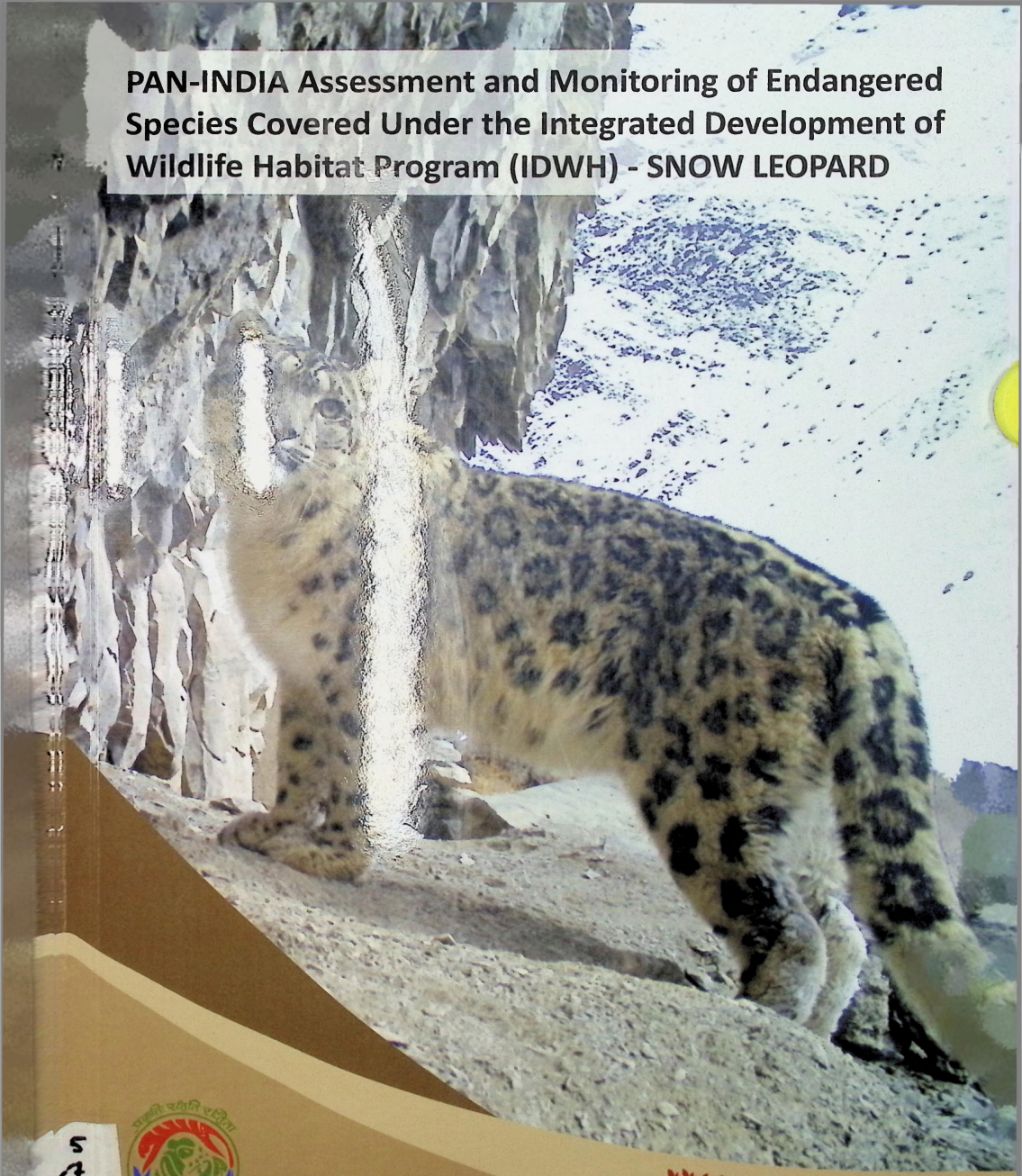
PAN-INDIA Assessment and Monitoring of Endangered Species Covered Under the Integrated Development of Wildlife Habitat Program (IDWH) - SNOW LEOPARD



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Wildlife Institute of India

PAN-INDIA Assessment and Monitoring of Endangered Species Covered Under the Integrated Development of Wildlife Habitats Program (IDWH) - SNOW LEOPARD

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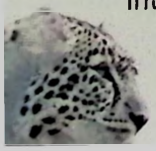

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PREFACE

The Integrated Development of Wildlife Habitats (IDWH) - Snow Leopard and the Snow Leopard Population Assessment in India (SPAI) together represent monumental progresses in conserving India's iconic snow leopard and its fragile Himalayan ecosystem. Under the IDWH program, the primary focus has been on assessing the snow leopard and its prey populations across the species' range, a critical aspect of understanding and maintaining the ecological balance. Simultaneously, SPAI complements this effort by generating robust population estimates of the snow leopard, aligning with the global "PAWS" (Population Assessment of the World's Snow Leopard) initiative. Together, these programs reflect India's holistic approach to wildlife conservation, integrating prey and predator dynamics.

The MoEF&CC, WII and their conservation partners, NCF-India, and WWF-India were involved in the SPAI exercise. By systematically assessing 70% of the snow leopard's potential range, this ambitious undertaking—spearheaded by scientists, knowledge partners, forest personnel, and researchers— solidifies India's leadership in global wildlife conservation. The implementation of these programs has not only highlighted population trends and prey distribution but also brought to light critical threats such as habitat degradation, poaching, and climate change.

Through prioritizing scientific consistency, international collaboration, and the empowerment of local communities, we reaffirm our commitment to securing the long-term survival of snow leopards and their high-altitude habitats. This combined effort under IDWH and SPAI strengthens our position as a global leader in conservation, showcasing the importance of ecosystem-level strategies.

This report stands as a testament to our unwavering dedication to environmental stewardship. It calls for continued collaboration with all stakeholders to ensure that the snow leopard, an apex predator and flagship species of the Himalaya, thrives for generations to come. Let us move forward together in safeguarding these magnificent creatures and their ecosystems, preserving their legacy as a symbol of balance and resilience.

Virendra R. Tiwari
Director, Wildlife Institute of India

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Executive *Summary*

In 2019, the MoEF&CC launched the 'Snow Leopard Population Assessment in India (SPAI)' program, as part of India's active participation in the National and Global Snow Leopard and Ecosystem Protection Program (NSLEP & GSLEP). India has contributed in three significant landscapes to NSLEP & GSLEP, *viz.* Hemis-Spiti, Nanda Devi-Gangotri, and Khangchendzonga-Tawang. Alongside twelve National Snow Leopard and Ecosystem Priorities (NSLEPs), these efforts are aimed at conserving snow leopard and its habitats. The SPAI was designed to generate scientifically robust national and state-wise population estimates of the snow leopard across the high-altitude habitats both inside and outside protected areas. Its overarching goal is to gather reliable data to guide effective conservation efforts and policy decisions.

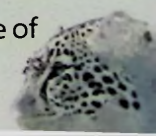
Based on the consultations with the Chief Wildlife Wardens (CWLWS) of the states and Union Territories (UTs) the SPAI sampling exercise was effectively executed across the

Union Territories of Ladakh and Jammu & Kashmir, and four snow leopard range states *viz*. Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh. The SPAI exercise was conducted from 2019 to 2023 following a two-step framework. Within this, the STEP-I involved a meticulous evaluation of snow leopard spatial distribution, incorporating habitat covariates into the analysis. This approach, founded on occupancy modeling, relied on data sourced from sign and interview surveys, comprehensive fieldwork, and precise geospatial mapping. This assessment culminated in the refinement of the snow leopard distribution map and the establishment of a foundational dataset for the stratification of snow leopard population sampling. In the STEP- II, snow leopard abundance estimation was achieved through camera trapping. Furthermore, comprehensive abundance assessments were conducted for the primary prey species at selected sites. Given the constraints posed by the situations of Covid-19, some states such as Sikkim and Arunachal Pradesh conducted the STEP-I and II exercises simultaneously.

Till 2016, a substantial third of the snow leopard range (spanning ca. 100,347 km^2) had not received research attention, which was reduced to just 5%, mainly in small pockets of Ladakh, Jammu & Kashmir, Uttarakhand, and Himachal Pradesh. However, status surveys in the recent years have increased the understanding on preliminary information about snow leopard or prey is available for 80% of the snow leopard range (ca. 79,745 km^2), compared to 56% in 2016. To provide robust information on the snow leopard numbers, the SPAI exercise involved surveying the snow leopard habitats using a substantial network of camera traps.

In total, the SPAI sampling exercise utilized 1,971 camera trap locations, leading to the identification of 241 unique individuals. These comprehensive findings allow for the estimation of a total snow leopard population of 718 individuals in India. A total of 126 unique snow leopard individuals were identified from the Union Territory of Ladakh, across a total of 956 camera trap locations, yielding an estimated density of 0.34 individuals/100 km^2 and a population of 477 individuals. Camera trapping efforts in 135 sites in the Union Territory of Jammu & Kashmir led to detection of 9 unique individuals across the snow leopard range. The estimated density was 0.75 individuals/100 km^2 and population of 9 individuals.

For the snow leopard range states, Himachal Pradesh recorded a total of 44 unique individuals identified across 284 camera trap locations. The density of snow leopard in the state ranged from 0.08 to 0.37 individuals/100 km^2. The exercise was indicative of a mean population size of 51 individuals of snow leopard in Himachal Pradesh. The state of



Uttarakhand recorded a total of 40 unique individuals, with a density ranging from 0.7 to 1.04 individuals/100 km^2. The population estimates of snow leopard in Uttarakhand was 124. In the eastern Himalayan states, Sikkim, with a total of 99 camera trap locations, recorded a total of 14 unique individuals with an estimated density of 0.40 snow leopards/100 km^2. The estimate was 21 snow leopards for this state. On the other hand, in Arunachal Pradesh, 8 unique snow leopards were identified across 115 camera trap locations. The density was 0.26 individuals/100 km^2 and the population was estimated as 36 individuals in the state.

In the Indian Himalayan region, two prey species dominate the diet of the snow leopard: the bharal or blue sheep (*Pseudois nayaur*), and the Siberian ibex (*Capra sibirica*). Bharal exhibit a near-total range overlap with snow leopard across the greater and trans-Himalayan regions, while ibex occupy extensive ranges within the northwestern trans-Himalayan region. In the subalpine and alpine region Himalayan tahr and musk deer form important component to snow leopard diet. Other mountain ungulates, though less prominent, contribute to the diet and hold local importance. Himachal Pradesh is the only snow leopard range state in India where systematic surveys on its primary prey species have been conducted. Conversely, states like Arunachal Pradesh and Jammu & Kashmir remain significantly understudied, while data from Uttarakhand and Sikkim are fragmented and localized. Ladakh, due to its visibility and accessibility, has a relatively well-documented history of ungulate monitoring. Limited long-term data suggest a decline in ungulate populations across the Himalaya, except for the Tibetan antelope (*Pantholops hodgsonii*), which has shown signs of recovery. Markhor (*Capra falconeri*) habitat shrank from 300 km^2 in the 1940s to just 120 km^2 by 2004–2005. Similarly, musk deer (*Moschus* spp.) in Kedarnath Wildlife Sanctuary (Uttarakhand) have seen a steady decline from 3.7 individuals/km^2 (1989–1991) to 1.2 individuals/km^2 by 2000. A similar declining trend is evident in ibex (*Capra sibirica*) populations in Pin Valley National Park, Himachal Pradesh. Density estimates dropped from 2.3 individuals/km^2 in 1989 to 1.2 individuals/km^2 in 1997, with a further reduction to 0.37 individuals/km^2 by 2012. These declines underscore the urgent need for targeted conservation efforts and systematic prey monitoring to ensure the long-term viability of snow leopard populations.

1.1 INTRODUCTION

Conservation of critically endangered fauna and flora has been one of the prime objectives of India's biodiversity conservation agenda. Understanding the ongoing depletion of the critically endangered biodiversity of the country, India has initiated a number of programmes particularly targeted at the assisted recovery of these species. The Ministry of Environment, Forests and Climate Change (MoEF&CC), in consultation with Wildlife Institute of India and other scientific institutions identified 16 terrestrial and 6 aquatic species with the objective to save critically endangered species and the species recovery plans were prepared for several of these species. The 'Integrated Development of Wildlife Habitats (IDWH) is a centrally sponsored scheme, which has been made operational by adding more components and activities to the erstwhile centrally sponsored scheme- 'Assistance for the Development of National Parks and Sanctuaries' during the 11th plan period. Under IDWH, the financial assistance is being provided to State/UT governments for protection and conservation of wildlife and its habitats, and also for the recovery programmes of the critically endangered species. Overall, the IDWH scheme of MoEF&CC has helped in conservation and improvement of habitats of at least 45% of endangered species. The following species have been identified under IDWH Scheme: marine turtles (4 species), dugong, Andaman swiftlet, wild buffalo, Nicobar megapode, Arabian sea humpback whale, snow leopard, Great Indian bustard, lesser florican, Bengal florican, Gangetic dolphin, hangul, Nilgiri tahr, Manipur deer, vulture (4 species), Malabar civet, one-horned rhino, Asiatic lion, swamp deer, Jerdon's courser, northern river terrapin, clouded leopard and red panda.

Conservation planning in India is based on the philosophy of identifying and protecting representative wild habitats across all the ecosystems. For this purpose, the entire country has been divided into 10 Biogeographic Zones and areas of ecological significance in each zone have been declared as Protected Areas (PAs) under the Act of Parliament. To conserve wild animals and their habitats a country-wide Protected Area network has been established under the provisions of the Wild Life (Protection) Act, 1972. These include National Parks, Marine Protected Area, Wildlife Sanctuaries, Conservation Reserves and Community Reserves, which cover important wildlife habitats across land and marine environments. Additionally, there are other sites of

conservation importance, which are conserved by varying levels of legal protection given by the policies formulated by the government or global conventions. Important conservation sites in India are: Tiger Reserves, Elephant Reserves, Biosphere Reserves, Ramsar Wetland Sites, Natural World Heritage Sites, Cultural World Heritage Sites, Mixed World Heritage Sites, Important Coastal and Marine Biodiversity Areas, Marine Protected Areas, Important Bird Areas, Potential Important Bird Areas, Key Biodiversity Areas and Biodiversity Heritage Sites.

Overall, the country has multiple mechanisms in hand to conserve its critically endangered fauna. Regardless, there are many looming threats on the biodiversity including habitat fragmentation, degradation and loss; over-exploitation of resources; shrinking genetic diversity; invasive alien species; declining forest resource base; climate change and desertification. As the country's biodiversity conservation, more specifically, the revival of critically endangered species involves a varied socio-cultural milieu and thus a resultant conflicting demands and approaches of stakeholders, there is an urgent need for augmenting the efforts for conservation of these species of concern. Socio-economic perspectives are thus necessitated to be involved in the decision making regarding the conservation of the critically endangered fauna. This must include rehabilitation efforts for the rural poor and tribal communities displaced due to conservation needs of species and habitats apart from encouragement to agroforestry, efforts for creation of corridors and connectivity between protected areas. These approaches will contribute to the enhancement of the implementation of the conservation measures of Indian fauna of critical conservation concern.

Rigorous population assessments offer a scientific foundation for the formulation of targeted conservation strategies, affording policymakers and wildlife practitioners informed directives for mitigating threats and ensuring the enduring viability of this emblematic and vulnerable species. The IDWH Snow Leopard Program and the Snow Leopard Population Assessment in India (SPAI) collectively strengthen conservation efforts for snow leopard in India's Himalayan region. Both these initiatives highlights the ecological, cultural, and economic importance of snow leopard while addressing threats like habitat degradation, climate change, and human-wildlife conflicts. Complementing this, SPAI operates under the National Snow Leopard and Ecosystem Protection Program (NSLEP) and aligns with global initiatives like the Population Assessment of the World's Snow Leopards (PAWS). Together, these programs aim to generate precise population estimates and guide evidence-based conservation strategies across critical landscapes, ensuring the long-term sustainability of high-altitude ecosystems.

1.2 IDWH - Snow Leopard Program

Conservation of critically endangered fauna and flora has been one of the prime objectives of India's biodiversity conservation agenda. Understanding the ongoing depletion of the critically endangered biodiversity of the country, India has initiated The IDWH program aims to strengthen wildlife conservation efforts across the nation. Under this umbrella, the WII has been instrumental in implementing targeted initiatives for the conservation of the snow leopard in the Indian Himalayan region. Among the 22 species have been identified under the IDWH species recovery programme, the snow leopard, besides its ecological significance, holds cultural and economic importance, embodying a symbolic representation for local communities (Chetri et al., 2017). Precise enumeration of the vulnerable snow leopard population assumes paramount importance in the field of conservation biology due to its pivotal role as an apex predator in the Himalayan ecosystem (Jackson et al., 2008). As an apex predator, the snow leopard exerts top-down regulation on prey populations, thereby influencing the ecological equilibrium of its habitat (McCarthy et al., 2017). Precise population quantification serves as a crucial ecological indicator, reflecting the broader health and resilience of high-altitude ecosystems (Alexander et al., 2016). The obtained data furnish insights into demographic trends, facilitating the identification of potential threats such as habitat degradation, climate-induced shifts, besides human-wildlife conflicts (Li et al., 2016).

The geographic distribution of the snow leopard across Himalaya encompasses the union territories of Ladakh, and Jammu & Kashmir besides the states of Himachal Pradesh and Uttarakhand in the western Himalayan region, and Sikkim and Arunachal Pradesh in the eastern Himalayan region. The integrity of these high-altitude habitats (>3,000m) is intertwined with the socio-cultural fabric of local communities and the economic sustenance of populations residing downstream. These habitats, pivotal in regulating seasonal runoff and providing water to northern regions, also harbor traditional pastoral economies, diverse medicinal flora, and a globally significant wildlife assemblage.

Acknowledging the global significance of conserving high-altitude environments, India actively participated in the Global Snow Leopard and Ecosystem Protection Program (GSLEP). Under the GSLEP, India and other snow leopard range nations initiated the National Snow Leopard and Ecosystem Protection Program (NSLEP). In

view of the growing interaction of the snow leopard, and the alpine ecosystems, with human beings, the need for concerted efforts to understand the habitats and plan for its conservation in the most appropriate and sustainable way was perceived. NSLEP represents a road map for this effort. India, underscores its commitment to safeguarding three landscapes (i) Hemis-Spiti, (ii) Nanda Devi- Gangotri, and (iii) Khangchendzonga-Tawang. The Snow Leopard Population Assessment in India (SPAI) is in sync with the global effort initiated by GSLEP called the Population Assessment of the World's Snow Leopards (PAWS). This ambitious scientific endeavor seeks to yield methodologically sound national and state-wise population estimates for the elusive snow leopard, thereby informing judicious conservation interventions and policy formulations

A significant achievement of the IDWH- snow leopard program is the development of the first national protocol for enumerating snow leopard populations, launched in October 2019. This protocol provides a standardized framework for assessing snow leopard populations across their range in India, facilitating more precise and consistent monitoring efforts. Building upon this, the Snow Leopard Population Assessment in India (SPAI) program was conducted between 2019 and 2023. In addition to population assessments, the program emphasized evaluating prey abundance, a critical factor influencing snow leopard distribution and density.

