methods are being employed and each of them will each have a unique folder on the cloud server along with a readme file that can further elaborate on the workflows.

## Sampling Strategy for SPAI

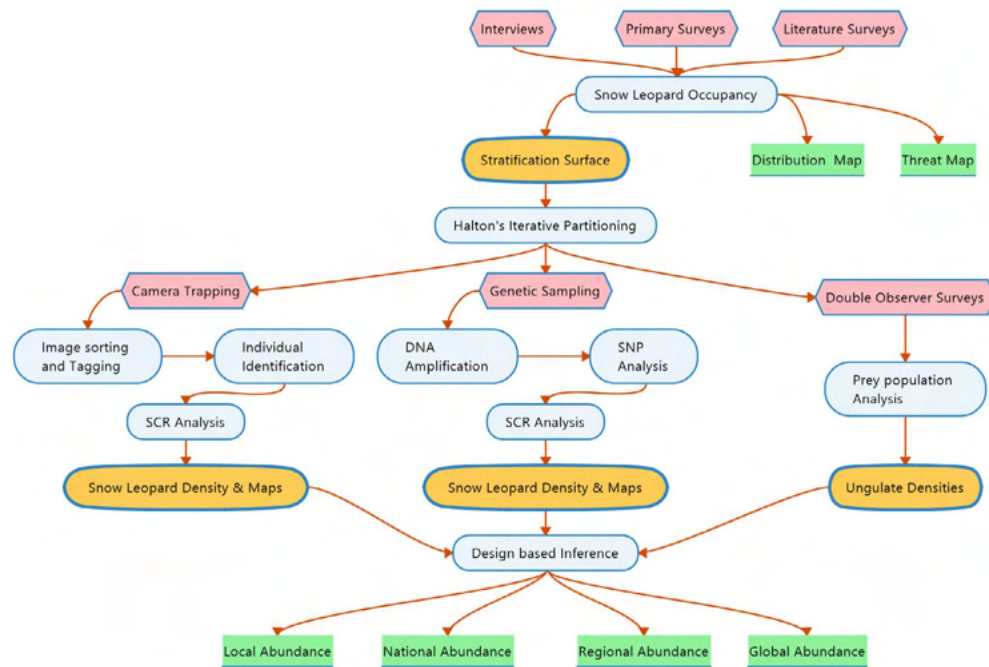


Fig. 2: Boxes in pink denote processes that involve field work and require researchers as well as trained field staff (field research include salaries for staff, accommodation, food and transport). Analyses are denoted in blue ovals and require researchers and interns with low to high level of competence. Orange ellipses denote intermediary outputs that will be used to inform or feed into another stage. Green boxes denote final outputs.

## Data Archiving

The nodal organizations have a history of collaboration and data sharing with government partners. Data will be processed and maintained on secure servers hosted by WII and NCF, protected by appropriate data sharing contracts between nodal agencies, respective state Forest /Wildlife departments, MoEFCC and other partners as and when required.

It is important archiving is not confused with backups. Teams generating data are advised to create backups in physical hard drives and on the cloud to protect their data in case of data corruption or loss. However, it is critical that the entire project is appropriately archived for the purpose of reference, retrieval and reuse. Archival must be done therefore keeping in mind that the information generated can be appropriately used by individuals not currently involved in the project. There are multiple ways to archive data but since this is a multi organisation project, the project is best archived on a cloud platform accessible to all teams, but should at the same time be secure enough to prevent theft and/or manipulation. The first task for archiving would be to describe the terms and conditions for data access and reuse and generate a license for the project accordingly.

As the data generated is already being stored in a structured framework, it is advised that it is archived with the same structure. The archived folders should contain:

- Scans of all the raw data
- Final versions of all the digitised data
- Preliminary results generated from the data
- Metadata and readme files wherever appropriate
- A final report of the project

It is important, to avoid confusion, that there are no duplicates present of any of the files in the archive. To also maintain longevity of the data all the files should be archived in the most ubiquitous formats such as csv, txt and pdf. Codes used for the data should also be archived and platforms such as github are recommended for this purpose; readme files in the archived data should contain links to the script repositories.

# Capacity Building Opportunities and plans

## a. Field Manuals and Training Workshops

A series of field manuals are being prepared and will be made available to the field practitioners and managers. These include the following, though the list may evolve in due course of time to correspond to need assessments in the field as part of the initiative. The manuals number 1 to 3 are meant for the planning phase and for the field teams while 4 and 5 are for teams specifically involved with analysis.

- **Data collection for occupancy surveys using primary and secondary survey data:**  
The manual will provide details about designing, surveying and managing occupancy data using interviews and sign surveys from large landscapes.
- **Data collection for spatial capture recapture using camera trapping data:**  
The manual will provide detailed advice on season, optimal camera layouts, useful approaches to identify locations to set up cameras, best practices for camera settings, alignments, heights and monitoring, and an installation to recovery guideline





that can lead to optimizing resources at the time of data analysis.

- **Data collection for genetic identification of individuals through fecal sampling surveys:**

The manual will provide detailed methodological update about optimal transect designs, do's and don'ts during fecal sampling surveys, and best practices to collect and store genetic material from the field.

- **Data analysis for occupancy surveys:**

The manual will provide details about processing field data and converting it into usable formats, identifying, recording and scaling covariates that are likely to affect different estimated parameters, best practices for determining candidate model sets, steps (and r codes) to run models using single-season and multi-season analysis, and an interpretation guide along with a manual to reproduce the outputs into usable maps and tables.

- **Data analysis for spatial capture recapture surveys:**

The manual will detail the steps involved in collating, managing and analyzing image data from camera traps. It will describe methods to organize camera trapping and genetic sampling data for use in spatial capture recapture framework. The manual will provide a guide to preparing the dataset with

the right spatial and temporal extent, methods to check validity of initial parameters and assumptions, identification of relevant covariates and their preprocessing before their inclusion in the analyses, identification and coding of candidate model sets, use of parallel processing, and interpretation of analyses using a step by step visual representation along with R-codes.