1.3 SNOW LEOPARD POPULATION ASSESSMENT PROGRAM

Given the methodological intricacies associated with precisely estimating snow leopard populations owing to their cryptic behavior and the expansive, rugged nature of their habitats, the imperative for standardized methodologies becomes paramount. In a collaborative scientific initiative aimed at conducting a comprehensive assessment of the snow leopard population in India, the Department of Wildlife Protection in the Union Territory of Ladakh, Jammu & Kashmir, and the State Forest Departments of Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh collaborated with the Wildlife Institute of India, NCF and WWF-India. This collective effort was initiated to obtain empirical insights into the population dynamics of the snow leopard, holding considerable cultural, ecological, and economic significance within the region.

1.3.1 Status of Knowledge of Snow Leopard in India

India has relatively rich natural history records from snow leopard range spanning over a century (see references in Schaller, 1977; Pal et al., 2016), but systematic surveys began in the 1980s covering parts of the western Himalaya such as Ladakh (Fox et al., 1988, 1991; Mallon, 1991), Himachal Pradesh (Bhatnagar et al., 2008), and Uttarakhand (Sathyakumar, 1993, 2003). Later studies continued to expand the systematic surveys into previously unexplored areas (Maheshwari et al., 2013; Ghoshal et al., 2019; Suryawanshi et al., 2021).

More recently, large parts of Eastern Himalaya in the states of Sikkim (Sathyakumar et al., 2014, WWF-India, unpublished data) and Arunachal Pradesh (WWF-India, unpublished data) are also being covered. Ecological studies in Ladakh (Chundawat, 1992; Chundawat and Rawat, 1994), Spiti (Bhatnagar, 1997; Mishra, 1997; Mishra et al., 2004; Sharma et al., 2021) and Uttarakhand (Bhattacharya et al., 2012, 2020; Kandpal and Sathyakumar, 2010; Koetke et al., 2020; Pal et al., 2021, 2022; Suryawanshi et al., 2021) have also added to the understanding of snow leopard and prey ecology and interactions between people and wildlife. Various studies exploring snow leopard abundance using modern tools have provided some robust estimates.

Research in snow leopard range has received increasing attention in the past five years mostly due to India's growing interest in protecting high-mountain watersheds under programs such as the Project Snow Leopard and increasing investment in climate change research. Large-scale and long-term monitoring projects/mission have been launched since 2015 in India contributing to an increase in information from snow leopard range such as the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and National Mission on Himalayan Studies (NMHS).

While early reports hinted at rare occurrences below 3000 m in the Greater Himalaya around 2700 m (Green, 1989), recent studies, incorporating advanced techniques like camera traps, indicate potential usage of lower forest tracts, occasionally overlapping with the common leopard *(Panthera pardus)* in regions such as Uttarakhand, Sikkim, and Himachal Pradesh (Harshil-2700m; Pangolakha Wildlife Sanctuary-2850m; Great Himalayan National Park-2495m; Bandyopadhyay et al., 2019; Manvi Sharma, NCF, unpublished report).

An updated knowledge map, based on new research, reveals a substantial increase in information across the snow leopard range. The entire potential snow leopard range in India (3200 to 5200 m) has been meticulously divided into 311 sub-catchments, providing a nuanced understanding of the levels of knowledge. This categorization ranges from "good," representing long-term and multidimensional studies, to "moderate" and "preliminary," indicating varying degrees of research attention. The review of studies since 2016 demonstrates a remarkable reduction in previously unstudied areas and an increase in both the spread and quality of information (Fig. 1).

While there has been commendable progress, several critical thematic areas still lack comprehensive understanding. Demographic parameters, interactions with free-ranging dogs, and the implications of climate change require heightened attention. Ongoing initiatives like the Snow Leopard Population Assessment in India (SPAI) program are poised to address these gaps, offering a promising outlook for the future. The evolving status of knowledge on the snow leopard

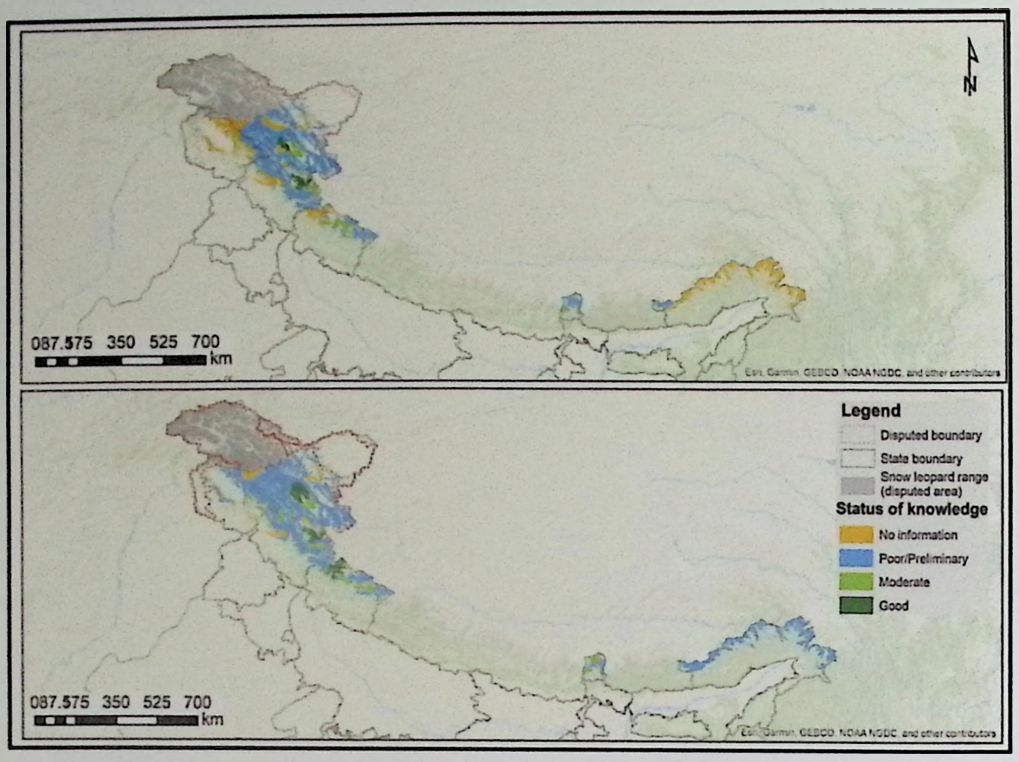


Fig. 1. Potential snow leopard range in India (3200-5200m) showing the information gaps. Status of knowledge on snow leopard and prey species in India in 2021 (bottom) and 2016 (top), as assessed by attributing values to 311 tertiary catchments within snow leopard range ranked as good (3), moderate (2), poor (1), and no information (0). See text for details. Note the substantial improvement in the spatial coverage and quality of studies between 2016 and 2021 (used with permission from Bhatnagar et al. 2024).

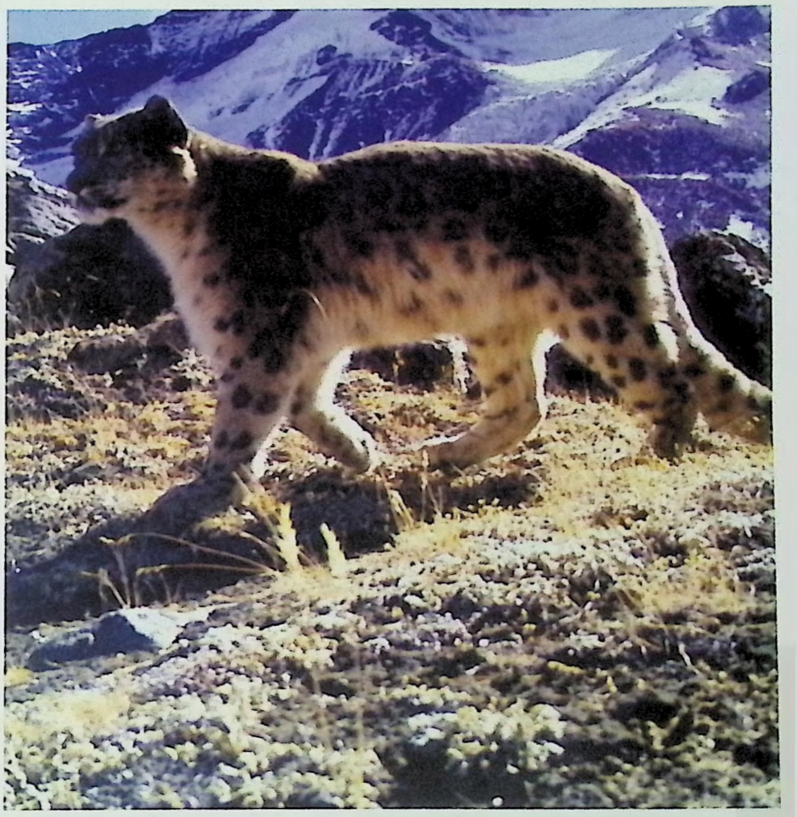
in India reflects a dynamic landscape of research and conservation efforts. The intersection of ecological, cultural, and economic dimensions underscores the imperative nature of these endeavors. Maintaining the long-term survival of the snow leopard in the Indian Himalaya is largely dependent on the joint efforts of academics, policymakers, and local communities. In1980s, a guesstimate of the snow leopard population in India was presented along with other range countries (Fox, 1989). Of the estimated approximately 4000-7500 snow leopards globally, 400 to 700 were estimated for India. However, the absence of standardized methodologies and reliable density estimates necessitated a revised assessment. The current SPAI exercise represents a significant step forward, employing improved protocols to generate robust population estimates and inform targeted conservation actions.

1.3.2 The Snow Leopard Range in India

The vast expanse of the Himalaya, extending over approximately 2500 km, forms a formidable arc along the northern and northeastern boundary of India. This area surveyed for the snow leopard population estimation traverses four Indian states Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh and two Union territories, namely Jammu & Kashmir and Ladakh. Within this geographical mosaic, the alpine tracts of the Himalaya and the arid marginal mountains of the Tibetan Plateau, nestled in the rain shadow of the main Himalayan range, collectively known as Trans Himalaya (Rodgers and Panwar, 1988; Rodgers et al., 2000), constitute the habitat of the elusive snow leopard.

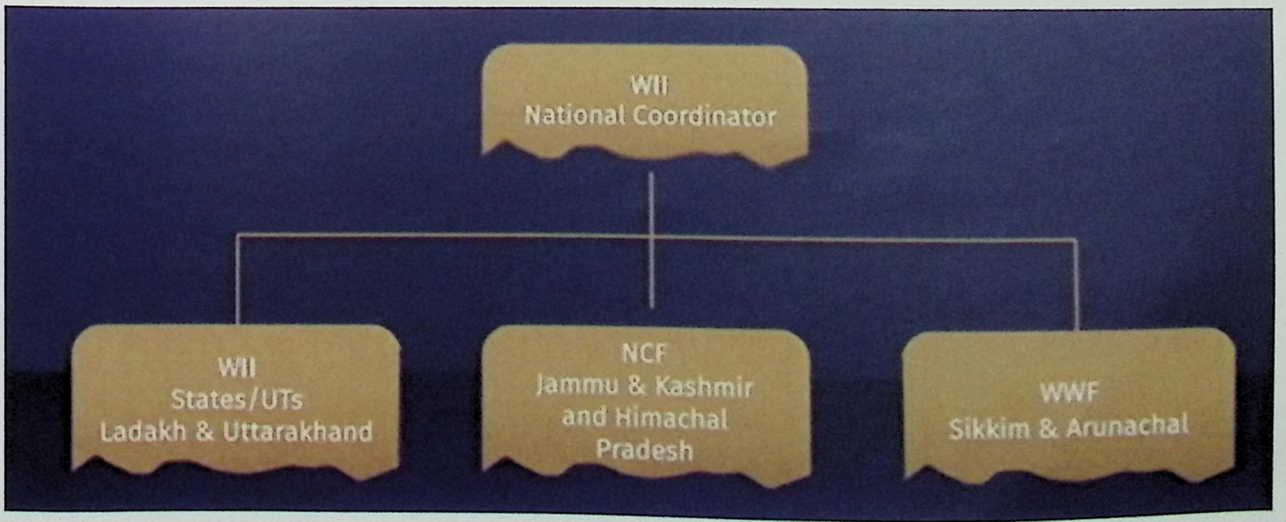
The high altitudes of the Indian Himalaya sustain a diverse and unique assemblage of wild flora and

fauna, attributable to distinct biogeographic characteristics (Mani, 1974; Rodgers et al., 2000). Some sections of this region are even classified as global biodiversity hotspots (Olson and Dinerstein, 1998; Myers et al., 2000). This snow leopard habitat spans nearly 120,000 km^2, with a gradient of increasing aridity from east to west and south to north. Existing between 3200 and 5200 m, these nonforested tracts are the preferred domains for snow leopard (Fox et al., 1991; Chundawat, 1992). All major rivers in northern India, critical lifelines supporting millions of people and their livelihoods, originate from the snow leopard range. Hence, the snow leopard habitat in Himalaya, beyond its immense biological value, also provides invaluable ecosystem services (MEA, 2005; World Bank, 2013), buttressing the need for its conservation and that of snow leopard, its major keystone species.



1.3.3 Methodology

The SPAI systematically covers over 70% of the potential snow leopard range in the country through an unprecedented exercise that involves capacity involvement of staff and volunteers, inputs from knowledge partners, and carrying out the surveys in two steps. For the SPAI exercise WII served as the National Coordinator and at the regional level, States and Union Territories provided technical inputs for Ladakh and Uttarakhand, the NCF coordinated sampling activities in Jammu & Kashmir and Himachal Pradesh, while WWF provided technical inputs in Sikkim and Arunachal Pradesh. The MoEF&CC regularly monitored the progress of work through virtual meetings conducted by WII. This coordinated approach ensured efficient sampling across landscapes and regions:



The SPAI was carried out in two steps following the guidelines of the national population assessment of snow leopards in India (MoEFCC, 2019). The first step involved systematically assessing the spatial distribution of snow leopard in its potential distribution range. This step used an occupancy-based sampling approach (questionnaire/sign survey) to understand the distribution of snow leopard and stratify potential snow leopard habitats. In the second step, the abundance of snow leopard was estimated using camera traps in each stratified region identified in STEP I. Before the sampling process, various workshops online and offline were organized with the forest department to focus on planning the implementation of STEP I and STEP II assessment. These workshops aimed to build an understanding of the sampling framework and planning logistics to carry out surveys. The trailing section details on the STEPS I and II of the SPAI exercise.

STEP I : Occupancy based assessment of snow leopard

The primary objective of step I was to gain a thorough understanding of snow leopard distribution in India. Snow leopard potential distribution ranges were divided into uniform grids (15x15 km), and the actual presence of snow leopards was assessed by sampling through the occupancy method framework (MacKenzie et al., 2006). Information on snow leopard occurrence was compiled using different sampling approach such as questionnaire, and sign survey.

Data from multiple interviewees/ sign survey or camera traps were analysed in the occupancy framework by modelling the variation in each sampling unit being used by snow leopard 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 leopard across the entire survey region for each sampled unit. These probabilities of site use were used to generate refined distribution maps of snow leopard, and identify strata that can then be used to choose sampling units for intensive sampling under step II. In Ladakh, a presence-only modeling approach was used to assess snow leopard habitat suitability. In Sikkim, existing information on snow leopard occurrences was used to stratify habitat types for step II, leveraging prior knowledge to guide survey design.

STEP II : Snow leopard population sampling for density estimation

Camera trapping efforts

Step II entails estimating the snow leopard population through intensive camera trap sampling in areas within each stratum (identified in step I), capturing spatial variation in snow leopard density. Step I assessment provides the basis for camera trap site level sampling approach- ensuring that camera trap surveys occur in each stratum. Areas for step II sampling within different strata were delineated. Camera trap sampling across identified grids was carried out using the spatial capture-recapture method (SCR) framework (Royle & Young,

2008). Forest department officials, collaborating NGOs and researchers from WII, NCF, WWF and their partners deployed cameras based on snow leopard signs such as scat, spray or scrape marks and the presence of suitable habitats such as cliffs or animal trails to maximize the capture of snow leopards. Major valleys in various high-altitude regions were approached by trekking trails, herder's routes, or walking along rivers and tributaries to their sources (glaciers). The method requires snow leopards to be sampled for a long enough duration to be encountered at multiple locations within the sampling area. Both side and single-side camera traps were used to optimize the area coverage and identification of individuals. In some areas, camera traps were positioned to obtain images of the forehead.

Individual snow leopards were identified from camera trap pictures using their unique coat patterns. Individuals which could not be identified because of poor picture quality (e.g., blurry, overexposed) were excluded from the analyses. The resulting spatial encounter history data were analyzed using SCR methods (Royle & Young, 2008).

1.3.4 Snow leopard Population in India

The SPAI sampling exercise was effectively executed across Ladakh, Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh. Within the SPAI framework, the initial stage involves an evaluation of snow leopard spatial distribution, incorporating habitat covariates into the analysis. This approach, founded on occupancy modeling, relies on data sourced from sign and interview surveys, comprehensive fieldwork, and precise geospatial mapping. This rigorous assessment culminates in the refinement of the snow leopard distribution map and the establishment of a foundational data set for the stratification of snow leopard population sampling. In the subsequent step, snow leopard abundance estimation is achieved through the deployment of camera trapping.

Overall, the assessment examined snow leopard populations in India using a substantial network of camera traps. In total, the SPAI sampling exercise involved 1,971 camera trap locations, leading to the identification of 241 unique snow leopard individuals. These comprehensive findings allow for the estimation of a total snow leopard population of 718 individuals in India, underscoring the significance of the research in enhancing the understanding of snow leopard populations in these critical areas (Table 1).

Table 1. Snow leopard population estimates in two Union Territories (Ladakh and Jammu & Kashmir) and four states (Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh and Sikkim) of India, based on the SPAI exercise. The table includes the number of camera traps deployed in each region, the number of unique snow leopard individuals identified, density estimates (expressed as individuals/100km^2), and the estimated total number of snow leopards in each region.

States I Uts	No. of Camera Trap Locations	No. of Unique Individuals	Density Estimates	Estimated Number of Snow Leopards
Ladakh	956	126	0.34±0.14	477
Jammu & Kashmir	135	9	0.75±0.52	9
Himachal Pradesh	284	44	0.08-0.37	51
Uttarakhand	382	40	0.7-1.04	124
Sikkim	99	14	0.40±0.11	21
Arunachal Pradesh	115	8	0.26±0.11	36
Total	1971	241		718

A total of 126 unique snow leopard individuals were identified from the Union Territory of Ladakh, across a total of 956 camera trap locations, yielding an estimated density of 0.34 individuals/100 km^2 and a population estimate of 477 individuals. The Union Territory of Jammu & Kashmir, on the other hand led to detection of 9 unique individuals across the snow leopard range with 135 camera trap locations. The estimated density was 0.75 individuals/100 km^2 and the population estimate 9 individuals.

For the snow leopard range states, Himachal Pradesh recorded a total of 44 unique individuals identified across 284 camera trap locations. The density of snow leopard in the state ranged from 0.08 to 0.37 individuals/100 km^2 and the estimated population was 51 individuals. The exercise was indicative of a mean population size of 51 individuals of snow leopard in Himachal Pradesh. The state of Uttarakhand recorded with a total of 40 unique individuals, with a density ranging from 0. 7 to 1.04 individuals/100 km^2. The population estimate for Uttarakhand was 124. In the eastern Himalayan states, Sikkim, with a total of 99 camera trap locations, recorded a total of 14 unique individuals with an estimated density of 0.40 individuals/100 km^2 and an estimate of 21 snow leopards for the state. In Arunachal Pradesh, 8 unique snow leopards were identified across 115 camera trap locations. The density was 0.26 individuals/100 km^2 and the population estimate was 36 snow leopards for the state (Fig 2).

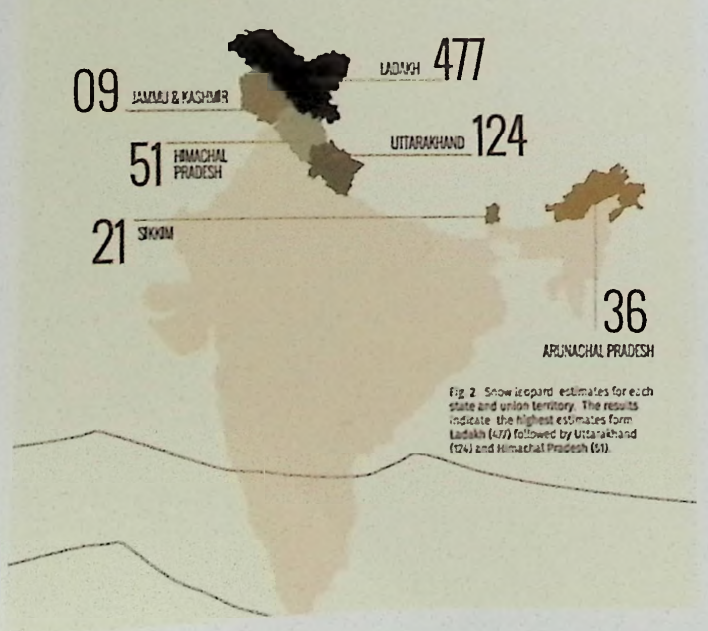


Fig. 2. Snow leopard estimates for each state and union territory. The results indicate the highest estimates form Ladakh (477) followed by Uttarakhand (124) and Himachal Pradesh (51).

LADAKH

Camera traps were strategically deployed across an area spanning 8,604 km^2, divided into seven blocks, with operational periods ranging from 120 to 180 days. These cameras successfully captured a total of 10,789 images of snow leopards within the study area. A total of 126 unique adult individuals were identified based on their distinctive forehead patterns. The estimated population of snow leopard in the Union Territory of Ladakh was calculated to be 477 (± 51) individuals, with an estimated density of 0.34 individuals/100 km^2, The detailed account of the SPAI exercise conducted in the region can be found in the UT report titled "Status of snow leopards in Ladakh", Department of Wildlife Protection, UT Ladakh (Appendix I).

JAMMU & KASHMIR

A total of 278 camera traps were deployed at 135 locations involving 80 grids across the entire landscape. A total of nine individual snow leopards were identified, comprising seven adults and two sub-adults. Employing the SCR method in the current sampling effort, the likely snow leopard population size was estimated to be between 7 to 14 individuals. However, it is noteworthy that four individuals were excluded from the analysis due to poor image quality and unfavorable capture angles. Nonetheless, it is crucial to emphasize that this data set falls short of providing a comprehensive estimate for the entire snow leopard population across the landscape. Detailed SECR results indicating an estimated density of 0.75 individuals /100 km^2. Consequently, the estimated abundance stands at 5 individuals, with a minimum of 4 and a maximum of 13 potentially residing in the area. The detailed account of the SPAI exercise conducted in the region can be found in the UT report titled "Snow leopard population assessment in Jammu and Kashmir", Department of Wildlife Protection Govt. of Jammu & Kashmir (Appendix II).

HIMACHAL PRADESH

A total of 44 individual snow leopards were detected on 187 occasions during this exercise. From this data set, the snow leopard population size was estimated to be 51 individuals, with a

reliable upper estimate of upto 73 individuals. In Himachal Pradesh, snow leopard density exhibited a range from 0.08 to 0.37 individuals per 100 km^2. Notably, the trans-Himalayan regions of Spiti and Pin Valley recorded the highest densities of snow leopards. Across the sampling sites, snow leopard densities displayed considerable variation, with a seven-fold difference between the sites with the highest and lowest densities. Specifically, Tabo, Hangrang, and Spiti exhibited the highest densities, registering 0.37 (95% confidence interval(CI): 0.18-0.72), 0.36 (95% CI: 0.18-0.73), and 0.3 (95% CI: 0.15-0.59) snow leopards/100 km^2, respectively. Conversely, Bhaga from the low stratum recorded the lowest density of 0.05 (95% CI: 0.01 -0.24) snow leopards per 100 km^2. The snow leopard densities estimated for each stratum closely aligned with the results of the occupancy surveys. The high occupancy stratum exhibited a robust density of 0.3 (95% CI: 0.21 - 0.42) snow leopards/100 km^2, while the low occupancy stratum displayed a lower density of 0.08 (95% CI: 0.05 -0.12). Additionally, the previously unsampled stratum reported a density of 0.08 (95% CI: 0.08 -0.14) snow leopards/100 km^2. The detailed account of the SPAI exercise conducted in the region can be found in the state report titled "Status of snow leopard and prey in Himachal Pradesh", Himachal Pradesh Forest Department, Government of Himachal Pradesh (Appendix-III).

UTTARAKHAND

A total of seven sampling blocks were surveyed using camera traps across the high altitude region of the state. Camera trapping efforts yielded 26,773 trap nights which resulted in 5632 photographs of wild animals, of which 396 were of snow leopards. A total of 41 individuals were identified (6 males, 8 females, 27 unknown). The estimated snow leopard population was 124 (SE range 103 to 145) at a density of 0.7 to 1.04 individuals/100 km^2 across potential habitat of Uttarakhand. The detailed account of the SPAI exercise conducted in the region can be found in the state report titled " Status of snow leopard in Uttarakhand, Uttarakhand Forest Department and Wildlife Institute of India, Dehradun (Appendix IV).

SIKKIM

A total of 14 individual snow leopards were detected through 64 snow leopard capture events, utilizing 99 camera trap locations across the state of Sikkim. Employing the null model, the population estimate for snow leopard in Sikkim is determined to be 21 individuals (SE = 3.54), inhabiting an extensive 5179 km^2 of snow leopard habitat within the state. This leads to a snow leopard density estimation for the state at 0.40 (±0.11) snow leopards /100 km^2, with a 95% confidence interval ranging from 0.23 to 0.69 snow leopards /100 km^2. The snow leopard population density estimate in Sikkim represents a significant milestone in scientific research and conservation efforts. The detailed account of the SPAI exercise conducted in the region can be found in the state report titled "Snow leopard population assessment of Sikkim", Sikkim Forest Department and WWF- India (Appendix V).

ARUNACHAL PRADESH

In Arunachal Pradesh, eight individual snow leopards were detected through more than 40 snow leopard capture events, utilizing a network of 115 camera trap locations in the Tawang and Bomdila Divisions. Employing the null model, the population estimate for snow leopards in Arunachal Pradesh is determined to be 36 individuals (SE =15), inhabiting a vast expanse of 14,156 km^2 of snow leopard habitat within the state. This leads to a snow leopard density estimation for the state at 0.26 (±0.11) snow leopards/100 km^2. It is noteworthy that snow leopard densities exhibited variability across the state, with the lowest recorded density at 0.11 snow leopards/100 km^2 and the highest at 0.57 snow leopards/100 km^2. The detailed account of the SPAI exercise conducted in the region can be found in the state report titled "Statewide Assessment of Population and Density of Snow Leopards in Arunachal Pradesh", Government of Arunachal Pradesh, Department of Environment, Forest & Climate Change, Itanagar (Appendix VI).

1.4 SNOW LEOPARD PREY ESTIMATION IN INDIA

1.4.1 Introduction

The abundance of snow leopard is intrinsically linked to the availability of their primary prey—wild ungulates (Mallon et al., 2016). Snow leopard are uniquely adapted to endure low-productivity ecosystems characterized by harsh climatic conditions and ecologically marginal habitats. Their specialized feeding ecology has evolved to primarily target wild sheep and goats that inhabit the rugged terrains of mountainous regions (Jackson & Hunter, 1996). Additionally, these ungulates play a pivotal role in maintaining the ecological integrity of arid and semi-arid rangelands by influencing vegetation structure and nutrient cycling (Hobbs et al., 2002).

Understanding their conservation status and threats is an important conservation priority.

The snow leopard landscape supports a diverse prey base, with significant variation influenced by habitat characteristics, prey abundance, and seasonal fluctuations. Despite this diversity, wild ungulates—primarily species of wild sheep and goats dominate snow leopard's diet, reflecting the rugged, mountainous habitats they share (Lyngdoh et al., 2014; Mallon et al., 2016). Seasonal prey availability also drives shifts in dietary preferences (Johansson et al., 2015). Although domestic livestock, particularly sheep and goats, are often abundant in snow leopard habitats, studies indicate that snow leopard disproportionately prefer wild prey over livestock when both are available (Bashir, 2013; Johansson et al.,2015;).However, livestock, occasionally including horses, yaks, goat and sheep and cattle becomes a significant dietary component in areas where wild prey is scarce. In addition to ungulates, snow leopards supplement their diet with smaller mammals such as pikas (*Ochotona* spp.) and hares, as well as game birds like chukar partridge (*Alectoris chukar*) and snowcock (*Tetraogallus* spp.) (McCarthy et al., 2003).

The wild ungulate population across much of the snow leopard range is threatened by multiple threats of land use change, forage competition with livestock, diseases, hunting, and poaching. A large portion of the snow leopard's range coincides with areas heavily stocked with domestic ungulates, leading to increased resource competition among prey and livestock and a subsequent decline in wild prey populations (Wegge et al., 2012). Wild prey scarcity further exacerbates human-wildlife conflict as snow leopard increasingly prey on domestic livestock, provoking retaliatory killings by herders. Such retribution is particularly detrimental to a species already living at low densities (Bagchi & Mishra, 2006; Lovari & Mishra, 2023). These disruptions decrease the carrying capacity of the snow leopard's habitat, forcing it to rely more heavily on livestock, which in turn magnifies conflict and retaliatory killings (Bagchi & Mishra, 2006; Lovari & Mishra 2023). Disease outbreaks among wild ungulates (Pal et al., 2023; Khanyari et al., 2024) and the increasing presence of feral dogs, which compete for the same prey base, further compound these challenges (Ahmad et al., 2022).

A decline in wild ungulate populations, or the local extirpation of even one key prey species, can significantly reduce snow leopard densities, underscoring the critical link between mountain ungulate abundance and snow leopard survival (Lovari & Mishra, 2023). Over the past two decades, snow leopard populations have declined by approximately 20%, with reduced prey resources identified as a major factor (McCarthy et al., 2017). Thus, their conservation planning and management must be informed by reliable estimates of their population size and density status.

1.4.2 Prey Distribution Across IHR

In the Indian Himalayan region, two prey species dominate the diet of the snow leopard: the bharal, or blue sheep, and the Siberian ibex (*Capra sibirica*). Bharal exhibit a near-total range overlap with snow leopards across the Greater and Trans-Himalayan regions, while ibex occupy extensive ranges within the northwestern Trans-Himalayan region (Fig 3; Table 2). In the subalpine and alpine region Himalayan tahr and musk deer form important component to snow leopard diet

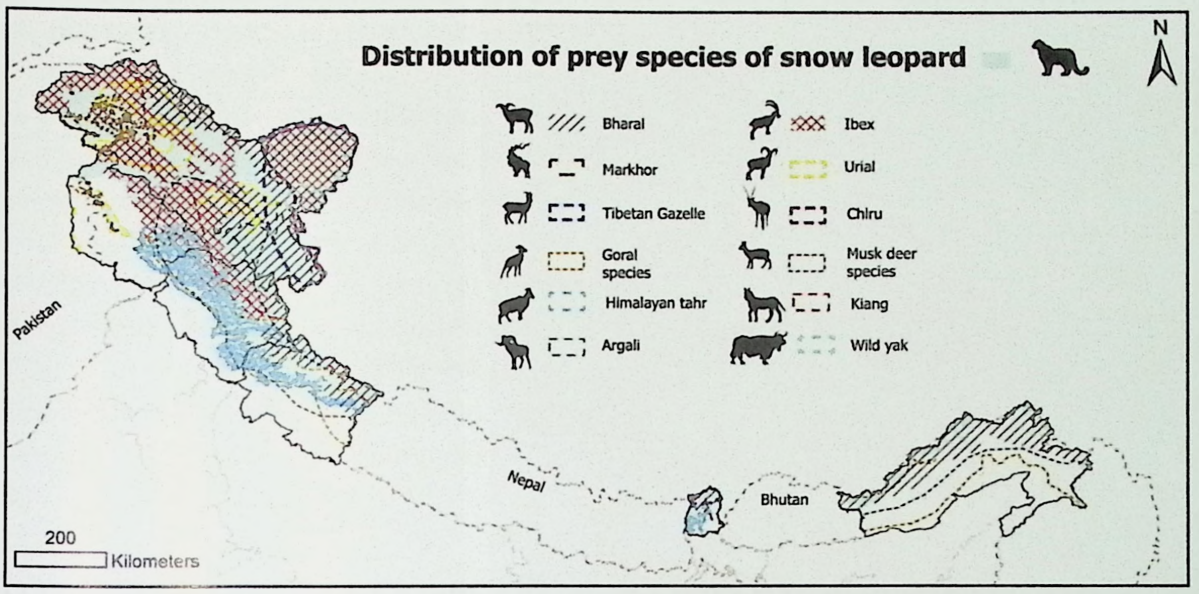


Fig. 3. Distribution of snow leopard and its potential prey species in Indian Himalayan Region (derived from IUCN).

(Ferretti et al., 2014; Chetri et al., 2017; Thapa et al., 2021; Pal et al., 2022). Other mountain ungulates, though less prominent, contribute to the diet and hold local importance (Fig. 3).

BHARAL OR BLUE SHEEP

Bharal is one of the most widely distributed species of ungulates in the greater and trans-Himalaya, found in Ladakh, Jammu & Kashmir, Uttarakhand, and Himachal Pradesh in the west, to Sikkim and Arunachal Pradesh in the east. Diet study from different areas recorded contribution ranging between 30% to 58% in snow leopard's diet (Bagchi & Mishra, 2006, Shrotriya et al., 2022; Pal et al., 2022). In certain region such as Trans Himalayan habitat of Utttarkhand, bharal is only primary wild prey species of snow leopard (Pal et al., 2022).

HIMALAYAN IBEX

The Siberian ibex is classified as Near Threatened by the IUCN and is listed under Schedule I of the Wildlife (Protection) Act, 1972 (Reading et al., 2020). In India, its distribution is confined to the Himalayan regions, including Jammu & Kashmir, the Karakoram Range, Zanskar, the trans-Himalayan region of Ladakh, and the Himalayan and trans-Himalayan areas of Himachal Pradesh. Ibex contribute significantly to the diet (17 % to 57%) of snow leopard along its distribution range (Bhagchi & Mishra, 2006; Shrotriya et al., 2022).

TIBETAN ARGALI

The Tibetan argali (*Ovis ammon hodgsoni*), the largest sheep species in the world. Its distribution in India coincides with snow leopard in the Tibetan Plateau of Ladakh, and small parts of North Sikkim (Namgail, 2004). Occasional presence of argali has also been reported from Himachal Pradesh (Khanyari & Bhatt, 2018), and Uttarakhand (Pal et al., 2021). It is classified as Near Threatened by the IUCN (Reading et al., 2020), and protected under Schedule I of the Indian Wildlife (Protection) Amendment Act, 2022. Argali is preyed upon by snow leopard in Changthang area of Ladakh (Shrotriya et al., 2022). As is typical of wild sheep, argali prefer less precipitous and more open, rolling terrain, and these differences in habitat preferences may therefore reduce the overlap in some localities (Mallon et al., 2016).

HIMALAYAN TAHR

In India, the Himalayan tahr (*Hemitragus jemlahicus*) is found in subalpine regions along the southern-forested slopes of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, and Sikkim

(Sathyakumar, 2002). Its populations are unevenly distributed, ranging from south-central Kashmir to the southern part of Kullu in Himachal Pradesh, at elevations of approximately 2,000 to 3,300 m (Sathyakumar, et al., 2014). It is classified as Near Threatened by the IUCN (Ale et al., 2020). While the overlap between Himalayan tahr and snow leopard distribution remains limited, research indicates that tahr serves as an important prey species in Sagarmatha National Park, Nepal (Lovari et al., 2009; Ferretti et al., 2014). This suggests that the species may also play a significant role in the predator's diet across the Greater Himalayan region of the Indian Himalaya. Studies from Gangotri National Park (Uttarakhand) and Sikkim recorded tahr contribute 7% and 12 % snow leopards diet respectively (Bashir, 2013; Pal et al., 2022).

LADAKH URIAL

The Ladakh Urial (*Ovis vignei*), locally known as Shapo, is a rare species with a restricted distribution in the Indus, Shayok, and Nubra valleys, along with an exclusive population in Hemis National Park, India (Ahmed, 2022). It inhabits the trans-Himalayan regions of Ladakh at elevations below 4,800 m above sea level, favouring flat, open areas, rugged terrain near cliffs, and lower elevations along the alluvial flats of river valleys (Namgail et al. 2010; Michel & Ghoddousi., 2020; Khara et al. 2021). It is classified as Near Threatened by the IUCN (Michel & Ghoddousi, 2020). Chundawat & Rawat (1994) recorded urial in 0.4% of 173 scats collected in Hemis National Park, Ladakh, India.