## b. Online tools

Several online tools are currently being developed by GSLEP Secretariat in collaboration with partner organizations to be made available online to users and participants of the PAWS initiative. These include:

- Data sharing and PAWS contribution portal
- Training app for identifying individual snow leopards from photographs
- A user friendly app to run primary analyses to help determine parameters for thorough density analysis
- A user friendly app to help determine sampling needs based on pilot occupancy survey
- Training toolkit for using Digikam and AI based tool to automate data organization
- Threat mapping tool

## c. Training workshops

Several training workshops have been developed and piloted in several countries to facilitate PAWS process. The workshop contents will be adapted and customized for their application in India before delivery through nodal organizations. The proposed training workshops include:

- **Introduction to Occupancy methods (1 day):**  
Occupancy methods can provide a handy tool-kit to survey large areas and guide intensive sampling to estimate populations of rare and elusive species such as the snow leopard. The one-day workshop introduces the participants to the methods of occupancy using simple on-site experiments with rice and magnets and leads the participants to understand and practice data collection, organization and analysis for single season, heterogeneous occupancy and detectability scenarios. It also covers basics of sampling and design principles in general, and model based inference for surveys of large areas in particular.
- **Introduction to Spatial Capture Recapture (1 day):**  
Spatial Capture Recapture methods are a useful tool to estimate density of species that can be identified as individuals. The workshop uses simple on-site experiments using gummy bears to help participants understand the basic assumptions and

principles of spatial capture recapture methods. The workshop leads the participants to understand the basics of sampling design and helps them run models that test heterogeneity in detection, ranging, density and movement parameters of snow leopards within a study area.

- **Image tagging and organization of camera trapping data (1 day):**

The amount of data to be managed increases substantially with an increase in the number of images generated from field work. Tagging, organizing and formatting the image data to be used in spatial capture recapture or occupancy frameworks for not only snow leopards, but other species makes it important that the images are organized and sorted correctly right from the beginning. This workshop provides hands-on training on using CamtrapR and Digikam from photographic data generated from camera traps.

- **Survey designs and analysis of occupancy data (3 days):**

The workshop provides detailed introduction about sampling basics, detection probability and maximum likelihood modeling using simple hands-on datasets. The workshop provides a crash course on modeling basics and helps participants understand the nuances of occupancy data collection, synthesis, analysis and interpretation

using single and multiple seasons, single and multiple methods, and single and multiple species models. Participants are encouraged to bring their own data or research question in this workshop to help them get hands-on experience with the planning and analysis.

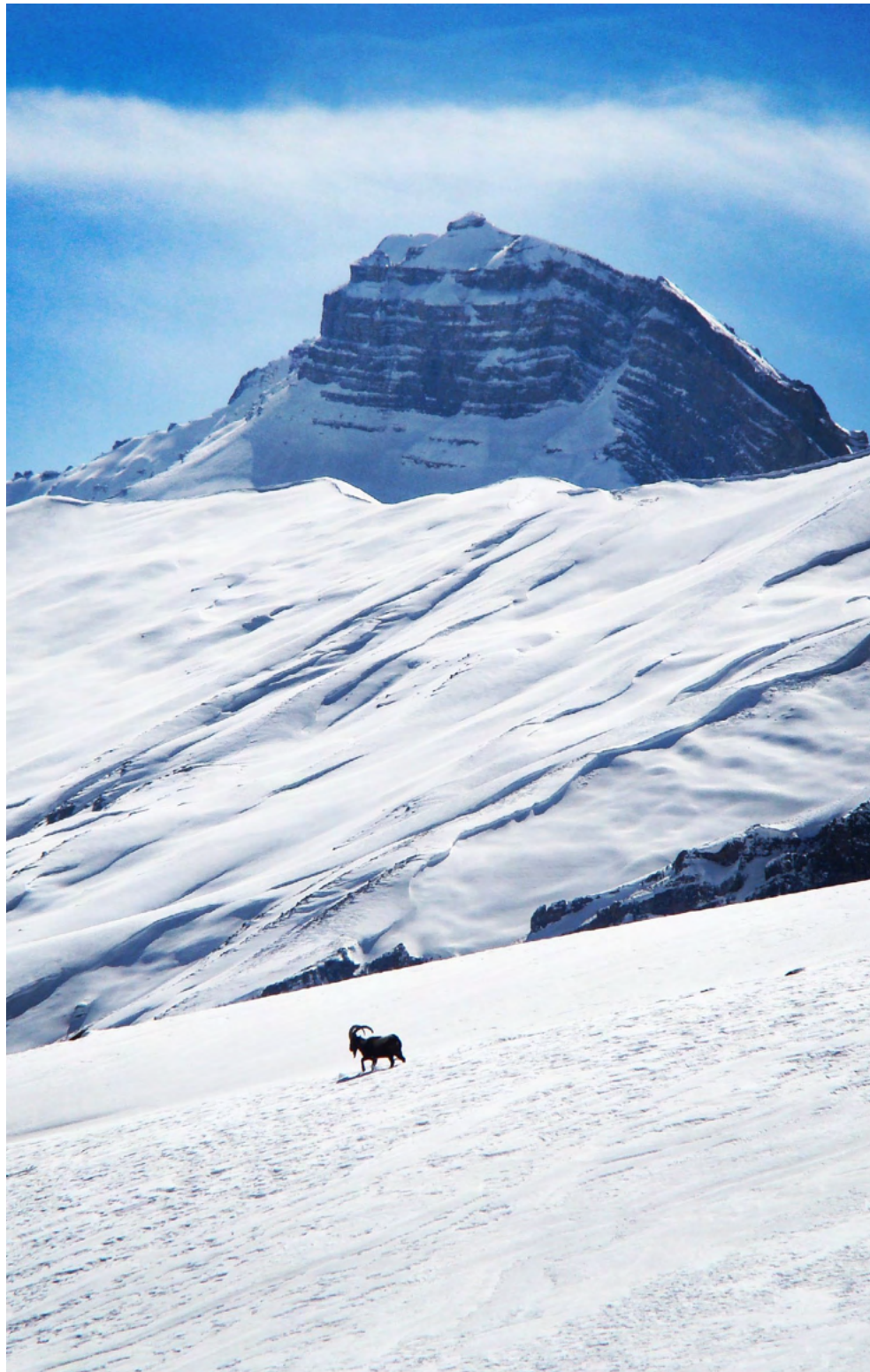
- **Survey designs and analysis of SCR data (5 days):**

A detailed workshop that provides all basics of sampling design, modeling, maximum likelihood theory, conventional capture recapture, spatial capture recapture, non-Euclidean movement patterns, least cost distance paths, multi-session, multi-season, and various detectors' analyses. The users are encouraged in the workshop to bring their own datasets to provide hands-on experience and assistance with study designs and analyses.