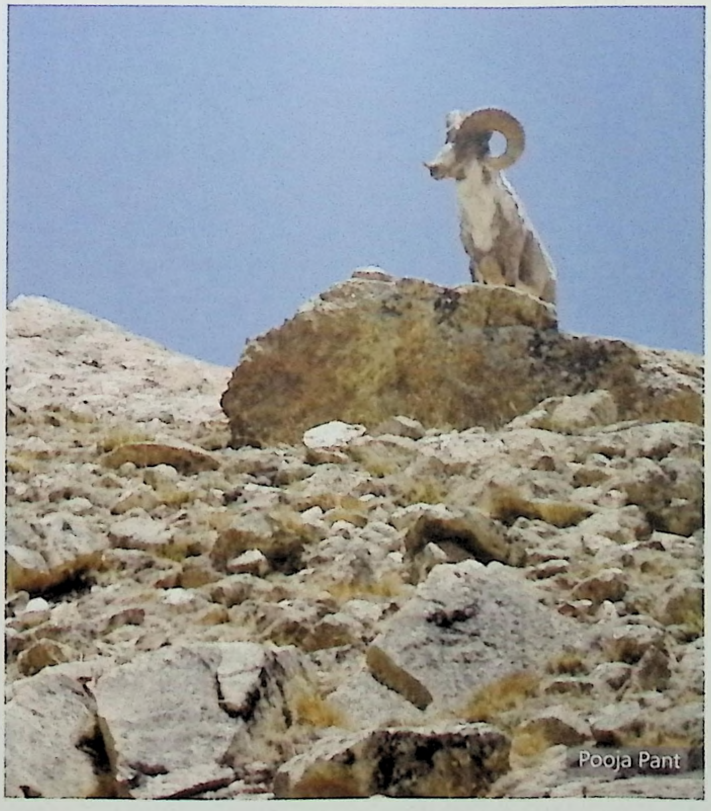
MARKHOR

The markhor (*Capra falconeri*), a large wild goat, is native to South and Central Asia. In India, its distribution is confined to parts of the Pir Panjal Range in southwestern Jammu & Kashmir (Ranjitsinh et al., 2005; Bhatnagar et al., 2007, 2009). Markhor populations in this region are scattered, extending from east of the Banihal Pass, approximately 50 km from the Chenab River on the Jammu-Srinagar highway, to the disputed border with Pakistan. Observations by Bhatnagar et al. (2009) confirmed markhor presence in Kajinag and Hirpura, with additional evidence from Boniyar and Poonch. A survey conducted between October 2004 and April 2005 in the Hirpura and Kajinag areas of the Pir Panjal Mountains recorded 35 groups, comprising a total of 155 individuals (Ranjitsinh et al., 2005). Markhor has been reported as an important prey item in Chitral and Gilgit, northern Pakistan (Schaller, 1977) and is similarly expected to contribute to snow leoaprd's diet in its distribution range in India. It is classified as Near Threatened by the IUCN (Michel & Rosen, 2015)

MUSK DEER

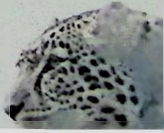
Musk deer (*Moschus* spp.) are small, solitary ruminants that inhabit forested regions and alpine scrub habitats across the mountainous landscapes of Asia (Sathyakumar et al., 2015). In India, they are found at elevations ranging from

approximately 2,500 m up to the tree line, occupying diverse ecological niches within the Indian Himalayan region (Sathyakumar et al., 2015). The region supports four distinct species of musk deer with specific geographic distributions and conservation statuses. The alpine musk deer (*Moschus chrysogaster*), is found in the Northeastern Indian Himalaya and Uttarakhand. The Himalayan musk deer (*Moschus leucogaster*), is distributed from Himachal Pradesh in the west through Uttarakhand, Sikkim, and Arunachal Pradesh. The Kashmir musk deer (*Moschus cupreus*), is confined to the Kashmir region of Jammu & Kashmir. Similarly, the black musk deer (*Moschus fuscus*), is found in Sikkim and Arunachal Pradesh. All four species of musk deer are globally threatened and classified as Endangered by IUCN (Timmins & Duckworth, 2015; Harris, 2016; Wang & Harris, 2015). Musk deer may account upto 20% of snow leopard diet in its greater Himalayan region (Pal et al., 2022). Studies from Nepal also have recorded contribution ranging from 5.4 to 20% in snow leopard's diet (Lovari et al., 2009; Thapa et al., 2021).



OTHER PREY SPECIES

Range restricted ungulate species Tibetan antelope (*Pantholops hodgsonii*), Tibetan gazelle (*Procapra picticaudata*), Kiang (*Equus kiang*) contribute limited to snow leopard diet. All three species are endemic to Tibetan plateau. The Tibetan antelope, also known as Chiru locally, an endemic bovid species of the Tibetan Plateau. In India, this species is found in the Daulat Beg Oldi region and the Chang Chenmo Valley in northeastern Ladakh (Ahmed et al., 2017). The Goa, or Tibetan gazelle is a small antelope native to the Tibetan Plateau. It is widely distributed across the Tibetan Plateau, but populations are scattered, with small herds spread across its range. In India, the species is represented by small populations in the Ladakh and Sikkim regions (Bhatnagar et al., 2006.). The Tibetan wild ass, or Kiang, is one of the largest wild ass species and is native to the Tibetan Plateau. In India, the western Himalayan population found in Ladakh is identified as the Western Kiang (*Equus kiang kiang*), while the Southern Kiang (*Equus kiang polyodon*), a subspecies, inhabits North Sikkim. They primarily inhabit alpine meadows and steppe habitats at elevations between 2,700 and 5,300 m. To date, no studies have confirmed the presence of Tibetan antelope, Tibetan gazelle, or Kiang in the snow leopard's diet. However, given their range overlap with the snow leopard, occasional predation cannot be ruled out. Their preference for gentle slopes and open habitats, contrasting with the snow leopard's affinity for rocky, precipitous terrain, likely reduces their significance as a prey source compared to cliff-dwelling ungulates. Another large-bodied ungulate, the wild yak (*Bos mutus*), has an extremely restricted range in India. It is believed to migrate seasonally into Ladakh from areas controlled by China (Schaller & Liu, 1996; Ul-Haq, 2003; Rawat & Sankar, 2011). Attacks on domestic yaks have been reported, suggesting that they are a viable prey source.



Goral may contribute to snow leopard diet in greater Himalayan region although evidence are limited. A study from Bhutan recorded a contribution of 2.5% in snow leopard's diet (Lham et al., 2021a). Two species of goral inhabit Indian Himalayan range: the Himalayan goral (*Naemorhedus goral*), and red goral (*N. baileyi*). Occasional records of Chinese goral (*N. caudatus*) has been recorded from northeast India (Mishra et al., 2004). In India, the species exhibits a patchy distribution along the Himalayan mountain ranges. In Jammu & Kashmir, its presence has been reported in Dachigam National Park (Johnsingh et al., unpublished data), Kisthwar National Park, and possibly in the Limber Wildlife Sanctuary. In Himachal Pradesh, and Uttarakhand, the goral is widespread , occurring at elevations of 1,800–4,000 m (Green, 1985; Fox et al., 1986; Pal et al., 2021). In the eastern Himalayan states of Sikkim and Arunachal Pradesh, it is found at elevations ranging from 900 to 2,750 m.

Table 2: The table provides a detailed account of the Distribution, conservation status, and ecological attributes of prey species for the snow leopard across the IHR Himalayan region (modified from Sathyakumar and Bhatnagar (2002).

S. No.	Common Name	Distribution						Elevation Range (m)	Body Mass (kg)	IUCN Red list Status	IUCN Population Trend	IWPA Status	Citation
		Ladakh	Jammu and Kashmir	Himachal Pradesh	Uttarakhand	Sikkim	Arunachal Pradesh						
1	Bharal *(Pseudois nayaur)*	✓	✓	✓	✓	✓	✓	2500-5500	40-45	LC	Unknown	Sch I	Harris, 2014
2	Himalayan Ibex *(Capra sibrica)*	✓	✓	✓	0	0	0	2000-5300	100-130	NT	Decreasing	Sch I	Reading et al., 2020
3	Himalayan Tahr *(Hemitragus jemlahicus)*	0	✓	✓	✓	✓	0	2500-5000	30-35.2	NT	Decreasing	Sch I	Ale et al.,2020
4	Argali *(Ovis ammon)*	✓	0	✓	✓	✓	0	3000-5300	160-180	NT	Decreasing	Sch I	Reading et al., 2020
5	Ladakh Urial *(Ovis vignei)*	✓	0	0	0	0	0	<4800	50-60	VU	Decreasing	Sch I	Michel & Ghoddousi,2020
6	Markhor *(Capra falconeri)*	0	✓	0	0	0	0	600-3600	35-41	NT	Increasing	Sch I	Michel & Rosen, 2015
7	Tibetan Wild Ass *(Equus kiang)*	✓	0	0	0	✓	0	4000-5200	250-275	NT	Stable	Sch I	Shah et al., 2015
8	Tibetan Antelope *(Pantholops hodgsoni)*	✓	0	0	0	0	0	3000-6000	25-27.5	NT	Increasing	Sch I	IUCN SSC Antelope Specialist Group. (2016)
9	Himalayan Musk Deer (*Moschus leucogaste)*	✓	✓	✓	✓	✓	0	2915-4000	7-15	EN	Decreasing	Sch I	Timmins and Duckworth, 2015
10	Alpine Musk Deer *(Moschus chryogaster)*	0	0	0	0	✓	✓	3730-4227	11-12	EN	Decreasing	Sch I	Harris, 2016
11	Kashmir Musk Deer *(Moschus cupreus)*	✓	✓	0	0	0	0	3000-3500	11-12	EN	Decreasing	Sch I	Timmins and Duckworth, 2015
12	Black Musk Deer *(Moschus fuscus)*	0	0	0	0	✓	✓	2600-4200	10-15	EN	Decreasing	Sch I	Wang and Harris, 2015
13	Tibetan Gazelle	✓	0	0	0	✓	0	4500-5500	20-25	NT	Decreasing	Sch I	IUCN SSC Antelope

1.4.3 State-Wise Prey Estimates

Ladakh supports the largest population of snow leopards in India, with approximately 25,308 km² of suitable habitat. The region hosts a diverse assemblage of wild ungulate species, including bharal, Asiatic ibex, Ladakh urial, Tibetan argali, kiang, Tibetan gazelle, Tibetan antelope (Chiru), and wild yak. Among these, bharal and Asiatic ibex are the most common, while other species exist in smaller, fragmented populations. Compared to other regions in Indian Himalaya, extensive research has been conducted to understand their ecology and status of mountain ungulates in the state. Earlier studies provided rough estimates, such as Fox et al. (1991) citing a minimum of 11,000 bharal and 200 individual of argali in Ladakh. Fox et al., 1991 estimated 6,000 Asiatic ibex in the region. The total urial population was estimated between 1,000 and 1,500 individuals (Fox et al. 1991; Mallon 1983, 1991). More recent surveys using robust methodologies report comparatively lower numbers of these species. Estimates of bharal are available from Changthang Cold Desert Wildlife Sanctuary with a reported density of 0.22 individuals per km² (CV 76.94) (Shrotriya et al., 2015).

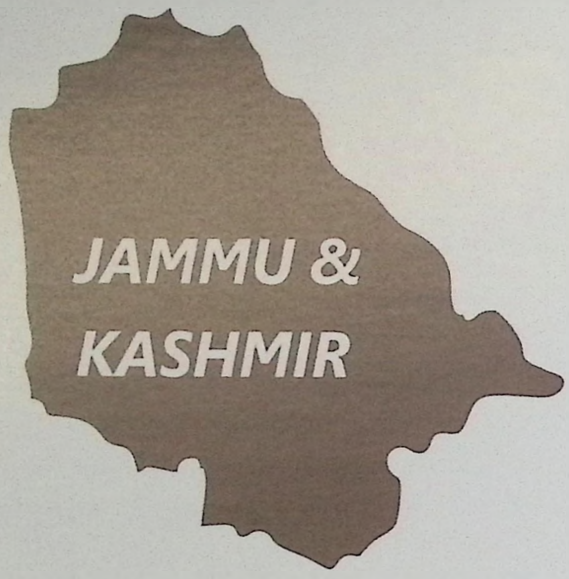
Raghavan et al. (2003) estimated the urial population in Hemis Stukpakchen, Ladakh, at approximately 690 individuals (range: 540–840) in 2002. Maheshwari et al., 2010 estimated a density of 0.09 individuals / km² in Boodkharbu and Kanji Wildlife Sanctuaries. More recently, Khara et al. (2021) estimated the urial population in the Upper Sham landscape at 355 individuals (95% CI: 355–389), with a density of 1.27 individuals/km². In the Heniskot-Lamayuru-Takmachik landscape, they recorded a population of 331 individuals (95% CI: 331–378), with a density of 0.96 individuals/km².

Changthang is the only region where Kiang are found and there is negligible presence of kiang outside the Changthang region. Bhatnagar et al. (2006) reported a mean density of 0.24 (± 0.44) individuals / km² for Kiang across Ladakh, with higher concentrations of up to 0.86 individuals /km² in the Loma-Demchok region of the Upper Indus Valley. Shrotriya et al. (2015) estimated a density of 0.86 per sq. km (CV%:42.37), which translates to total population of 4462 individuals in 5200 km² area.

Namgail et al (2009) estimated total population of argali in Ladakh to be 300-360 animals. NCF has stated an estimate of 600- 800 animals in India and 400-600 animals in eastern Ladakh (http://ncfindia.org/ projects/status-of-tibetan-argali). Tso Kar Basin population is possibly the largest in Ladakh with an estimated 120 argali. Shotriya et al., 2015 although believed to be an underestimation, estimated 0.02 (95% CI: 0-0.27) individuals /km², giving population estimate of 191 individuals for Ladakh.

Chiru and Tibetan gazelle are one of the least studied ungulates. The migratory nature and clumped distribution of the Tibetan Antelope complicate extrapolation and calculation of accurate population estimates, but recent assessment (UCN SSC Antelope Specialist Group. 2016; Ahmad unpub. 2024) sources agree that the population has been increasing. Rawat & Sankar, 2011 estimate a population of 20-30 chiru in Changchenmo Valley. Bhatnagar et al., 2006 surveyed the entire historic range of Tibetan gazelle in Ladakh and its presence was only

confirmed from Hanle valley where and estimated a population of ~ 50 individuals over a range of <100 km^2 and its status is believed to be declining (Bhatnagar et al., 2006). Wild yak occur seasonally in India and a maximum of 110 yak are known to occur in Changthang (Buzzard & Berger, 2016).



Jammu & Kashmir support an area of 12.700 Km^2 of snow leopard habitat. Potential prey for snow leopard in Jammu & Kashmir includes Asiatic ibex, musk deer, goral and markhor. The Asiatic ibex population in Jammu & Kashmir was estimated to be around 4,000 individuals on the southern side of the main Himalayan range (Fox et al., 1992).

The markhor is known to occur in the Hirpura and Kajinag areas of the Pir Panjal Mountains. A survey conducted between October 2004 and April 2005 in these area recorded 35 groups, comprising a total of 155 individuals (Ranjitsinh et al., 2005). Based on direct field observations and interviews with local informants, the estimated population in the surveyed areas ranged between 350–375 individuals. This estimate represents a slight increase from earlier population estimates of 200–300 individuals (Schaller, 1977; Fox & Johnsingh, 1997). The higher population estimate could be attributed to more comprehensive survey efforts compared to earlier studies, which relied on limited data from specific parts of the Kashmir Valley. Despite this localized increase, the

Table 3:
Camera Trap-Based Relative Abundance Index (RAI) of Potential Ungulate Prey in Jammu & Kashmir during the SPAI Survey.

Landscape	Species	No. of Detections	No. of Locations Detected at	Total no. of Cameras (trap nights)	Relative Abundance Index
Gurez	Asiatic ibex	45	9	30 (1350)	3.33
	Musk deer	61	14		4.52
Thajawas	Asiatic ibex	6	4	26 (1170)	0.51
	Musk deer	10	4		0.85
Warwan	Asiatic ibex	19	2	25 (1125)	1.69
	Musk deer	1	1		0.09
Kishtwar National park	Asiatic ibex	22	4	44 (1980)	1.11
	Musk deer	1	1		0.05
Paddar	Asiatic ibex	1	1	41 (1845)	0.08
	Musk deer	10	3		0.78

geographical range of the Markhor has significantly contracted over the decades. Historical records indicate that the species occupied approximately 300 km² in the late 1940s. However, by 2004–2005, this range had diminished to about 120 km² (Bhatnagar et al., 2009).

The recent SPAI survey in Jammu & Kashmir has provided valuable insights into the relative abundance of these ungulate species across snow leopard habitats (Table 3). However, significant knowledge gaps remain regarding the diet of snow leopards and population status of potential prey species in the state.

The snow leopard habitat in Himachal Pradesh span a significant portion of the Lahaul-Spiti and Kinnaur districts, covering an estimated 26,112 km² of suitable habitat. Bharal and Himalayan ibex serve as the primary prey species, while other potential prey includes the Himalayan tahr, musk deer, and goral. Earlier estimates of ungulate populations in the region are available for Himalayan ibex, bharal, and Himalayan tahr. In Pin Valley National Park, Pandey (1992) estimated an Ibex density of 2.3 individuals/km² in 1989, while Johnsingh et al. (1997) reported a lower density of 1.2 individuals/km². More recently, Suryawanshi et al. (2012) estimated a density of 0.37 ibex individuals/km². In Kibber Wildlife Sanctuary, ibex density was estimated at 0.11 individuals/km² (Suryawanshi et al., 2012). In the Lossar area of Spiti Valley, ibex density was recorded at 0.14 individuals/km² (Suryawanshi et al., 2012). Suryawanshi et al. (2012) also provided bharal density estimates for different regions of the Upper Spiti landscape: Kibber (1.60 individuals/km²), Tabo (1.49 individuals/km²), and Lingti (3.19 individuals/km²). A survey conducted between 1996 and 1998 in the Tirthan Valley of the Great Himalayan National Park identified 50 Himalayan tahr individuals (Vinod & Sathyakumar, 1999).

Recent estimates of ungulate populations were obtained from a systematic survey of snow leopard habitats during the SPAI survey (Table 4; Anon.2021). The study covered 10 sampled sites with a total area of 4,489 km². Surveys used double observer method to estimate the densities of ungulates. Bharal was recorded in Spiti, Tabo, Hangrang, and Baspa, whereas ibex was recorded in all sites except in Kullu, Tabo and Baspa. Tahr was recorded from Kullu and Bharmour regions. Camera trap recorded presence of musk deer from Baspa, Bharmour, Kullu, Bhaga, and goral from Bharmour and Kullu.

The highest wild prey density was recorded in Spiti (1.09 individuals/km²; 95% CI: 1.07–1.14), while the lowest was in Chandra (0.11 individuals/km²; 95% CI: 0.08–0.22). Solely for bharal, the site with the highest density was Spiti (0.99 individuals /km²; 95% CI 0.97– 1.04) and the lowest was Baspa (0.19 individuals/km²; 0.13 – 0.44). For ibex, the site with the highest density was Pin (0.75 individuals/km²; 95% CI: 0.75 – 0.86) and the lowest was Chandra (0.11 individuals/km²; 0.08–0.22). Himalayan tahr were recorded from Bharmour and Kullu where their density was estimated to be 0.54 individuals/km² (95% CI: 0.43-0.88) and 0.31 individuals /km² (0.23-0.64) respectively.

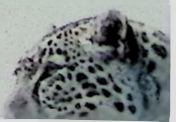


Table 4: Summary of double-observer surveys for estimating wild prey density in snow leopard habitats across 10 Sites in Himachal Pradesh (SPAI, Anon.2021, Himachal Pradesh).