The State Forest Departments are the key lead stakeholders for snow leopard monitoring but the training programs will involve active participation of research institutions, academic organizations, NGOs, CBOs, volunteers and the armed forces.

## Appendix I: Rationale for two step sampling strategy for SPAI

Population abundance and density estimated as state variables are useful and important measures for managers, researchers, donors, politicians, and members of the community alike. The number of individuals is the most sought state variable for monitoring most species across the world. However, the high cost of implementation, and violation of assumptions are potential obstacles in estimating number of individuals in a population. Low densities of snow leopards in their habitat and large home ranges potentially lead to low probability of being encountered on camera traps or in genetic samples. Low number of recaptures increases the variance and the confidence intervals therefore reducing the power to detect changes. Spatial Capture Recapture provides an opportunity to estimate more than one state variable for monitoring (Borchers et al. 2008). In addition to estimation of abundance and density of snow leopard populations in a landscape, and understand population dynamics over a period of time, it also helps understand habitat use at different scales. The data can, for example also be used to answer questions about impact of conservation action in sites with different levels of intervention.



## Appendix I: Rationale for two step sampling strategy for SPAI

Although spatial capture recapture analysis can be used to estimate abundance from reasonably large landscapes, there are significant costs associated with covering large areas with either camera traps or transects to collect capture-recapture data of individual animals. This is where methods of site occupancy (Mackenzie et al. 2002) can help determine the space use pattern of snow leopards across relatively large landscapes. Occupancy methods are widely used to determine probability of occurrence, site use, local colonization/extinction, and range contraction/expansion with the help of indirect surveys such as interviews (e.g. Taubmann et al. 2015; Ghoshal et al. 2017), or direct surveys such as those recording signs or camera trap encounters. The flexibility that occupancy methods provide over variable methods, spatial extent, unequal effort, and data make them a valuable tool for developing distribution maps and monitor changes over large timelines. Occupancy or probability of site use as a function of habitat can help develop strata for which specific sampling strategies can be developed. When analyzed for large landscapes, provinces, countries or regions, the resultant occupancy maps can provide empirical knowledge about the true distribution of the species of interest, despite variation in effort and quality of information. An occupancy survey from the entire species' potential range in India is expected to produce reliable probabilistic distribution maps for the species of interest.

## Appendix I: Rationale for two step sampling strategy for SPAI

Snow leopard habitats are facing numerous threats emerging from local dependencies and increasing developmental pressures. The identification, spread and intensity of these threats is a key aspect of developing suitable mitigation strategies and actions. The exercise for occupancy surveys can help study these patterns that can be transcribed into maps as a tool for more effective planning of threat mitigation.

As an apex predator, snow leopard has considerable impact on the ecology of the alpine and subalpine ecosystem of upper Himalaya. The predator-prey dynamics of snow leopard and its prey have serious consequences on the entire region which is rich in terms of ungulate diversity. It is widely accepted that the availability of the wild ungulates determines the population of the large carnivores (Karanth et al. 2004) and impacts livestock depredation and also affects negative human-wildlife interactions (Mishra et al. 2003). Reduced wild ungulate populations have been shown to increase livestock hunting by snow leopards in these landscapes which leads to retaliatory killing (Suryawanshi et al., 2013) of large carnivores and has potential to undermine the conservation initiatives.

The country wide snow leopard survey gives us a unique opportunity to survey parts of the entire snow leopard range for estimating its ungulate populations. The State Forest Departments have a relatively large number of field staff that can be trained to carry out these surveys. Some of these have already participated

## Appendix I: Rationale for two step sampling strategy for SPAI

in large carnivore surveys being coordinated by the Wildlife Institute of India.



## Appendix II: Data collection protocols for camera trapping and genetic sampling

### Camera trap data collection (field surveys)

Typically, camera trapping studies have been designed keeping in mind the recommendation of at least two cameras within each potential home range. Some of these design constraints are relaxed in planning spatial capture recapture surveys in lieu of other requirements, such as getting an adequate number of recaptures of snow leopards on multiple cameras. In general, the most efficient model for obtaining camera trapping data is that of setting up cameras in an array so that as many snow leopards as possible can be photographed on more than one camera. A useful rule of thumb is to separate cameras by something a bit less than the expected home range radius (if we think of 2 times the standard deviation of a normal distribution describing the activity range as the activity range's radius). Cameras should be spaced such that there is very high probability that individual animals will be detected on more than one camera (preferably considerably more than one), and a very low probability that individual animals will be detected on all cameras.

Information on how far animals range (and hence how their detectability reduces with distance from their

## Appendix II: Data collection protocols for camera trapping and genetic sampling



activity centres) comes from the distances between cameras on which each animal was either detected or not detected. If animals were only ever detected on one camera this tells us no more than that they do not range farther than half the distance between cameras, but not whether they range a hundredth of that distance or just under half that distance. Conversely, if animals were detected on all cameras, this tells us that they range at least as far as the farthest distance between any of the cameras, but not whether they range a hundred times that far, or only just that far.

We need information from detections on how far they range in order to estimate what area the array of cameras covers, as this in turn allows us to estimate density, not just relative abundance. We anticipate that recent/ ongoing studies being conducted by various research institutions/ organizations in India and other Snow leopard range countries will be helpful in making informed decision about some of the above parameters.

The key to maximizing recapture probability for a few individuals is installing cameras in clusters as opposed to uniform grid unless one has an infinite supply of cameras and resources to monitor them (Sollman et al 2012; and Sun et al. 2014). A networking design where each new unit is installed within 3-5 km of another unit may work alright, though data quality improves considerably if cameras are set in clusters. Setting up more than one camera in close proximity to another if there is more than one promising location in turn

## Appendix II: Data collection protocols for camera trapping and genetic sampling

helps inference as it provides high resolution data on the ranging parameter ( $\sigma$ ). Objective methods have been developed to identify approximate camera locations using a computer based simulation, and then field teams use local and species knowledge to deploy the camera at a location that maximizes detection on that camera (we say it should be deployed within 500m of the proposed point for example).

It is important to collect micro-level habitat data (e.g. topography, altitude, terrain, presence of waterbody etc) from each of the sites where a trapping station is installed so that one can use it to model the variability in detection probability as a function of habitats or other relevant covariates.

Spatial capture recapture methods may assume closure of populations, which is why it is important to collect data from a session for a period short enough that an assumption of closure is likely to be met. Our experience from various sites indicates that between 2-3 months of sampling with 30-40 camera stations typically generates reasonable data for spatial capture recapture inference. Studies indicate that on most cameras set up at scraping and spray sites snow leopards tend to mill around and present both sides. Once both sides are recorded, it can be identified even on those cameras where the animal simply walks past a camera allowing only one side to be photographed. Use of a single camera per station also allows expansion of

## Appendix II: Data collection protocols for camera trapping and genetic sampling

trapping effort without adding much cost in terms of losing images deemed unsuitable for identification.

Spatial capture recapture analysis allows the possibility of moving cameras during this period as long as times of installation and removal are recorded with each camera location. If one is able to install a greater density of traps within the study area, this can provide higher quality of data for estimation of the shape of the detection functions. This, however affects the spatial extent that can be covered during a sampling effort. Recent recommendations propose a denser trapping grid in a relatively smaller area (provided it is large enough to encompass a reasonable sample of snow leopard activity ranges for the sampling period) as opposed to a rarefied trapping grid in a large area. One important assumption is that all habitat types being represented in the study area are being covered. Ideally one would sample all potential habitat types even if some are less likely to produce snow leopard captures.

Similar principles apply in case of using genetics data in spatial capture recapture framework. However, in case transects are run to collect genetic samples such as fecal matter, the data are treated differently as each transect can be treated as multiple detectors (by cutting the transect into multiple segments, each of which is treated as a detector), with a strong assumption that all scats being collected were deposited during a short enough period of time within which there were no individual animals added or lost. The most effective



## Appendix II: Data collection protocols for camera trapping and genetic sampling

means is that of dividing the study area into manageable strata (grids or watersheds) that are smaller than the activity range of the animal. Surveys can be conducted by identifying physically accessible parts of the study area (without risking life of the research team) representing all available habitats to the snow leopard. Surveys are conducted by walking on transects whose lengths are recorded to inform the effort being put in the sampling. Each transect may have its own characteristics such as terrain, topography, substrate type etc. that can in turn affect the probability of the snow leopard leaving feces there and that of the field personnel detecting them. Sometimes weather conditions can also have strong effects on the team's ability to detect feces. It is valuable to collect this information that can in turn help model the detectability as a function of one or more of these covariates.

### **Data collection protocols for genetic sampling using fecal matter**

Scat samples contain many sloughed epithelial cells from the digestive tract. Most fecal samples are also large enough to allow multiple attempts at DNA recovery. For carnivores there is usually relatively little ambiguity as to the number of individuals that deposited a particular set of fecal samples. Similarly, hair samples extracted from hair snares have follicles that can potentially be used to recover DNA.

## Appendix II: Data collection protocols for camera trapping and genetic sampling

Genetic data can be collected at a relatively smaller investment from much wider areas that would be required for sampling with camera traps. Genetic data can be collected using scats detected from transect surveys, or hair snares set up at points. Collecting hair snare data requires regular site visits to each snare reduce to data losses and this can be tedious, but the data generated is known to be superior to that from feces, which may be much older. However, most data published or analyzed using genetic sampling for snow leopard population has been collected using fecal DNA.

Transects to collect scats can be positioned covering trails, mountain ridges, river beds and mountain passes covering a fair representation of all habitat types available to the snow leopard. Feces are typically found on cliff bases, dry riverbeds, ridgelines and animal trails. Each vertex or point of interest in a transect should be recorded (using GPS trail feature) and can be further classified based on its characteristic features. On encountering a purported snow leopard scat, a small portion of its outer dried layer shall be extracted using a knife and preserved either in a plastic tube with silica desiccant or a high quality zip lock bag for DNA analysis. Each preserved sample should be annotated properly to provide its precise location of collection and the relevant information about its age and micro-habitat characteristics around the collection site.

A relatively low level of skill is required to conduct genetic sampling transects, which can be achieved

## Appendix II: Data collection protocols for camera trapping and genetic sampling

through quick pre-survey training. Field personnel can be trained to identify putative snow leopard scats during the survey and collect the outer epithelial layer present in the scat. Amini stool sample collection kit can then be used to collect the swab from the upper layer of the scat. Individuals collecting DNA sample need to take utmost care to prevent cross-contamination. Ideally, samples need to be stored below  $-20^{\circ}\text{C}$  sans moisture. If not possible in the field, samples should be transferred immediately to the lab where they can be frozen in cold gel packs. Running samples through a freeze-thaw cycle can destroy valuable information, which is why once it is stored it should be taken out only for preparation. The preparation and analysis of the samples should be done as soon as possible.

The limitations of genetic sampling include high cost of data analysis at genetic laboratories and high variability found due to unknown factors in people's ability to identify individuals. Given the strong dependence of spatial capture recapture analyses on identified individuals, any uncertainty in identification, particularly false positives can lead to substantial biases in the results.

### Genetic data processing using SNP's

A set of low-cost, non-invasive genomic tools that can be applied in the field by conservationists are currently under development. These tools will allow conservationists to identify the species, individuals,





## Appendix II: Data collection protocols for camera trapping and genetic sampling

and even reconstruct family relationships based on genetic signatures in fecal, hair, saliva, or even environmental DNA samples at substantially low costs and much greater reliability. The genomic and metadata can be aggregated and analyzed on an intelligent cloud platform to give both conservation practitioners as well as policy makers an unparalleled insight into the health of populations and species using such as information as reproductive success, diet, resistance to disease, human-wildlife conflict, illegal wildlife trade and other key indicators and will provide the basis for data-driven management and policy decisions.

The development of snow leopard genome using single nucleotide polymorphism (SNP) panels will allow genotyping additional individuals at a very low cost from low-quality DNA material. This will in turn result in development of effective, efficient, and affordable DNA field-kits using multiplex PCR to be used with the SNP panels for local, low-cost and rapid processing of DNA collected through non-invasive sampling or wildlife trade samples. A user-friendly intelligent cloud-based database in conjunction with the field-kits will ensure simple, rapid in-country DNA analysis of genomic data for population assessments, management and for forensics in the wildlife trade. The interface will be suitable for individuals with minimal genetic training and provide a robust and easy to use analysis platform which can be applied to a variety of questions.