Block	Year	Species	Effort (Km)	Area (Km^2)	Abundance (95% CI)	Density (95% CI)
Pin	2016	Ibex	45.5	298	224(224 -256)	0.75(0.75 -0.86)
Spiti	2017	Bharal	96.5	816	810(790 -850)	0.99(0.97 -1.04)
		Ibex			94(82 -127)	0.12(0.10 -0.16)
		Combined			891(872 -932)	1.09(1.07 -1.14)
Tabo	2017	Bharal	43.5	341	351(342 -392)	1.03(1.00 -1.15)
Hangrang	2017	Ibex	119.4	589	99(84 -156)	0.17(0.14 -0.26)
		Bharal			454(435 -505)	0.77(0.74.0.86)
		Combined			547(519 -600)	0.93(0.88 -1.02)
Bhaga	2018	Ibex	124	456	229(200 -290)	0.5(0.44 -0.64)
Miyar	2018	Ibex	88	604	164(142 -254)	0.27(0.23 -0.42)
Chandra	2018	Ibex	47.4	447	47(35 -100)	0.11(0.08 -0.22)
Baspa	2019	Bharal	66.2	480	93(62 -212)	0.19(0.13 -0.44)
Kullu	2019	Bharal	51.42	256	177(163 -229)	0.69(0.64 -0.89)
		Tahr			79(59 -163)	0.31(0.23 -0.64)
Bharmour	2019	Tahr	67.3	202	109(87 -177)	0.54(0.43 -0.88)
		Ibex			33(25 -81)	0.16(0.12 -0.40)

Uttarakhand provides an estimated 13,000 km^2 of potential habitat for the snow leopard. The primary prey species in the region include bharal, Himalayan tahr, and musk deer, while goral may occasionally contribute to the snow leopard's diet. Information on the status and distribution of these prey species remains fragmented across the state. Pindari Valley, Nanda Devi Biosphere Reserve was surveyed between 2007 and July 2009. The estimated density of bharal was 0.90 ± 0.37 individuals/km^2. Himalayan tahr population density varied seasonally, ranging from 2.18 ± 0.81 individuals/km^2 in spring to a significantly lower 0.22 ± 0.15 individuals/km^2 in winter (Kandpal, 2010).

In the Kedarnath Wildlife Sanctuary, previous surveys have documented changes in Himalayan Tahr populations. In the Kedarnath Wildlife Sanctuary, Sathyakumar (1994) recorded a density of 7 individuals/ km^2, while Kittur et al. (2006) reported a density of 10 individuals/ km^2 in the Tungnath region of the sanctuary. The musk deer population in Kedarnath Wildlife Sanctuary has been monitored for decades using the silent drive count method. Green (1985) estimated a density of 3.2 in 1979-81. Sathyakumar (1994) estimated musk deer density at 3.7 ± 0.2 individuals/km^2

(1989–1991). Subsequent surveys indicated a declining trend, with density estimates decreasing to 2.2 individuals/km² in 1994–1995 (Sathyakumar & Malik, unpubl. data) and further dropping to 1.2 individuals/km² in 2000 (Sathyakumar unpubl. data).

A 2016 survey of the Greater and Trans-Himalayan alpine regions employed the point count method to estimate Himalayan tahr and bharal populations across Uttarakhand (Habib et al., 2016). The total Himalayan tahr population was estimated at 297 individuals (range: 222–565) with a density of 0.32 individuals/km² (CV = 27.96%). The bharal population was estimated to be 8,549 individuals (range: 5,896–12,048), with a density of 0.99 individuals/km² (CV = 18.06%).

A more recent survey conducted in the trans-Himalayan landscape of Gangotri National Park employed camera trap distance sampling to estimate seasonal bharal densities (Pal et al., 2021). The density was found to be 0.5 individuals/km² (CV= 0.31) in summer and 0.6 individuals/km² (CV = 0.37) in winter. Additionally, musk deer population in the sub-alpine regions of Gangotri National Park and adjoining areas were estimated at 0.4 individuals/km² (CV = 0.34) in summer and 0.1 individuals/km² in winter (CV = 0.48) (Pal et al., 2021). Efforts to apply camera trap distance sampling to estimate ungulate densities in other snow leopard habitats across Uttarakhand during SPAI were unsuccessful due to low captures of species. The survey report includes capture rates of ungulates across different regions (Table 5).

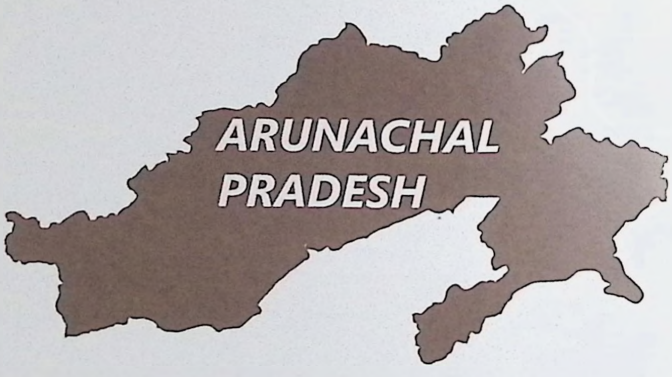
Table 5: Capture (No. of capture/ 100 trap nights ± Standard Error, No. of captures) rate of potential prey species captured during SPAI sampling in different high-altitude regions of Uttarakhand.

Area	Himalayan tahr	Bharal	Musk deer	Goral
Sumna -Niti	-	3.22 (±0.83) N=153	0.04 (±0.04) N=2	-
Mana	2.14 (±0.88) N=47	0.40 (± 0.23) N=11	-	-
Valley of Flowers, Nandadevi National Park & adjoining areas including Dronagiri, Jhelum, Kosa, Lata & Malari	1.06 (±0.73) N=29	0.50 (±0.41) N=15	0.72 (±0.43) N=23	0.38 (±0.25) N=5
Kedarnath Forest Division	1.56 (±0.68) N64	-	0.42 (±0.26) N=14	-
Govind National Park and Sanctuary	-	1.30 (±0.83) N=37	0.18 (±0.11) N=5	-
Gangotri National Park	1.18 (±0.92) 39	14.51 (±11.17) 267	1.78 (±0.99) 98	4.83 (±4.03) 117

The state of Sikkim encompasses approximately 3,031 km² of suitable habitat for snow leopards, supporting a diverse assemblage of prey species. These include bharal, Himalayan tahr, argali, kiang, musk deer, and Tibetan gazelle. However, information on the status and distribution of these potential prey species remains limited, with available data restricted to only two study areas.

In the Prek Chu catchment of the Khangchen-dzonga Biosphere Reserve, bharal density was estimated at 3.67 individuals/km² (SE: 0.78) in 2009 (Bhattacharya et al., 2010). The same study reported a density of 0.06 individuals/km² (SE: 0.05) for the musk deer.

Chanchani et al., 2010 surveyed the trans-Himalayan habitat of Sikkim, Tso Lhamo plateau during winter (December 2006–April 2007) and late summer (August–September 2007). The estimated argali density was 4.40 individuals/km² (SD: 3.45) in winter and 5.93 individuals/km² (SD: 5.03) in late summer. Similarly, the Tibetan gazelle was recorded at densities of 1.36 individuals/km² (SD: 1.99) in winter and 1.16 individuals/km² (SD: 1.75) in late summer. Information on other prey species remains limited to relative abundance estimates.



The snow leopard in Arunachal Pradesh has been reported only from the Tawang and Bomdila regions, despite its expected habitat (>3,000 m in elevation) spanning approximately 6,162 km². Among its potential prey species, only the bharal, goral, and musk deer (*Moschus* spp.) are known to inhabit these areas (Mishra et al., 2006). The state hosts two species of goral—the Red goral (*Naemorhedus baileyi*) and the Himalayan goral (*Naemorhedus goral*)—with additional occasional records of Chinese goral (*Naemorhedus griseus*) (SPAI, 2024). However, data on prey availability remain limited, primarily consisting of occurrence records, with only a few studies providing insights into relative abundance. Much work is required to understand the diet, prey status of snow leopard in Arunachal Pradesh.

1.4.4 Density information of potential prey of snow leopard

Among the snow leopard distributional range states in India, Himachal Pradesh emerges as the sole region where systematic, empirical surveys targeting the primary prey species of the snow leopard have been conducted. Nevertheless, status of musk deer and goral remain lacking. Comparable comprehensive assessments are notably deficient across other range states. Our study compiles available density estimates for these regions based on published literature.

Ladakh has a long history of ungulate monitoring, primarily due to its relatively better visibility and accessibility compared to other high-altitude landscapes. These factors have facilitated consistent research efforts in the region. Conversely, Arunachal Pradesh and Jammu & Kashmir remain significantly understudied, with limited data on ungulate populations. Addressing this research gap requires targeted scientific initiatives and the adoption of novel methodological approaches to overcome challenges related to rugged terrain, remoteness, and logistical constraints in studying prey species. Density estimates for ungulates are available for Uttarakhand and Sikkim, this information however remains fragmented and is largely restricted to localized habitats within the snow leopard's range. A more systematic and region-wide, assessment is necessary to improve our understanding of ungulate populations across these states.

Limited long-term data on prey populations indicate a general decline in ungulate numbers and habitat range across the Himalaya, with the notable exception of the Tibetan antelope (Chiru), which has shown recent population recovery. Historical records indicate that markhor occupied approximately 300 km^2 in the late 1940s. However, by 2004–2005, this range had diminished to about 120 km^2 (Bhatnagar et al., 2009), illustrating a substantial contraction of habitat over time. Similarly, long-term monitoring of the musk deer in Kedarnath Wildlife Sanctuary has revealed a steady decline in population density. Using the silent drive count method, Sathyakumar (1994) estimated musk deer density at 3.7 ± 0.2 individuals/km^2 between 1989 and 1991. Subsequent surveys reported a decline, with densities dropping to 2.2 individuals/km^2 in 1994–1995 (Sathyakumar & Malik, unpubl. data) and further decreasing to 1.2 individuals/km^2 by 2000 (Sathyakumar unpubl. data). A similar trend is observed in ibex populations in Pin Valley National Park, Himachal Pradesh. Pandey (1993) estimated an ibex density of 2.3 individuals/km^2 in 1989, while Johnsingh et al. (1997) reported a lower density of 1.2 individuals/km^2. More recent assessments by Suryawanshi et al. (2012) estimated a further decline, with an ibex density of 0.37 individuals/km^2, highlighting a continuing reduction over time. Methodological differences may limit the direct comparison of the ibex estimates.

1.4.5 Methodological advances in prey abundance techniques

Precise estimation of animal density is always a challenging task. This is particularly so in species that live in rugged and harsh terrain where there are many logistical challenges, and those challenges cause violation of assumptions of contemporary survey methodologies. Since the late 20th century, numerous studies have employed diverse methodologies to survey the population and distribution of mountain ungulates in the Indian Himalayan Region (IHR). These methodologies have evolved significantly over time, reflecting advancements in technology and analytical techniques to address challenges in estimating population densities and understanding ungulate distribution. During the 1980s and 1990s, early studies primarily relied on encounter rates (ER) and relative abundance indices (RAI). In the encounter rate method, observers traversed fixed transect lines to count individual ungulates or groups, providing basic estimates of abundance and baseline data on prey density and activity patterns (Bauer, et al. 1990). RAI, which became more widely adopted later in this period, calculated detections per unit effort, allowing researchers to compare ungulate presence across time and locations (Vinod & Sathyakumar, 1999). However, its inability to provide absolute density estimates highlighted the need for more advanced methodologies. To address these limitations, double-observer surveys were introduced in the late 1990s and refined in the 2000s. This method involved two groups of observer's independently recording sightings and crosschecking them to reduce detection biases. It proved particularly effective in varied terrain and vegetation, offering reliable density estimates while being cost-effective and less labor-intensive (Vinod & Sathyakumar, 1999;

Suryawanshi et al., 2012). As a result, double-observer surveys remain a valuable tool in recent ungulate studies.

Distance sampling, introduced in the 1990s, also gained prominence as a robust method for estimating prey densities. By modelling detection probabilities based on sighting distances, distance sampling provided reliable density estimates across varied habitats (Kandpal, 2010). Its affordability, simplicity, and effectiveness ensured its continued use in wildlife studies. Technological advancements in the 2000s further transformed ungulate surveys with the widespread adoption of camera traps. Their non-invasive nature and ease of use made them an invaluable tool for monitoring wildlife populations, especially cryptic or nocturnal species. Camera traps revolutionized density estimation and behavioral studies by minimizing disturbance to the animals. In 2017, the integration of camera traps with distance sampling modeling led to the development of camera trap distance sampling, combining the strengths of both approaches to enhance density estimation accuracy (Pal et al., 2021). Camera trap distance sampling can be analysed in Density surface modelling framework to extrapolate and generate landscape scale spatial density information of prey species (Miller et al., 2013).

The double observer method is currently the most well established technique for estimating mountain ungulate populations. However, its application remains limited to open habitats, particularly in trans-Himalayan landscapes. There is an urgent need to develop and standardize monitoring methods for mountain ungulates in rugged and subalpine habitats, where traditional techniques are often less effective. Recent studies suggest that camera trap-based methods could help overcome some of these limitations (Pal et al., 2021). However, further refinement is needed to adapt these methods to specific habitat types and species ecology in mountainous regions, ensuring their accuracy and reliability.

1.4.6 Trend in pattern of research on mountain ungulates

Research on mountain ungulates has spanned over a century, beginning in 1872. Studies witnessed a significant surge in the 1990s, followed by an exponential increase in recent decades (Fig. 4). This growth reflects a rising interest in understanding the ecology and conservation of mountain ungulates in the Himalayan region. A thematic analysis of the literature revealed that the majority of studies focused on status and distribution (Fig. 5). This was followed by research on habitat use, population monitoring, and human-wildlife interactions (Fig. 5). In contrast, other critical topics such as diet, diseases, ethology, conservation, and management received comparatively limited attention (Fig. 5). Spatial analysis further revealed that research efforts have been concentrated in specific hotspots within the Himalayan range, leaving vast areas with limited or no research coverage (Fig. 6). The highest number of studies were reported from Ladakh, followed by Himachal Pradesh, Uttarakhand, Sikkim, Jammu & Kashmir, and Arunachal Pradesh, in decreasing order (Fig. 6). Notably, Jammu & Kashmir and Arunachal Pradesh had relatively fewer studies on ungulates compared to other states, suggesting substantial gaps in research coverage.

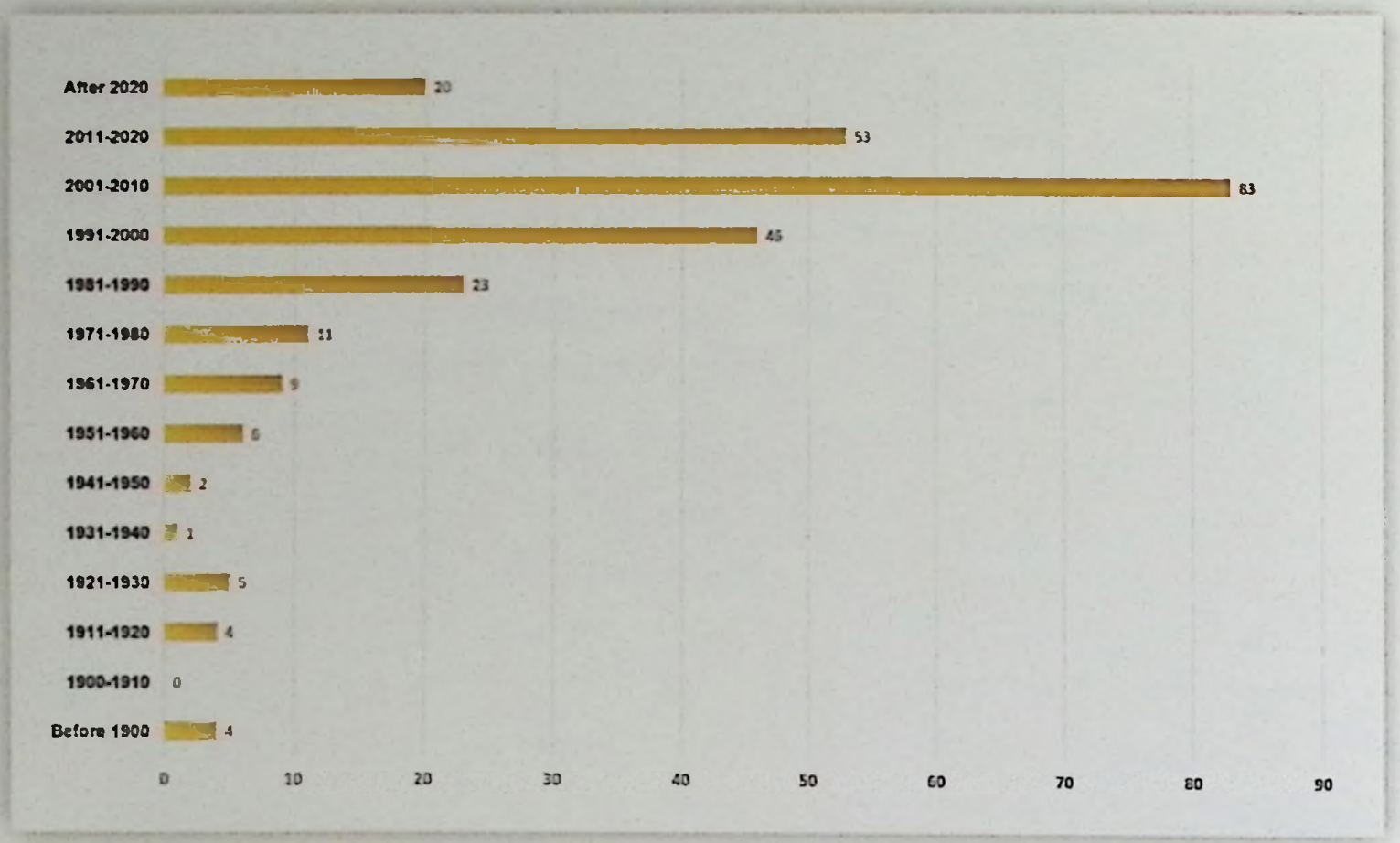


Fig. 4 Number of peer-reviewed publications on mountain ungulates, potential prey species of snow leopard, from 1872 to 2024.