## Appendix II: Data collection protocols for camera trapping and genetic sampling

Whole genome sequencing of snow leopard will be the first attempt to develop primers for target regions that can be amplified for better analysis. Single nucleotide polymorphisms are changes in base pair in only one nucleotide pair in a particular allele. Only 1% of human genome, for example, consists of SNPs, but variation in the alleles consisting of SNPs are highly variable across individuals. So by targeting a particular area of the gene and amplifying it, we can easily sequence the nucleotide arrangements in the DNA. Thus, aligning the sequence of targeted areas against the whole genome sequence will help us to easily identify individuals. Appropriate statistical analysis should help the confidence of correctly identifying individuals before running the data through analysis.

As the populations separated in space have less chance of inbreeding and hence likely to retain their diversity, studying them at such unprecedented scale where different populations are likely to be separated in space, comparing the SNP sets will help us understand the population structures and variability in different snow leopard populations.

Thus, the potential for genetics application is high, though many of the techniques are still under development and refinement, because of which SPAI focuses largely on camera trapping in the current phase.

## Appendix III: Workflows for data organization and management

### Work-flow for occupancy data management

Occupancy surveys are to be carried out for different regions and each will be saved with unique meta-data on the cloud space in particular folder(s) depending on the agreed upon data sharing agreements. The recommended dropbox folder structure is:

- ↳ Occupancy survey
  - ↳ State
    - ↳ Region
      - ↳ Year
        - ↳ Organization/Lead

The 'occupancy survey' folder will contain a map of the snow leopard habitat appropriately gridded and a csv file representing these grids. The folder will also provide template excel sheets for entering the collected survey data and the transect covariates from a region. The filled sheets, tagged by the organization/lead researcher name should be uploaded into the 'Year' folder within the appropriate region. It is advised to



## Appendix III: Workflows for data organization and management

have a readme file in each 'Year' folder describing the covariates and other information used. Digital scans of all the raw data from each transect (surveys and interviews) should also be uploaded into this folder for reference and archival purposes.

The entered data will then be run through developed R scripts or PRESENCE software workflow for such datasets to arrive at probability of sites being used by snow leopards in the region. Finally, a habitat use map can be uploaded to the folder in the 'Year' it was conducted along with the associated shapefiles.

### Work-flow for analysis of camera trap image datasets

Once the Camera traps are retrieved and images downloaded, the images are to be uploaded onto a cloud server. This folder should contain all the raw images. For structure purposes, the folders are typically organised as:

- Camera Trap Images
  - State
    - Region
      - Year
        - Location

## Appendix III: Workflows for data organization and management

The images from a single camera are stored in a unique location folder within this structure along with information about the organization/lead researcher. Within the year folder, along with multiple location sub folders, a trap info file must be uploaded using a standardized format whose template will be provided.

At this stage, it is recommended to save a copy of all images by renaming them according to camera/location names. This is achieved using the function `imageRename` in `CamtrapR`. To make analysis quicker, the folder is duplicated and the images are then cleaned and tagged. The duplicated folder should maintain the same folder structure as in the raw data folder.

The images to be removed prior to further analysis are:

1. Empty images triggered by vegetation movement, clouds etc.
2. Livestock images, except for the first and last image of every event.
3. Images of people, except the first (recording the person who set it up) and the last (recording the person who retrieved it).

We propose to conduct the camera trap image data processing using the R package- `CamtrapR`. The package allows management of and data extraction from camera trap photographs. It provides a workflow for storing and sorting camera trap photographs, computes record databases for species and individual

## Appendix III: Workflows for data organization and management

snow leopards, detection/non-detection matrices for occupancy and spatial capture-recapture analyses with great flexibility. In addition, it provides simple mapping functions (number of species, number of independent species detections by station) that help visualise activity data.

Generally, one can start with tagging pictures where metadata tags are assigned to images in image management software such as `digiKam` (free and open-source software). Metadata tagging is used to assign custom tags to images, e.g. species ID, individual ID for capture-recapture analyses etc. The tags are saved in the image metadata automatically, from where they can later be read out by two `CamtrapR` functions (`recordTable` and `recordTableIndividual`) to generate database for all the species and individual snow leopards. `digiKam` makes use of a fast and robust database to store these meta-information which makes adding and editing of tags very reliable. Before assigning metadata tags, users need to set up a hierarchical tag structure (e.g. Species > Individual). In `digiKam`, this is done using a Tag Manager.

Once the species and individual snow leopards are tagged, we can organise the folders using `CamtrapR` as explained in their vignette “Organising raw camera trap images in `CamtrapR`”. It is recommended to save renamed copies of the original images based on camera/location names and not use the original

generic file names. This is achieved using the function `imageRename` in `CamtrapR`.

Once the images are cleaned, `DigiKam` software can be used to tag the images with the species present. In case of a snow leopard image, the image is also tagged with an individual ID. Individual identification is to be performed by trained personnel, who will go through a period of training and self-evaluation tests. Based on the individual IDs, a file is to be uploaded into the relevant region folder describing each individual and its identification markers.

`CamtrapR` codes are then run in R to read the metadata and create separate files for species and individuals captured within a year in a region. These csv files should also be uploaded into the 'Year' folder. At this stage the 'Year' folder should contain, along with the region subfolders, three csv files:

1. A file with all the trap information manually entered (care should be taken so the names of traps in this file match the region folders and the image metadata)
2. The generated species capture file
3. The generated individual capture file

These files are then used to run models in R (using package `secr` or `oscr`. To use Bayesian modeling approach, the data needs to be prepared differently, details of which can be found on the appropriate

package vignettes) to estimate snow leopard density, and estimates of detection probability and ranging parameters.

### Workflow for Double-observer survey data

The double observer survey will follow the same dropbox folder structure as the above two methods.

‣ Double observer survey

‣ State

‣ Region

‣ Year

‣ Block

The 'Double observer Survey' along with the region subfolders contains templates for data collection and data entry. Scans of the raw data collection forms for each transect are to be uploaded in their respective 'Block' folders. The compiled data sheet entered should be uploaded within the 'Year' folder, which will then be run through developed R scripts for analysis to arrive at ungulate densities. The 'Year' folder should also contain a file describing the species in the scope of the survey; this is to record all the unobserved species in the survey that will not be captured in the actual data sheets. See Appendix IV [page 65] for details of data analyses and interpretation.

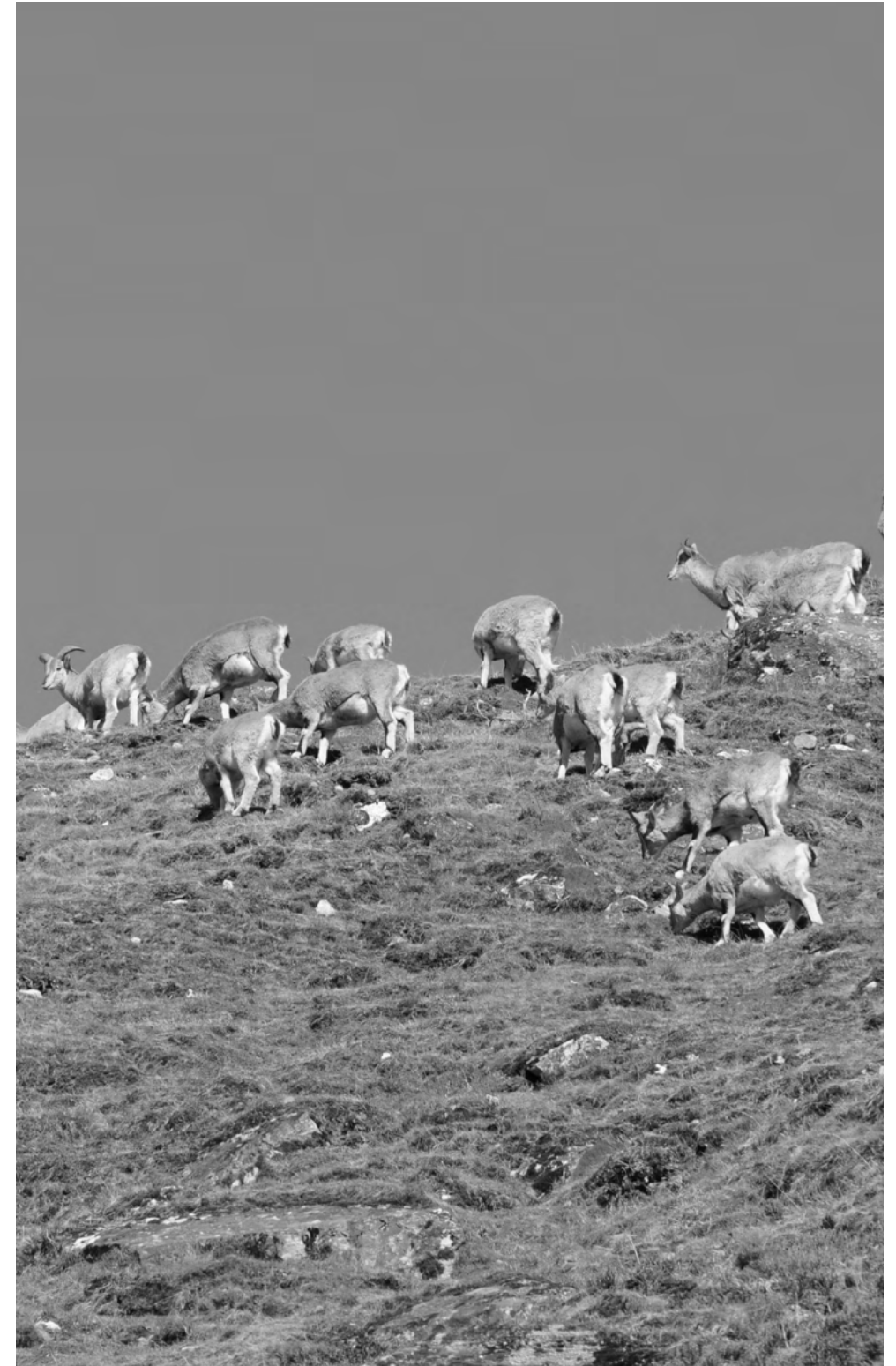
## Appendix III: Workflows for data organization and management

### Workflow for Situation Description and Threats data

The exercise to collect secondary and primary data across the snow leopard range will provide us with an unprecedented opportunity to identify and list organizational presence, and also map threats reportedly being faced by snow leopards and other wildlife.

A simple form describing situation of organizational and departmental presence and mandates in different parts of the range across India can be filled up and archived during occupancy and/or camera trapping surveys or be sought directly on the online page.

A simple datasheet recording key perceived and observed threats can be used with appropriate annotations and compiled to run probabilistic models that can effectively be used to develop reliable heat maps of threats to biodiversity across the snow leopard range in India. These maps can then provide valuable guidance to prioritize conservation models and action on ground. Additionally, these threat maps can become useful monitoring and evaluation benchmarks to gauge the performance of State or organization run conservation programs. More details about monitoring conservation action through threat reduction assessment protocols can be found here (Margolui & Salafsky 2001).





## Appendix IV: Abundance estimation of wild ungulate prey of snow leopards

Throughout its range in India, at least 12 species of ungulates form the potential prey base of snow leopard. These include markhor *Capra falconeri*, argali *Ovis ammon*, urial *Ovis orientalis vignei*, ibex *Capra sibirica*, blue sheep *Pseudois nayaur*, Tibetan wild ass *Equus kiang*, wild yak *Bos mutus*, Tibetan antelope *Pantholops hodgsoni*, Tibetan gazelle *Procapra picticaudata* and possibly Hangul or Kashmir red deer *Cervus hanglu*, musk deer *Moschus sp.* and Himalayan tahr *Hemitragus jemlahicus*. Understanding the abundance of these ungulates is crucial to understand the snow leopard distribution, behaviour, abundance and population dynamics.

Although there are studies estimating the population of relatively common species such as blue sheep, other rarer species remain less studied. A few studies on population estimation of ungulates have been undertaken in in Nepal (Thapa, 2005; Aryal et al., 2014; Leki et al., 2017) and Bhutan (Thinley et al., 2018). In India, assessments have been undertaken in a few sites in the Himalayan (e.g. Kandpal and Sathyakumar 2010) and Trans-Himalayan regions (Suryawanshi et al. 2012).



## Appendix IV: Abundance estimation of wild ungulate prey of snow leopards

Probabilistic survey techniques such as double observer counts and distance sampling have been successfully used in estimating populations of the mountain ungulates (Suryawanshi et al., 2012).