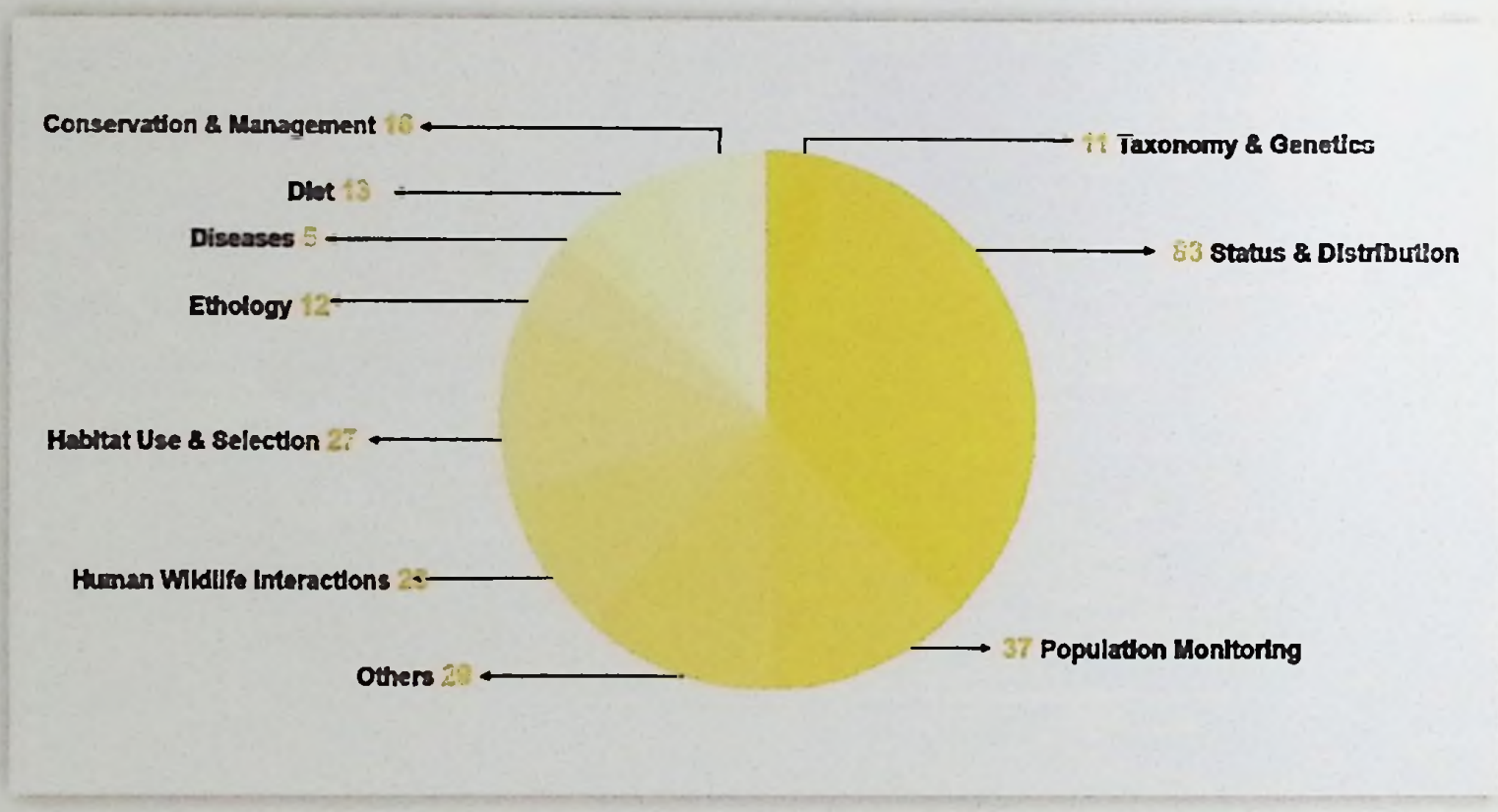


Fig. 5 Frequency of various themes of mountain ungulates research in the snow leopard range from 1872-2020.

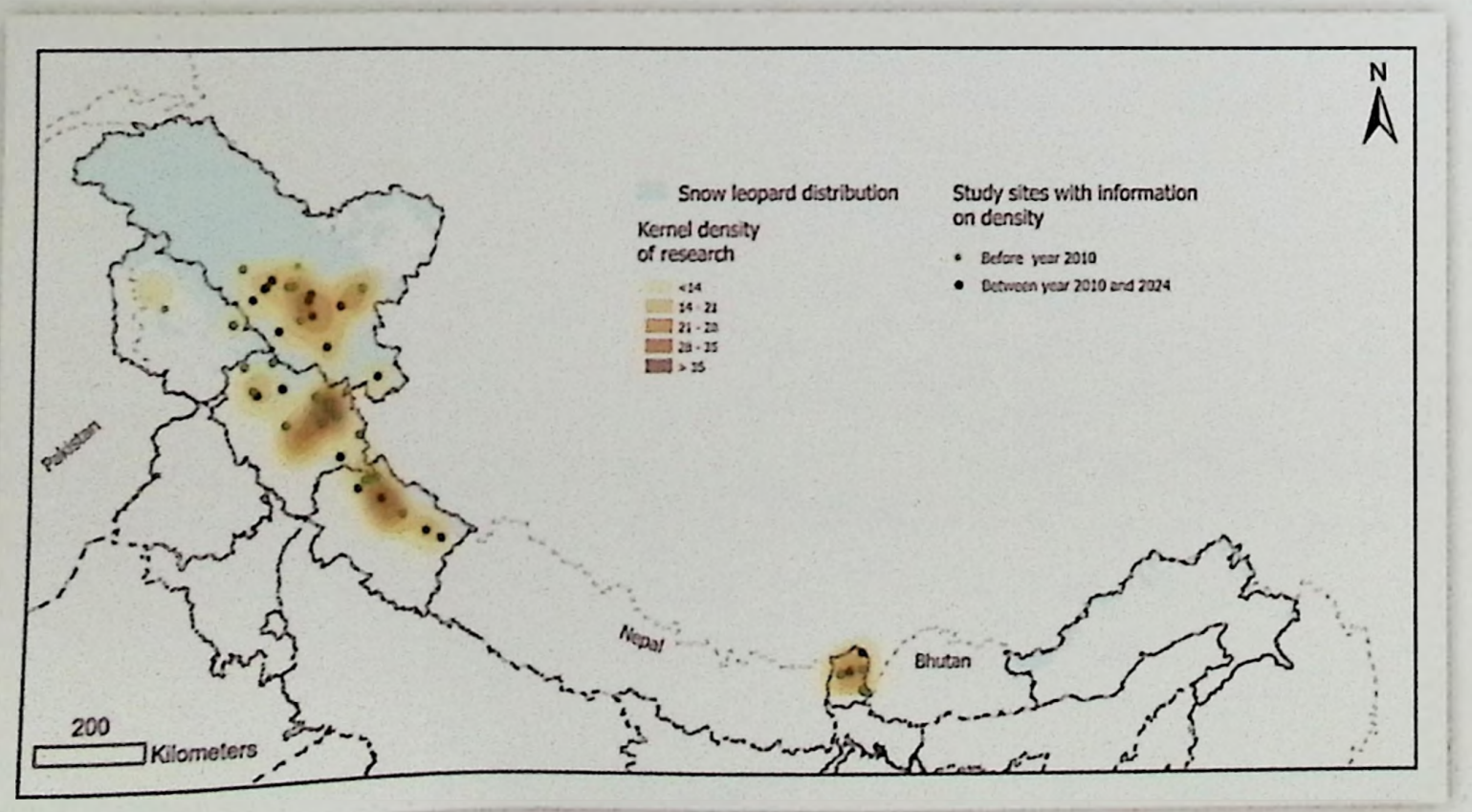


Fig. 6 Distribution of research on ungulates within the snow leopard range from 1872 to 2024. A few hotspots of research include Hemis National Park (Ladakh), Spiti Valley (Himachal Pradesh), and Kedarnath Wildlife Sanctuary and adjoining areas (Uttarakhand). The snow leopard range map was derived from the IUCN.

The mountain ungulate population across much of the snow leopard range is threatened by multiple threats of land use change, forage competition with livestock, diseases, hunting, and poaching. The compilation of density estimates and other research aspects on snow leopard prey species suggests that despite a notable increase in research efforts over the past few decades, several critical knowledge gaps persist. Reliable estimates of prey species remain incomplete, and their spatial variation across vast portions of the snow leopard's range has yet to be accurately mapped. Addressing these gaps requires a dedicated focus on standardized methodologies for density estimation, with an enhanced focus generating such information on large spatial landscapes. Given the importance of prey availability for sustaining viable snow leopard populations, further research is required to assess full spectrum of snow leopard diet and prey availability across the range and over different seasons. This knowledge is crucial for assessing current and future population dynamics, particularly in the context of emerging threats such as disease outbreaks, climate change, shifting human-livestock relationships, and increasing infrastructure development. Additionally, the potential influence of habitat quality, competition with livestock, and human-wildlife interactions on prey populations warrants further investigation. A more comprehensive understanding of these factors will be crucial for devising effective conservation strategies for the snow leopard and its prey and the ecological integrity of high-altitude ecosystems.

1.5 LIMITATIONS AND INFORMATION GAP

In all the states and UTs, the assessment of snow leopard populations is conducted through the deployment of camera traps within predetermined strata, as outlined in step I, with the aim of capturing spatial variations in population density. The placement of camera traps in all the states and UTs was conducted according to established methodologies. However, it should be mentioned that in Ladakh, a strategic modification was implemented to improve the accuracy of individual identification. Specifically, camera traps were mostly positioned to capture the forehead region of snow leopards, which is an effective method for individual identification (Alexander et al., 2015).

Given these findings, it is recommended that the camera traps may be placed to capture both the flanks and the forehead. Such an approach is expected to facilitate the identification of common individuals across the snow leopard range states and UTs, thereby contributing significantly to the establishment and maintenance of a comprehensive, long-term pan-India database for snow leopards in the future.

The elusive nature of snow leopard poses a significant limitation, as it makes direct observation and data collection challenging, resulting in relatively less precise information about their diet and ecological aspects compared to other large carnivores. While studies have

provided insights into their site-specific dietary habits influenced by prey availability, the lack of a comprehensive understanding across their entire range hampers efforts to accurately identify their prey preferences and adapt conservation strategies to varying landscapes.

Our assessment of research coverage on high-altitude ungulate species highlights several critical knowledge gaps that require urgent attention. To address these gaps, we propose the following priority areas for future research:

Understanding snow leopard diet and prey preferences: Snow leopard habitats is expected to vary across it distribution range due to diversity of prey species across it is extensive range in India. However, there is a notable lack of research on snow leopard diet composition in the Greater Himalayan landscape, particularly in Sikkim, Jammu & Kashmir and Arunachal Pradesh. Understanding dietary preferences and prey selection is fundamental to developing effective conservation strategies for snow leopards.

Advancing population density estimation techniques: The tools and techniques for estimating prey species density require significant refinement, particularly for species inhabiting rugged and closed habitats. While the double observer method has proven useful for estimating population densities in open landscapes, it is less effective in steep, forested, or inaccessible terrain. Additionally, certain species, such as the musk deer, exhibit nocturnal activity patterns, necessitating the development of specialized survey techniques to ensure accurate population assessments. Recent advancements in camera trap-based (for example: CTDS (Howe et al., 2017); REM (Palencia et al., 2022); REST (Garland et al., 2020)) density estimation have shown promise, but their applicability for large-scale monitoring require further validation.

Establishing long-term monitoring programs: Long-term ecological monitoring in priority landscapes is essential for tracking population trends in wild ungulates and livestock. Such programs can also help identify key drivers of population change, including climate change, habitat degradation, and anthropogenic pressures. While long-term monitoring efforts for snow leopards are already underway, a parallel effort is urgently needed to assess the status and population dynamics of their potential prey species. Integrating this data will provide critical insights for informed conservation strategies, allowing for evidence-based decision-making.

1.6 THE WAY FORWARD

Looking ahead, it is evident that India has made significant steps in snow leopard conservation. With approximately 34% of the habitat under legal protection and over 35,000 km^2 designated for landscape-level conservation, there is a strong foundation in place. However, India has moved towards participatory, landscape-based conservation projects after realising the limitations of exclusive protected areas and capacity restrictions. This shift is critical since about 70% of the land used by snow leopards is still unprotected and provides critical habitat for wildlife.

The mountain ungulate population across much of the snow leopard range is threatened by multiple threats of land use change, forage competition with livestock, diseases, hunting, and poaching. The compilation of density estimates and other research aspects on snow leopard prey species suggests that despite a notable increase in research efforts over the past few decades, several critical knowledge gaps persist. Reliable estimates of prey species remain incomplete, and their spatial variation across vast portions of the snow leopard's range has yet to be accurately mapped. Addressing these gaps requires a dedicated focus on standardized methodologies for density estimation, with an enhanced focus generating such information on large spatial landscapes.

Given the importance of prey availability for sustaining viable snow leopard populations, further research is required to assess full spectrum of snow leopard diet and prey availability across the range and over different seasons. This knowledge is crucial for assessing current and future population dynamics, particularly in the context of emerging threats such as disease outbreaks, climate change, shifting human-livestock relationships, and increasing infrastructure development. Additionally, the potential influence of habitat quality, competition with livestock, and human-wildlife interactions on prey populations warrants further investigation. A more comprehensive understanding of these factors will be crucial for devising effective conservation strategies for the snow leopard and its prey and the ecological integrity of high-altitude ecosystems.

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To strengthen conservation efforts, a deeper understanding of snow leopard dietary patterns across their range is necessary to identify prey preferences and optimize foraging strategies.

Ensuring connectivity between habitats is equally important, as ecological corridors allow for the free movement of snow leopards and their prey, preserving genetic diversity and population stability. By identifying high-priority regions capable of supporting prey biomass, these areas can serve as vital refuges for snow leopards and their prey.

Furthermore, establishing a dedicated Snow Leopard Cell at the Wildlife Institute of India under the MoEFCC is proposed, with a primary focus on long-term population monitoring, supported by well-structured study designs and consistent field surveys. Effective communication is crucial, reaching various segments of the local population, including communities, government departments, and developmental agencies, the military, and other stakeholders. Programs such as GSLEP, PSL and SPAI will play a crucial role in this regard.

Given that a significant portion of snow leopard habitat lies along international borders, the involvement of security forces is crucial. It is essential to provide proper training and sensitization program for conservation needs, and engage them through focussed programs to raise awareness and foster long-term cooperation for the conservation of critical snow leopard habitats.

Lastly, landscape-level management planning and coordination are essential for effective implementation and management. In order to identify biologically significant landscapes, a landscape-level strategy is required. The continuous creation of scientifically informed, collaborative, and landscape-based management plans is also an essential component of our conservation efforts.

REFERENCES

Ahmad, K., Ahmed, R., Nigam, P., & Thapa, J. (2017). Analysis of temporal population trend and conservation of Tibetan Antelope in Chang Chenmo Valley and Daulat Beg Oldie, Changthang, Ladakh, India. Antelope Specialist Group Newsletter GNUSLETTER, 34(2), 16-20.

Ahmad, S., Nabi, G., Hacker, C. E., Strelnikov, I. I., & Luan, X. (2022). Increasing threats to snow leopard survival in Pakistan. Frontiers in Ecology and Evolution,10, 818798.

Ale, S. B., Sathyakumar, S., Forsyth, D. M., Lingyun, X., & Bhatnagar, Y. V. (2020). *Hemitragus jemlahicus*. The IUCN Red List of Threatened Species 2020: e.T9919A22152905. https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T9919A22152905.en

Alexander, J.S., Cusack, J.J., Pengju, C., Kun, S. & Riordan, P. (2016). Conservation of snow leopards: spill-over benefits for other carnivores? Oryx, 50(2), 239-243.

Anon. (2021). Status of snow leopard and prey in Himachal Pradesh, 2021.Wildlife Wing - Himachal Pradesh Forest Department, Government of Himachal Pradesh, Shimla

Anwar, M.B., Jackson, R., Nadeem, M.S., Janec?ka, J.E., Hussain, S. (2011). Food habits of the snow leopard *Panthera uncia* (Schreber, 1775) in Baltistan, Northern Pakistan. European Journal of Wildlife Research 57: 1077-1083.

Augustine, B. C., Royle, J. A., Kelly, M. J., Satter, C. B., Alonso, R. S., Boydston, E. E., & Crooks, K. R. (2018). Spatial capture-recapture with partial identity: An application to camera traps. Annals of Applied Statistics, 12, 67-95.

Bagchi, S., & Mishra, C. (2006). Living with large carnivores: predation on livestock by the snow leopard (*Uncia uncia*). Journal of zoology, 268(3), 217-224.

Bandyopadhyay, M., Dasgupta, T. & Krishnamurthy, R. (2019). New records of snow leopard in Great Himalayan National Park, Western Himalaya. Cat News, 70,1-6.

Bashir, T. (2013). An assessment of abundance, habitat use and prey selection by Carnivores in Khangchendzonga Biosphere Reserve, Sikkim (Doctoral dissertation, Saurashtra University).

Bhatnagar, Y. V. (1997). Ranging and Habitat Use by Himalaya Ibex (*Capra ibex sibirica*) in Pin Valley National Park. Ph.D. Dissertation, Saurashtra University, Rajkot.

Bhatnagar, Y. V., Mishra, C., Peerzada, R. A., Trivedi, P., Raghunath, R. & Kaul, R. (2007). Conservation of the Markhor in Kashmir. Nature Conservation Foundation., Mysore, India.

Bhatnagar, Y. V., Wangchuk, R., & Mishra, C. (2006). Decline of the Tibetan gazelle *Procapra picticaudata* in Ladakh, India. Oryx, 40(2), 229-232.

Bhatnagar, Y. V., Wangchuk, R., Prins, H. H., Van Wieren, S. E., & Mishra, C. (2006). Perceived conflicts

between pastoralism and conservation of the kiang (*Equus kiang*) in the Ladakh Trans-Himalaya, India. Environmental Management, 38, 934-941.

Bhatnagar, Y.V., Ahmad R., Subba Kyarong S., Ranjitsinh, M.K., Seth, C.M., Ahmed Lone, I., Easa, P.S., Kaul, R. & Raghunath, R. (2009). Endangered markhor *Capra falconeri* in India: through war and insurgency. Oryx 43(3): 407-411. doi:10.1017/S0030605309001288.

Bhatnagar, Y.V., Mathur, V.B., Sathyakumar, S., Pal, R., Ghoshal, A., Sharma, R.K., Bijoor, A., Raghunath, R., Timbadia, R. & Lal, P. (2024). Securing India's snow leopards: Status, threats, and conservation. In Snow Leopards (pp. 513-529). Academic Press. DOI:10.1016/B978-0-323-85775-8.00003-0.

Bhatnagar, Y.V., Rana, B.S., Bhalla, K.K., Sharma, M.P., Rana, H.L., Singh, P. & Raghunath, R. (2008). Exploring the Pangi Himalaya: A Preliminary Wildlife Survey in the Pangi Region of Himachal Pradesh. Technical Report. The Wildlife Wing, Himachal Pradesh Forest Department & Nature Conservation Foundation, Mysore.

Bhattacharya, A., Chatterjee, N., Rawat, G.S. & Habib, B. (2020). Blue sheep resource selection in alpine grasslands of a western Himalayan landscape - a point process approach. Zoological Studies, 59, e11.

Bhattacharya, T., Bashir, T., Poudyal, K. A. M. A. L., Sathyakumar, S., Bisht, S., & Saha, G. K. (2010). Distribution, relative abundance and habitat use by mountain ungulates in Prek Chu catchment, Khangchendzonga Biosphere Reserve, Sikkim, India. Galemys, 22, 149-170.

Bhattacharya, T., Kittur, S., Sathyakumar, S. & Rawat, G.S. (2012). Diet overlap between wild ungulates and domestic livestock in the Greater Himalaya: implications for management of grazing practices. Proceedings of the Zoological Society, 65, 11-21.

Burnham, K.P. & Anderson, D.R. (2002). Model selection and multimodel inference: a practical information-theoretic approach. New York, NY: Springer.

Buzzard, P., & Berger, J. (2016). Bos mutus. The IUCN Red List of Threatened Species 2016: e.T2892A101293528. https://doi.org/10.2305/IUCN.UK.2016-2.RLTS.T2892A101293528.en

Chanchani, P., Rawat, G. S., & Goyal, S. P. (2010). Unveiling a wildlife haven: Status and distribution of four Trans-Himalayan ungulates in Sikkim, India. Oryx, 44(3), 366-375.

Chetri, M., Odden, M., & Wegge, P. (2017). Snow leopard and Himalayan wolf: food habits and prey selection in the Central Himalayas, Nepal. PloS one, 12(2), e0170549.

Chundawat, R. S., & Rawat, G. S. (1994). Food habits of snow leopard in Ladakh, India. In Proceedings of the 7th International Snow Leopard Symposium, International Snow Leopard Trust, Seattle, Washington, USA (pp. 127-132

Chundawat, R.S. (1992). Ecological studies on Snow leopard and its associated species in Hemis National Park, Ladakh. Ph.D. Thesis, University of Rajasthan, 166 pp. Duckworth, J.W. & MacKinnon, J. (2008). Naemorhedus goral. The IUCN Red List of Threatened Species 2008: e.T14296A4430073. . Accessed on 06 March 2025.

Ferretti, F., Lovari, S., Minder, I., & Pellizzi, B. (2014). Recovery of the snow leopard in Sagarmatha (Mt. Everest) National Park: effects on main prey. European Journal of Wildlife Research, 60, 559-562.

Fox, J. L., Nurbu, C., & Chundawat, R. S. (1991). The mountain ungulates of Ladakh, India. Biological Conservation, 58(2), 167-190.

Fox, J. L., Sinha, S. P. and Chundawat, R. S. (1992). Activity patterns and habitat use of ibex in the Himalaya Mountains of India. Journal of Mammalogy 73: 527-534.

Fox, J.L. & Johnsingh, A.J.T. (1997). India. In: D.M. Shackleton (ed.), Wild Sheep and Goats and their Relatives. Status Survey and Conservation Action Plan for Caprinae, pp. 215-231. IUCN/SSC Caprinae Specialist Group, Gland, Switzerland and Cambridge, UK

Fox, J.L., (1989). A Review of the Status and Ecology of the Snow Leopard *Panthera uncia*. International Snow Leopard Trust, Seattle, p. 40.

Fox, J.L., Sinha, S. P., Chundawat, R. S., & Das, P. K. (1988). A field survey of snow leopard presence and habitat use in northwestern India. In: Proceedings of the Fifth International Snow Leopard Symposium. International Snow Leopard Trust and Wildlife Institute of India, Seattle, Washington (pp. 99-111).

Fox, J.L., Sinha, S.P., Chundawat, R.S., Das, P.K. (1991). Status of the snow leopard *Panthera uncia* in Northwest India. Biological Conservation. 55, 283-298

Garland, L., Neilson, E., Avgar, T., Bayne, E., & Boutin, S. (2020). Random encounter and staying time model testing with human volunteers. The Journal of Wildlife Management, 84(6), 1179-1184.

Gaston, A. J., Garson, P. J., & Hunter Jr, M. L. (1983). The status and conservation of forest wildlife in Himachal Pradesh, Western Himalayas. Biological conservation, 27(4), 291-314.

Gaston, A. J., Hunter, M. L., & Garson, P. J. (1981). The wildlife of Himachal Pradesh, Western Himalayas. Report of the Himachal Wildlife Project. Technical Notes, (82).

Ghoshal, A., Bhatnagar, Y. V., Pandav, B., Sharma, K., Mishra, C., Raghunath, R., & Suryawanshi, K. R. (2019). Assessing changes in distribution of the Endangered snow leopard *Panthera uncia* and its wild prey over 2 decades in the Indian Himalaya through interview-based occupancy surveys. Oryx, 53(4), 620-632.

Green, M. J. B. (1988). Protected areas and snow leopards: their distribution and status. Pages 3-19 In: H. Freeman (ed.). Proceedings of the Fifth International Snow Leopard Symposium, Int. Snow Leopard Trust and Wildlife Institute of India. p. 269.

Green, M.J. B. (1985). Aspects of the ecology of the Himalayan musk deer. PhD. Dissertation, Cambridge University, p. 292.

Habib, B., Mohan, D., Bhattacharya, A., Shrotriya, S., Mondal, I., & Rawat, G. S. (2016). Status of wildlife in Trans-Himalayan regions of Uttarakhand. Report, 44pp.

Harris, R. (2016). *Moschus chrysogaster*. The IUCN Red List of Threatened Species 2016: e.T13895A61977139. https://doi.org/10.2305/IUCN.UK.2016-1.RLTS.T13895A61977139.en

Hobbs, R. J. (2002). Habitat networks and biological conservation. In Applying landscape ecology in biological conservation (pp. 150-170). Biological Conservation, K. J. Gutzwiller, Ed., New York, NY: Springer, 2002, pp. 150-170. ttps://doi.org/10.1007/978-1-4613-0059-5_9.

Howe, E. J., Buckland, S. T., Després?Einspenner, M. L., & Kühl, H. S. (2017). Distance sampling with camera traps. Methods in Ecology and Evolution, 8(11), 1558-1565.

IUCN SSC Antelope Specialist Group. (2016). *Procapra picticaudata* (Errata version published in 2017). The IUCN Red List of Threatened Species 2016: e.T18231A115142581. https://doi.org/10.2305/IUCN.UK.2016-3.RLTS.T18231A50192968.en

Jackson R. & Hunter D. O. (1996). Snow Leopard Survey and Conservation Handbook. 2nd edition. International Snow Leopard Trust, Seattle, Washington and U.S. Geological Survey, Fort Collins Science Center, Colorado. 154 pp

Jackson, R., Mallon, D., McCarthy, T., Chundaway, R. A., Habib, B., & Asadov, A. (2008). *Panthera uncia*. The IUCN Red List of Threatened Species 2008.

Johansson, Ö., McCarthy, T., Samelius, G., Andrén, H., Tumursukh, L., & Mishra, C. (2015). Snow leopard predation in a livestock dominated landscape in Mongolia. Biological Conservation, 184, 251-258.

Johnsingh, A. J. T., Rawat, G. S., Manjrekar, N., Bhatnagar, Y. V. and Stuwe, M. (1999). Ecology and conservation of Asiatic ibex, *Capra ibex sibirica*, in Pin Valley National Park, Himachal Pradesh, India. Dehradun, India: Wildlife Institute of India and US Fish and Wildlife Service.

Johnsingh, A.J.T. Mishra, C. and Bhatnagar, Y.V. (1997). Conservation status and research of mountain ungulates in India. Paper presented in the 2nd World Conference on Mountain Ungulates, Saint Vincent, Italy, 5-7 May, 1997. Abstracts.

Kandpal, V. (2010). Distribution and relative abundance of mountain ungulates in Pindari Valley, Nanda Devi Biosphere Reserve, Uttarakhand, India. Galemys, Spanish Journal of Mammalogy, 22(NE), 277-294.

Kandpal, V., Sathyakumar, S. (2010). Distribution and relative abundance of mountain ungulates in Pindari Valley, Nanda Devi biosphere reserve, Uttarakhand, India. Galemys, 22, 277-294.

Khanyari M., & Bhatt K. (2018) Rare sighting of Tibetan Argali in the Spiti Valley, Himachal Pradesh. Caprinae 1/2018: 15-16.

Khanyari, M., Oyanedel, R., Khara, A., Sharma, M., Milner-Gulland, E. J., Suryawanshi, K. R., Vineer H.R., & Morgan, E. R. (2024). Predicting and reducing potential parasite infection between migratory livestock and resident Asiatic ibex of Pin valley, India. Journal of biosciences, 49(2), 50.

Khara, A., Khanyari, M., Ghoshal, A., Rathore, D., Pawar, U. R., Bhatnagar, Y. V., & Suryawanshi, K. R. (2021). The forgotten mountain monarch? Understanding conservation status of the Vulnerable Ladakh urial in India. European Journal of Wildlife Research, 67, 1-10.

Kittur, S., Sathyakumar, S., & Rawat, G. S. (2010). Assessment of spatial and habitat use overlap between Himalayan tahr and livestock in Kedarnath Wildlife Sanctuary, India. European Journal of Wildlife Research, 56, 195-204.

Koetke, L., Bhattacharya, T. & Sathyakumar, S. (2020). Diet overlap between livestock and wild herbivores in the greater Himalaya. Mountain Research and Development, 40, R21- R27.

Lham, D., Cozzi, G., Sommer, S., Thinley, P., Wangchuk, N., Wangchuk, S., & Ozgul, A. (2021b). Modeling distribution and habitat suitability for the snow leopard in Bhutan. Frontiers in Conservation Science, 2, 781085.

Lham, D., Cozzi, G., Sommer, S., Wangchuk, S., Lham, K., & Ozgul, A. (2021). Ecological determinants of livestock depredation by the snow leopard *Panthera uncia* in Bhutan. Journal of Zoology, 314(4), 275-284.

Li, J., McCarthy, T. M., Wang, H., & Weckworth, B. V. (2016). Snow leopard survival strategy. Snow Leopard Trust, Seattle, USA.

Lovari, S., & Mishra, C. (2016). Living on the edge: depletion of wild prey and survival of the snow leopard. In Snow leopards (pp. 69-76). Academic Press.

Lovari, S., Boesi, R., Minder, I., Mucci, N., Randi, E., Dematteis, A., & Ale, S. B. (2009). Restoring a keystone predator may endanger a prey species in a human?altered ecosystem: the return of the snow leopard to Sagarmatha National Park. Animal Conservation, 12(6), 559-570.

Lyngdoh, S., Shrotriya, S., Goyal, S. P., Clements, H., Hayward, M. W., & Habib, B. (2014). Prey preferences of the snow leopard (*Panthera uncia*): regional diet specificity holds global significance for conservation. PloS one, 9(2), e88349.

Mackenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, I.I. & Hines, J.E. (2006). Occupancy estimation and modeling: Inferring patterns and dynamics of species occurrence. Academic Press, San Diego, USA.

Maheshwari, A., Sharma, D. & Sathyakumar, S. (2013). Snow leopard (*Panthera uncia*) surveys in the Western Himalayas, India. Journal of Ecology and The Natural Environment, 5, 303-309.

Maheshwari, A., Takpa, J., Sandeep, K., & Shawl, T. (2010). An investigation of carnivore-human conflicts in Kargil and Drass areas of Jammu and Kashmir. Report submitted to Rufford Small Grant, 23pp.

Mallon, D. P. (1983). The status of the Ladakh urial (*Ovis orientalis vignei*) in Ladakh, India. Biological Conservation 27: 373-381.

Mallon, D., Harris, R. B., & Wegge, P. (2016). Snow leopard prey and diet. In Snow leopards (pp. 43-55). Academic Press.

Mallon, D.P. (1991). Status and conservation of large mammals in Ladakh. Biological Conservation, 56, 101-119.

Mani, R. (1974). Biogeographic classification of India. Ecology, 55(2), 311-312.

McCarthy, T. M., & Chapron, G. (2003). Snow leopard survival strategy. International Snow Leopard Trust & Snow Leopard Network.

McCarthy, T., Mallon, D., Sanderson, E., Zahler, P., Fisher, K., McCarthy, K., & Seidensticker, J. (2017). *Panthera uncia* (errata version published in 2018). The IUCN Red List of Threatened Species, 2017.

Michel, S. & Ghoddousi, A. (2020). *Ovis vignei* (errata version published in 2021). The IUCN Red List of Threatened Species 2020: e.T54940655A195296049. . Accessed on 06 March 2025.

Michel, S., & Rosen Michel, T. (2015). *Capra falconeri* (errata version published in 2016). The IUCN Red List of Threatened Species 2015: e.T3787A97218336. https://doi.org/10.2305/IUCN.UK.2015-4.RLTS.T3787A82028427.en

Millennium Ecosystem Assessment (MEA). (2005). Ecosystems and human well-being: Biodiversity synthesis. World Resources Institute.

Miller, D. L., Burt, M. L., Rexstad, E. A., & Thomas, L. (2013). Spatial models for distance sampling data:

recent developments and future directions. Methods in Ecology and Evolution, 4(11), 1001-1010.

Mishra, C. (1997). Livestock depredation by large carnivores in the Indian trans-Himalaya: conflict perceptions and conservation prospects. Environmental Conservation, 24, 338- 343.

Mishra, C., Madhusudan, M. D., & Datta, A. (2006). Mammals of the high altitudes of western Arunachal Pradesh, eastern Himalaya: An assessment of threats and conservation needs. Oryx, 40(1), 29-35.

Mishra, C., Van Wieren, S. E., Ketner, P., Heitkönig, I. M. A., & Prins, H. H. T. (2004). Competition between domestic livestock and wild bharal (*Pseudois nayaur*) in the Indian Trans-Himalaya. Journal of Applied Ecology, 41(2), 344-354.

MoEF & CC. (2019). Snow leopard population assessment in India: Population assessment of the world's snow leopards. Ministry of Environment, Forest and Climate Change; Wildlife Institute of India; Nature Conservation Foundation-Snow Leopard Trust; and Global Snow Leopard and Ecosystem Protection Program-PAWS Advisory Panel.

Morin, D.J., Fuller, A.K., Royle, J.A. & Sutherland, C. (2017). Model-based estimators of density and connectivity to inform conservation of spatially structured populations. Ecosphere, 8, e01623.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), 853-858.

Namgail, T. (2004). Interactions between argali and livestock, Gya-Miru wildlife sanctuary, Ladakh, India. Final Project Report. International Snow Leopard Trust, Seattle, WA, USA.

Namgail, T., Fox, J. L., & Bhatnagar, Y. V. (2009). Status and distribution of the Near Threatened Tibetan argali (*Ovis ammon hodgsoni*) in Ladakh, India: Effect of a hunting ban. Oryx, 43(2), 288-291.

Namgail, T., Van Wieren, S. E., Mishra, C., & Prins, H. H. T. (2010). Multi-spatial co-distribution of the endangered Ladakh urial and blue sheep in the arid Trans-Himalayan mountains. Journal of Arid Environments, 74(10), 1162-1169.

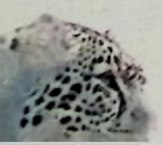
Olson, D. M., & Dinerstein, E (1998). The Global 200: A Representation Approach to conserving the Earth's most biologically valuable ecoregions. Conservation Biology, 12(3), 502-515.

Pal, R., Arya, S., Thakur, S., Mondal, K., Bhattacharya, T. & Sathyakumar, S (2016). Bibliography on the mammals of the Indian Himalayan region. In: Sathyakumar, S. (Ed.), Bibliography on the Fauna and Microflora of the Indian Himalayan Region. Wildlife Institute of India, Dehradun, pp. 10-52.

Pal, R., Bhattacharya, T., Qureshi, Q., Buckland, S. T., & Sathyakumar, S. (2021). Using distance sampling with camera traps to estimate the density of group-living and solitary mountain ungulates. Oryx, 55(5), 668-676.

Pal, R., Khanyari, M., Aguilar, X. F., Nigam, P., Sambandam, S., (2023). Infectious keratoconjunctivitis in Asian Mountain ungulates. Caprinae 1/2023: 7-10.

Pal, R., Panwar, A., Goyal, S. P., & Sathyakumar, S. (2022). Changes in ecological conditions may influence intraguild competition: inferring interaction patterns of snow leopard with co-predators. PeerJ, 10, e14277.



Pal, R., Sutherland, C., Qureshi, Q. & Sathyakumar, S. (2022). Landscape connectivity and population density of snow leopards across a multi-use landscape in Western Himalaya. Animal Conservation, 25(3), 414-426.

Pal, R., Thakur, S., Arya, S., Bhattacharya, T., & Sathyakumar, S. (2021). Mammals of the Bhagirathi basin, Western Himalaya: understanding distribution along spatial gradients of habitats and disturbances. Oryx, 55(5), 657-667.

Palencia, P., Barroso, P., Vicente, J., Hofmeester, T. R., Ferreres, J., & Acevedo, P. (2022). Random encounter model is a reliable method for estimating population density of multiple species using camera traps. Remote Sensing in Ecology and Conservation, 8(5), 670-682.

Pandey, S. (1992). Estimation of density of ibex (*Capra ibex* Linn.) in Pin Valley National Park, Himachal Pradesh. Journal of the Bombay Natural History Society, 89(3), 361-363.

Raghavan, B., Bhatnagar Y.V., Qureshi, Q. (2003). Interactions between Livestock and Ladakh Urial (*Ovis vignei vignei*). Final Report. Wildlife Institute of India.

Ranjitsinh, M. K., Seth, C. M., Ahmad, R., Bhatnagar, V. Y. & Kyarong, S. S. (2005). Goats on the border: A rapid assessment of the Pir Panjal Markhor in Jammu and Kashmir: Distribution, status and threats. Wildlife Trust of India, New Dehli, India.

Rawat, G.S. & Sankar, K. (2011). Habitat Ecology and Conservation Status of Wild Ungulates in Northern Parts of Changthang Wildlife Sanctuary, Ladakh. Wildlife Institute of India.

Reading, R., Michel, S. & Amgalanbaatar, S. (2020). Ovis ammon. The IUCN Red List of Threatened Species 2020: e.T15733A22146397. Accessed on 06 March 2025.

Rodgers, W. A., & Panwar, H. (1988). Biogeographical Classification of India. Oxford University Press.

Rodgers, W. A., Panwar, H.S. & Mathur, V.B. (2000). Wildlife Protected Area Network in India: A Review. Wildlife Institute of India.

Royle, J. A., & Young, K. V. (2008). A hierarchical model for spatial capture-recapture data. Ecology, 89(8), 2281-2289.

Royle, J.A., Sutherland, C., Fuller, A.K. & Sun, C.C. (2015). Likelihood analysis of spatial capture-recapture models for stratified or class structured populations. Ecosphere, 6(2),1-11.

Sathyakumar, S. & Bhatnagar , Y.V. (2002). Envis Bulletin: Wildlife and Protected Areas- Mountain ungulates, Wildlife Institute of India, Dehradun, pp.128.

Sathyakumar, S. (1993). Status of mammals in Nanda Devi National Park. Scientific and ecological expedition on Nanda Devi. Wildlife Institute of India, Dehradun, pp. 5-15.

Sathyakumar, S. (1994). Habitat ecology of ungulates in Kedarnath Musk Deer Sanctuary. Ph.D. Dissertation, Saurashtra University, Rajkot, p. 244.

Sathyakumar, S. (2002). Species of the greater Himalaya. In: S. Sathyakumar (ed.), ENVIS Bulletin: Wildlife and Protected Areas, Wildlife Institute of India, Dehradun, pp. 44-49.

Sathyakumar, S. (2003). Conservation status of Mammals and Birds in Nanda Devi National Park: An assessment of changes over two decades, pp. 1-14. In: Biodiversity Monitoring Expedition Nanda Devi 2003. A report.

Sathyakumar, S., Bhattacharya, T., Bashir, T. & Poudyal, K. (2014). Developing a monitoring programme for mammals in Himalayan protected areas: a case study from Khang- chendzonga National Park and biosphere reserve, Sikkim, India. Parks 20, 35-48.

Sathyakumar, S., G.S. Rawat & A.J.T. Johnsingh. (2015). Himalayan tahr (*Hemitragus jemlahicus*) In Mammals of South Asia, Vol. 2. In A.J.T. Johnsingh and Nima Manjrekar (Eds.). pp 385-408. Universities Press.

Sathyakumar, S., G.S. Rawat & A.J.T. Johnsingh. (2015). Musk deer (*Moschus* Spp.) In Mammals of South Asia, Vol. 2. In A.J.T. Johnsingh and Nima Manjrekar (Eds.). pp 42-172. Universities Press.