To conduct double observer surveys, the study area can be delimited according to geographical features (e.g. river valleys) prior to field survey on maps. It is then divided into defined 'blocks' of around 20-30 sq. km and within each block, survey routes (i.e. transects) are identified. This is done based on local knowledge and accessibility of the study area. The blocks are selected in a manner that allow little to no movement between blocks, during the survey period. Multiple transects can be carried out in search of ungulates generally along ridgelines or valleys that optimize visual coverage of the survey area. During the surveys, two observers walk along the transects independent of each other in time and space, collecting information on ungulate sightings, their group size, age-sex classification, GPS locations and behavior. The findings are then reconciled to ensure movement of groups between blocks or transects to avoid double counting.

Set in mark capture-recapture theory, the population data is estimated by modelling detection as a function of the observer number (ie. observer one and two). The population estimate ( $N\text{-hat}$ ) is generated by multiplying the randomly picked estimate from the posterior distribution of estimated number of groups ( $\hat{G}$ ) with a randomly picked estimate from the distribution of

## Appendix IV: Abundance estimation of wild ungulate prey of snow leopards

group size ( $\mu$ ). This is then repeated 10,000 times to get a distribution of the population estimate along with the respective confidence intervals.



# Appendix V: Data analysis and interpretation

## Analysis of snow leopard distribution data from primary and/or secondary occupancy data

### 1. Identify candidate model sets

Occupancy estimation deals with 2 or more unknowns. The basic models estimate probability of a site being occupied, and probability of detection of a species given presence. Advanced models can be used to estimate other unknowns such as probability of species becoming locally extinct or colonizing new sites. Each of the above unknown can be tested as a function of one or more covariates (e.g. habitat type, altitude, least cost distance from sources of disturbance, etc). The detection-non detection data, and site and detection covariates as discussed in the data management section can be used and a candidate set of ecologically reasonable potential relationships can be listed before running the models. Site covariates affect the probability of a species of interest occupying (or using in case the closure assumption is violated), whereas detection covariates are tested to affect the



probability that given presence, a species might be seen (and reported about to the interviewer) in the sampling units. It is possible for modeled parameters to have additive or interactive effects of more than one covariates, both of which can be formulated using standard modeling procedures.

## 2. Run models on Presence (or R)

The formulation of models varies between software PRESENCE and package Rpresence or Unmarked on R, but conceptually both use the same approach. Details about developing specific models can be found on Mackenzie et al. 2005; Donovan and Hines 2007; User manual for Presence; or the vignette for the R packages Rpresence and Unmarked. A wide range of interactive, full identity, relational models are possible to develop in PRESENCE, RPresence or Unmarked. Models are ranked based on AIC (or AICc), and can be used to determine the best model balancing between number of parameters and fit.

## 3. Model average results

Models are ranked based on minimum AICc (or AIC), which balances the improved fit due to use of more parameters against the increased variance due to use of more parameters (Burnham et al., 2010). Coefficients of model parameters can be used to determine the direction and intensity of the effects of covariates (on

density or detection probability). The AIC weight of each model is an indication of the level of support in the data for each model. If the top model has model weight close to 1, it is simplest to explain density and detection based on the coefficients defined by that model. However, it is possible at times that models will have small AIC or AICc difference (e.g. differences of less than 2). In this case, Burnham et al (2010) recommend use of model averaging techniques.

## Snow leopard density estimation from camera trapping and/or genetic data using SCR

### 1. Identify candidate model sets

Spatial capture recapture analyses allow estimation of detection probability, ranging parameter and density that can be used to estimate abundance. Detection probability, ranging parameters and density can depend on variables associated with traps, occasions, biology of the encountered individuals (sex, age class, status etc) and location in space. Heterogeneity in capture probabilities due to factors other than distance from snow leopard activity centre can be addressed by modeling them as a function of one or more of these variables. Neglecting heterogeneity can result in biased estimates of density and hence abundance.

Individual heterogeneity refers to differences in capture probability due to variables that are specific to individuals (e.g. sex, age classes). Models are available for dealing with individual heterogeneity whose source is not observed (e.g. if sex was not recorded and detection probability depends on sex).

Similar to detection, changing animal density within the sampling area can also be modeled as a function of one or more covariates (e.g. habitat, elevation, water, etc.).

As the first step in running an analysis considering effects of covariates affecting density and detection, a candidate set of models should be prepared based on an ecologically meaningful set of potential relationships between detection probability (or encounter rate) and available covariates, and between density and available covariates. Different models can be used to explore complex relationships by using additive or interaction effects of two or more covariates. Density is often assumed to be constant (homogeneous) within an entire study area. The ability to model density as a function of one or more covariates allows one to investigate whether differences between two sampled areas are because of a specific conservation/protection regime or just because one area has a better gradient of more suitable habitats to support higher densities, for example.

## 2. Develop SCR codes

To analyze the spatial capture recapture data, one needs to first load all relevant data about traps, captures, extent of study area (integration space or mask), trap covariates and density covariates on the R platform. Standard data formats and codes informing the software about the formats being loaded can be found on secr vignettes. All trap specific covariates are read at the time the trap information is being loaded by clearly highlighting the particular columns in the trap data listed after '/' as covariates.

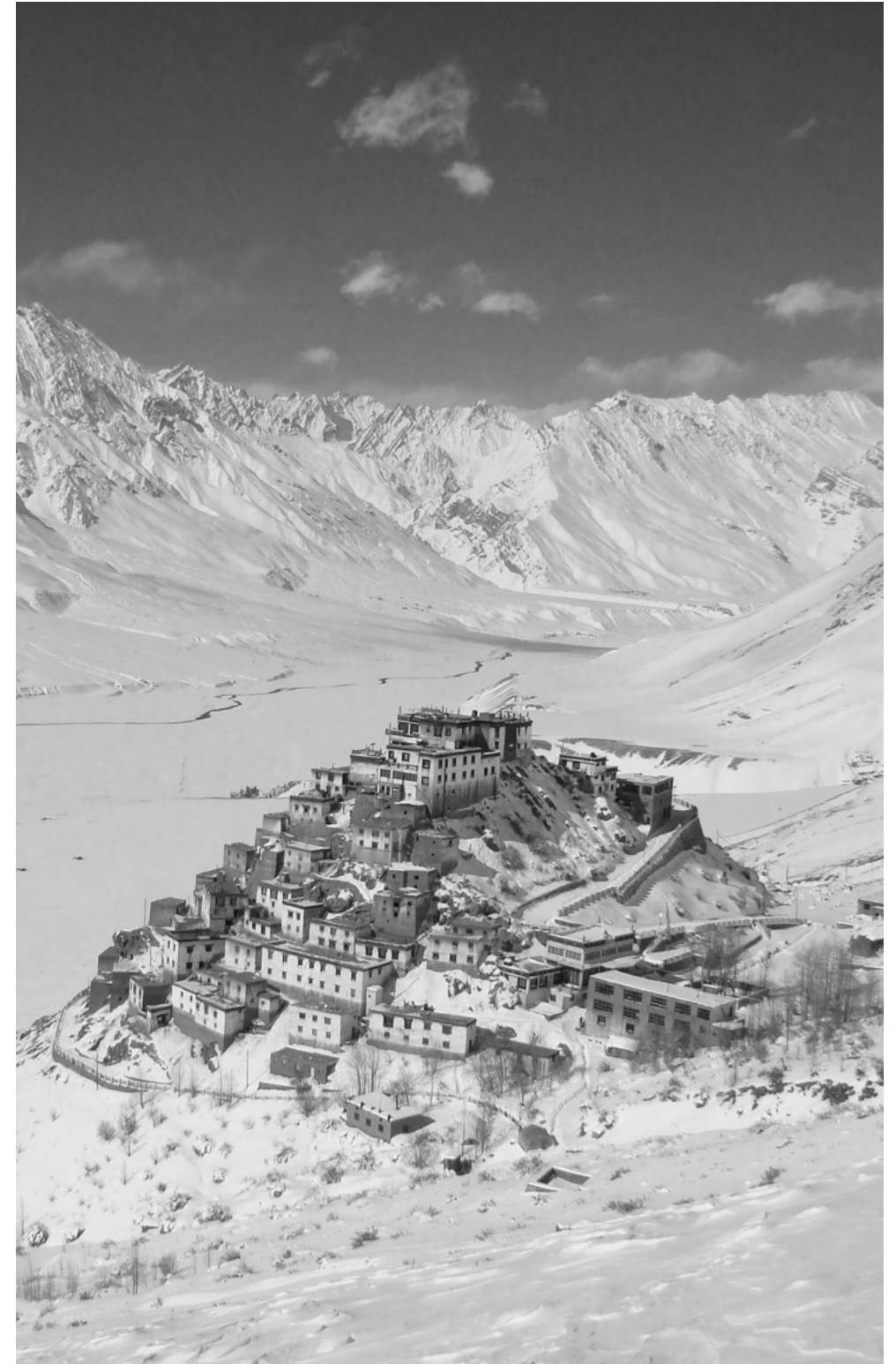
The integration region (also known as mask) can be made by uploading a shapefile defining the extent beyond which there is negligible likelihood of the trapped animals being captured. The integration region can be constructed by specifying a 'buffer' region around the detectors. Typically, a buffer is defined to be bigger than known radius of snow leopard home ranges and checked for bias using inbuilt secr functions. Spatial covariates can be included in the integration area (mask) either by adding covariates from R objects uploaded as shapefiles or rasters. Alternately one can use a process that requires a few additional steps, but can be executed faster using GIS software where the mask is exported as a csv file, opened as a spatial dataset in a third party GIS application, covariates are added using standard point overlay features, and saved as a csv before reading the csv file as a mask object.

## Appendix V: Data analysis and interpretation

It is advisable to center and scale continuous covariates to have a mean of 0 and a standard deviation of 1. This standardization, also known as z-transformation of data is known to make model fits more stable.

It is usually advisable to plot integration area (mask), spatial covariates, traps and encounters to visually verify that all relevant information is loaded correctly.

Model codes can be written by using secr vignettes for heterogeneous density and detection. To speed up analyses, secr allows use of more than one core, where this is available on computers. The cores can however only be accessed by each model one at a time, meaning a single model estimating density and detection in a single area can only access one core. Multiple cores can only be utilized to improve speed when comparing with more than one sites or sessions. Alternately, if the entire candidate set of all models is ready, one can run the whole set by threading all models into a single code block in series and then utilizing one core for each model. This approach can speed up the overall analysis by a number of times equal to the number of cores available on the CPU.



# Appendix VI:

## Future developments

Various techniques and tools exist that help quantify the quality of individual identification, including the ones that are used by the Wildlife Institute of India for identifying tigers, the AI based tools that are currently being developed by Microsoft and Snow Leopard Trust, or the training and evaluation toolkit being launched by GSLEP for reporting individual skills. The cost and benefit of using these different methods to identify individuals, and quantify analysts' ability to identify individuals will be estimated, for they can potentially impact accuracy of the estimated populations.

### **Artificial Intelligence for species and individual snow leopard identification**

Modern advances in Artificial Intelligence and Deep Learning have the power to safeguard wildlife and can offer researchers new lenses to explore ecosystem dynamics. Of many, monitoring wildlife populations can require extraordinary effort. Monitoring wildlife populations generates massive datasets whose size and scale can become prohibitive for field practitioners. Microsoft is collaborating with several conservation organizations to develop novel technologies for

monitoring and protecting wildlife. More specifically, deep transfer learning has been used to tackle the issue of snow leopard detection in remote camera trap images. By scanning through hundreds of thousands of images and using deep neural networks, the current algorithms are detecting snow leopards with 95% accuracy.

As the next step, the teams are currently developing three dimensional virtual models of snow leopards to train the algorithms on identifying individuals from spot patterns. Once available, these tools should make it possible for researchers and conservationists to reduce the amount of manual labour required to scan and identify these images without any probabilistic framework to consider misidentification.

### **Drone survey for prey estimation**

Assessing the abundance of snow leopard prey species is critical to the effective management of conservation areas. However, manual methods of data collection are expensive and time-consuming given the large spatial scales at which sampling needs to be conducted. Drones or unmanned aerial vehicles can help address this challenge (Koh and Wich 2012). A workflow is currently being developed that utilizes a combination of UAVs, artificial intelligence and the latest statistical tools to remotely detect and measure the abundance of snow leopard prey species. As part of the system, low latency deep object detection networks will be used

## Appendix VI: Future developments

to automatically detect prey species in visual imagery from aerial surveys and abundance estimation will be attempted by comparing various methods including the recently developed cluster capture-recapture methodology (Stevenson, Borchers et al. 2018). This workflow is expected to enhance the scale at which habitats are monitored and provide a more time-dense picture of prey abundance. In addition, detection capabilities will be further expanded by deploying and testing drone-mounted thermal cameras. Lastly, the methodological insights with regards to drone usage in high-altitude regions will be beneficial in the long-term development of surveillance systems for monitoring snow leopard and its habitats.







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