Schaller, G. B. (1977). Mountain monarchs: Wild sheep and goats of the Himalaya. The University of Chicago Press, Chicago.

Schaller, G.B. & Liu, W.L. (1996). Distribution, status, and conservation of wild yak Bos grunniens. Biological Conservation 76: 1-8.

Sharma, R.K., Sharma, K., Borchers, D., Bhatnagar, Y.V., Suryawanshi, K.R., & Mishra, C. (2021). Spatial variation in population-density of snow leopards in a multiple use landscape in Spiti Valley, Trans-Himalaya. PLoS One, 16, e0250900.

Shrotriya, S., Reshamwala, H. S., Lyngdoh, S., Jhala, Y. V., & Habib, B. (2022). Feeding patterns of three widespread carnivores-the wolf, snow leopard, and red fox-in the Trans-Himalayan landscape of India. Frontiers in Ecology and Evolution, 10, 815996.

Shrotriya, S., Reshamwala, H. S., Mahar, N., Habib, B., Suhail, I., & Takpa, J. (2015). Distribution and Population Estimation of Ungulates in Changthang Region, Ladakh, Jammu & Kashmir (p. 15). India. Technical Report-Wildlife Institute of India and Department of Wildlife Protection, Govt. of J&K.

Suryawanshi, K. R., Bhatnagar, Y. V., & Mishra, C. (2012). Standardizing the double-observer survey method for estimating mountain ungulate prey of the endangered snow leopard. Oecologia, 169, 581-590.

Suryawanshi, K., Reddy, A., Sharma, M., et al. (2021). Estimating snow leopard and prey populations at large spatial scales. Journal of Wildlife Management, 1-13.

Suryawanshi, K., Reddy, A., Sharma, M., Khanyari, M., Bijoor, A., Rathore, D., Jaggi, H., Khara, A., Malgaonkar, A., Ghoshal, A. & Patel, J. (2021). Estimating snow leopard and prey populations at large spatial scales. Ecological Solutions and Evidence, 2, e12115.

Sutherland, C., Royle, J. A., & Linden, D. W. (2019). oSCR: a spatial capture-recapture R package for inference about spatial ecological processes. Ecography, 42(9), 1459-1469.

Thapa, K., Schmitt, N., Pradhan, N. M., Acharya, H. R., & Rayamajhi, S. (2021). No silver bullet? Snow leopard prey selection in Mt. Kangchenjunga, Nepal. Ecology and Evolution, 11(23), 16413-16425.

Timmins, R. J., & Duckworth, J. W. (2015). *Moschus leucogaster*. The IUCN Red List of Threatened Species 2015: e.T13901A61977764. https://doi.org/10.2305/IUCN.UK.2015-2.RLTS.T13901A61977764.en

Ul-Haq, S. (2003).Mountain ungulates of Ladakh, Jammu, and Kashmir. In: S. Sathyakumar and Y. V. Bhatnagar (eds), ENVIS Bulletin: Wildlife and Protected Areas, pp. 27-33.

Vinod, T. R. & Sathyakumar, S. (1999). Ecology and conservation of mountain ungulates in Great Himalayan National Park, western Himalaya. An ecological study of the conservation of biodiversity and biotic pressures in the Great Himalayan National Park Conservation Area - an ecodevelopment approach. FREEP-GHNP 03/10

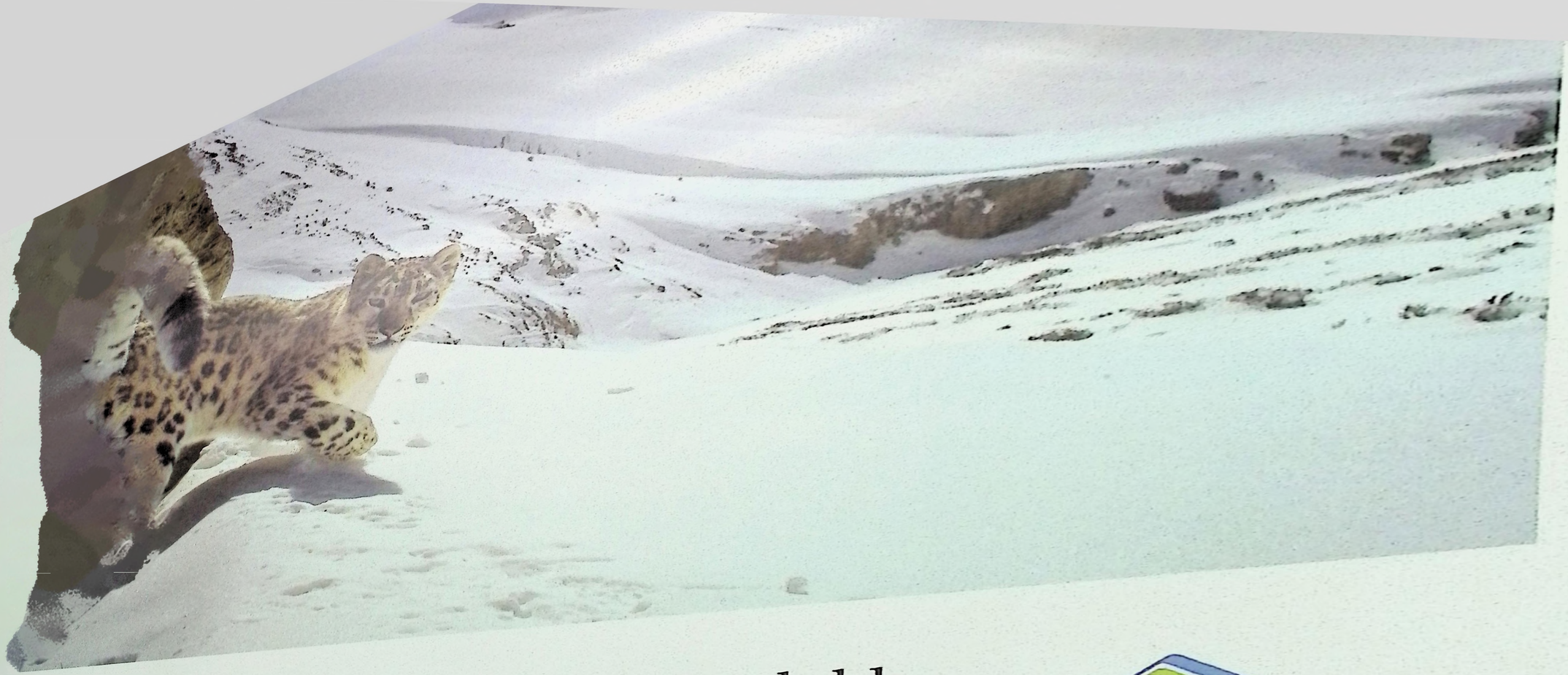
Wang, Y., & Harris, R. (2015). Moschus fuscus. The IUCN Red List of Threatened Species 2015: e.T13896A61977357. https://doi.org/10.2305/IUCN.UK.2015-4.RLTS.T13896A61977357.en

Wangdi, T., Tobgay, S., Dorjee, K., Dorji, K., & Wangyel, S. (2019). The distribution, status and conservation of the Himalayan Musk Deer *Moschus chrysogaster* in Sakteng Wildlife Sanctuary. Global Ecology and Conservation, 17, e00466.

Wegge, P., Shrestha, R., & Flagstad, Ø. (2012). Snow leopard *Panthera uncia* predation on livestock and wild prey in a mountain valley in northern Nepal: implications for conservation management. Wildlife Biology, 18(2), 131-141.

World Bank. (2013). Himalayan Ecosystems: Providing Water, Sustaining Livelihoods. World Bank.

(Appendix I)



Status of snow leopards in Ladakh

Department of Wildlife Protection
UT Ladakh

NMHS
National Mission on
Himalayan Studies

Status of snow leopards in Ladakh

Department of Wildlife Protection
UT Ladakh

सत्यमेव जयते

NMHS
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Jhala Y. V. (2023) Status of snow leopards in Ladakh.
Department of Wildlife Protection, Union Territory of Ladakh, India.

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Photo repository of individually identified snow leopards in Ladakh

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- Changthang 43
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- Kargil 61
- Nubra 73

1

>6,600 km trails surveyed to record snow leopard signs

2

Cameras deployed at **956** locations, for **97,313** trap nights, effectively sampled **8,604** km²

3

Around **35,100** km² area sampled for snow leopard occupancy, prey and habitat

4

4.5 lakh camera trap photographs, representing **97** species of mammals and birds in Ladakh

5

Snow leopard occupancy recorded in **25,303** km² and estimated presence in **47,572** km²

6

159 unique snow leopards photographed. Population estimated to be **477** (±51) in entire occupied habitat of Ladakh

Occurrence and abundance of Snow Leopards in Ladakh

Executive Summary:
The status of snow leopards are indicators of intact functional ecosystems and sustainable human-nature. The snow leopard symbolizes thriving ecosystems and human-nature relationships in the Himalayan and Trans-Himalayan regions. Its survival is challenged by ongoing climatic and land use changes, as well as unsustainable harvest of wildlife. To protect snow leopards and their ecosystems from these anthropogenic impacts, it is critical to assess their population status at landscape scales and devise evidence-based conservation strategies. India's largest snow leopard habitat occurs in Ladakh. Its distribution and abundance remained unassessed due to challenging terrain, untrained human resources, and inefficient scientific approaches. Present study addresses this lacuna and presents the first scientific population assessment of snow leopards at landscape scale in Ladakh which can be emulated in other areas for robust scientific assessment.

The assessment was conducted in three distinct phases. Phase I involved intensive occupancy survey across 35,000 km^2 areas with data collected digitally using smart mobile application and conducted by trained local naturalists and researchers. Phase II involved large-scale intensive camera trapping across 8,604 km^2, to photo-capture and identify individual snow leopards using fore-head pattern recognition program. Phase III integrated data from occupancy and camera trap surveys to estimate the population and the area occupied by snow leopard. This survey marks a pioneering initiative, being the first of its kind and the largest intensive survey conducted for snow leopards. The assessment revealed snow leopard population of 477 (±51), occurring in 47,572 km^2 areas. Snow leopard occurrence was higher in areas with abundant prey species, moderate elevation, and in areas of less dense human habitation.

With the current population, Ladakh houses one of the world's largest strongholds of snow leopards. The distribution maps, snow leopard photo-data archive, biodiversity status generated using mobile apps, and scientific process developed and tested in this assessment are vital outcomes of this study. It not only provides essential foundation for strategic conservation investments but also offers a model process for other regions to conduct scientific population assessments in similar systems. Importantly the study underscores the sustenance of a key charismatic flagship species within fragile socio-ecological systems of Himalaya and Trans-Himalaya, providing timely hope and rekindling conservation optimism in our rapidly changing world.

Snow leopard population assessment in Ladakh

The snow leopard (*Panthera uncia*) is a vital part of India's natural heritage and culture, and a symbol of thriving ecosystems and human-nature relationship. It is distributed in the Himalayan and the trans-Himalayan landscapes of India, with the largest habitat in the Ladakh region. Snow leopards are iconic species that symbolise the unique and beautiful ecosystems they inhabit, and a culture of land sharing with human societies. Known for its shy and elusive behaviour and an almost mythical ability to blend into the rocky vastness it inhabits, snow leopard has earned the label of "Ghost of the Mountains".

To survive in this extreme environment, snow leopards have evolved adaptations to combat low temperatures and hunt steep heterogeneous slopes in high-altitude landscapes. The snow leopard is the smallest of the big cats in the genus Panthera, and like the other big cats, it hunts by stalking and exhibits territorial behaviour. Although the snow leopard is the smallest of the big cats, it is the largest/dominant predator of high-altitude mountain ecosystems. The snow leopard is the apex predator and is the keystone species in the habitats in which it thrives. Snow leopards share these landscapes with different prey species, including mountain ungulates, domestic livestock, smaller mammals, and birds (Schaller 1977). The two most frequently reported prey species for snow leopards are blue sheep (*Pseudois nayaur*) and Siberian ibex (*Capra sibirica*) (McCarthy & Mallon 2016). In regions like Ladakh that support eight species wild mountain ungulates, snow leopards can prefer diverse prey based on their relative availability. These herbivore species are dependent on abundance of nutritious forage, which is in turn dependent on the climatic patterns and hydrological regimes. Thus, snow leopard sustenance represents a thriving ecological chain has it has hence emerged as a flagship species for the conservation of fragile mountain ecosystems.

Climatic changes and increasing human population are rapidly changing ecosystems globally. Cold regions like the Himalaya are witnessing rapid warming and the glaciers are retreating changing the hydrological regimes. This can distort the dependent ecosystems and have far reaching consequences on ecosystem services and people dependent on it. It can certainly influence the sustenance of snow leopards. Moreover, illegal trade, poaching, and killings continues threatening snow leopards, with an estimate of 221-450 snow leopards poached annually across the world (Nowell et al. 2016). The IUCN lists snow leopards as a vulnerable species. Abating and mitigating these threats necessitate proactive monitoring of snow leopard populations and strategic protection regimes, which in turn necessitates precise population estimation at a landscape level. However, less than 1% of the snow leopard range had peer reviewed abundance and population estimate (Suryawanshi et al. 2019), and a national estimation of snow leopards in India is yet to be conceived.

The knowledge about the ecology of the snow leopard is limited due to the harshness of the habitat that it inhabits and the lack of infrastructure and trained scholars, along with the paucity of funds for the conservation of these habitats. There are significant gaps in the knowledge about the distribution, population status, ecology, and behaviour of this charismatic species in the trans-Himalayan region of Ladakh and elsewhere. Most of the studies of snow leopards are constrained by their spatial scale, where only a limited area is intensively sampled, or where the resolution of sampling is extremely diluted. Often indirect evidence of snow leopards gathered by interviewing people is used to understand species occurrence, which is ineffective in monitoring real-time changes in population and its precise spatial variability. There is an urgent need to design and conduct precise population estima-

tion at landscape level, without compromising on spatial resolution and quality of information. India's tiger population assessment, which is world's largest wildlife survey can be an inspiration for adapting to the context of snow leopard landscapes and institutionalize for long-term application. Such approach will add to our knowledge on snow leopard ecology, their populations, and help prioritise conservation interventions to manage these unique ecosystems.

The current study aims to implement snow leopard population estimation in the largest prime habitat in India, i.e. Ladakh landscape. We use advance techniques like mobile applications for assisting ground sampling and transparency in data archiving, machine learning in identification of individual snow leopards, big data framework for statistical analysis and evidence-based inferences. The study is timely as it will aid in the effective management and preservation of snow leopards in Ladakh and serve as a benchmark for similar assessment and monitoring in other regions in India and beyond.

Study Area

The snow leopard range from '...southern Siberia in the north across a broad arc including the mountains of Central Asia, the Tibetan Plateau and ending in the Himalayas in the south and east' (McCarthy and Mallon 2016). In 2008, the Snow Leopard Range-wide Assessment and Conservation Planning workshop was held in China, where 3,256,841 km^2 of potential snow leopard range were formally identified across nine ecological spectrum that include Altai-Sayan, Trans-Altai Alashan Gobi, Tian Shan, Pamirs, Hindu-Kush, Karakoram, Himalayas, Hengduan, and Tibetan Plateau. In 2008, experts stated that snow leopard occurrence was certain in only 27% of the 3.26 million km2 potential geographical range. This area was further divided into 69 Snow Leopard Conservation Units (SLCUs) with a combined area of about 1.2 million km2, or about 38% of the potential range (McCarthy & Mallon 2016). Of these 69 SLCUs, three fall within the proposed study area in India: The Western Tibetan Himalayas, India Zanskar (south of the Indus), and India Nubra region, which together constitute 80,808 km^2 of prime snow leopard habitat, part of which was taken as study area for the current study.

The Trans-Himalayan region of India is the country's northernmost area (33-35 N, 76-79 E). It is a high-elevation, dry land of rugged mountains and open plains north of the main Himalayas. The trans-Himalayan landscape in India spans over 186,000 km^2 shared between two union territories and three states on the northern boundary of the country, viz., Jammu and Kashmir and Ladakh UT, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh State. Trans-Himalaya in India includes Leh and Kargil districts, Parts of Jammu and Kashmir, Spiti valley (Himachal Pradesh), parts of Uttarkashi, Chamoli and Pithoragarh districts (Uttarakhand), Tso-Lhamo region of north Sikkim district (Sikkim) and Tawang district (Arunachal Pradesh). Indian Trans-Himalayan region is one of the least populated areas, with a human density of 2.5/km^2 (Fox & Chundawat 1995). Except for Kashmir, the entire area falls in the rain shadow of the Himalayas, and annual precipitation ranges from 500-1000 mm in valleys just north of the high Himalayan ranges to approximately 100 mm in the central Trans-Himalayan valleys. The elevation of the area ranges from 1800 m to more than 7000 m above mean sea level.

The landscape witnesses an east to west gradient in decreasing above ground productivity with increasing cold aridity. Valleys are in general moist and dominated with higher plant cover. Vegetation is predominantly dry alpine steppe consisting of widely spaced shrubs or subshrubs, including pea-shrub (*Caragana spp.*), worm-wood (*Artemisia spp.*), woundwort (*Stachys spp.*), and ephedra (*Ephedra gerardiana*), with buckthorn (*Hippophae salicifolia*), willow (*Salix spp.*), wild rose (*Rosa webbiana*), myricaria (*Myricaria elegans*), poplar (*Populus spp.*), and birch trees (*Betula spp.*) along river courses. The meadows in valley bottoms were dominated by sedges Carex spp. and Kobresia spp.

Within the dry Trans Himalayan parts, eight species of wild ungulates are present and provide the main source of wild prey for predators. Blue sheep and Asiatic Ibex are the most common wild ungulates; small populations of Ladakh urial (*Ovis vignei vignei*), Tibetan argali (*Ovis ammon hodgsoni*), Kiang (*Equus hemionus kiang*), Tibetan gazelle (*Procapra picticaudata*), Tibetan antelope (*Pantholops hodgsoni*) and wild yak (*Bos grunniens*) are also present (Chundawat & Qureshi 1999). Marmot (*Marmota bobak*), hare (*Lepus ostioleous*), mouse hare (*Ochotona spp.*), snowcock (*Tetraogallus himalayensis* and *T. tibetanus*) and chukar (*Alectoris chukar*) can also form a part of wild prey for snow leopard. These herbivores along with the domestic

livestock support sympatric a carnivore guild of the snow leopard including Himalayan grey wolf, lynx (*Lynx lynx isabellina*), Dhole (*Cuon alpinus laniger*) and Brown bear (*Ursus arctos*) (Fox & Chundawat 1995).

Most of the people in these landscapes are agro-pastoralist and nomadic, semi-nomadic and settled villagers. Livestock grazing and associated use of rangelands is widespread across the Trans-Himalayan landscape and has played a crucial role in shaping the ecological history of the region (Mishra 2001; Bagchi et al. 2004).

Methodology

The methods were divided into three phases, where Phase I included foot survey for recording snow leopard occupancy across the region; Phase II included camera trapping across the density spectrum to identify snow leopards and their population parameters; Phase III included spatial and statistical analyses for estimating landscape scale population.

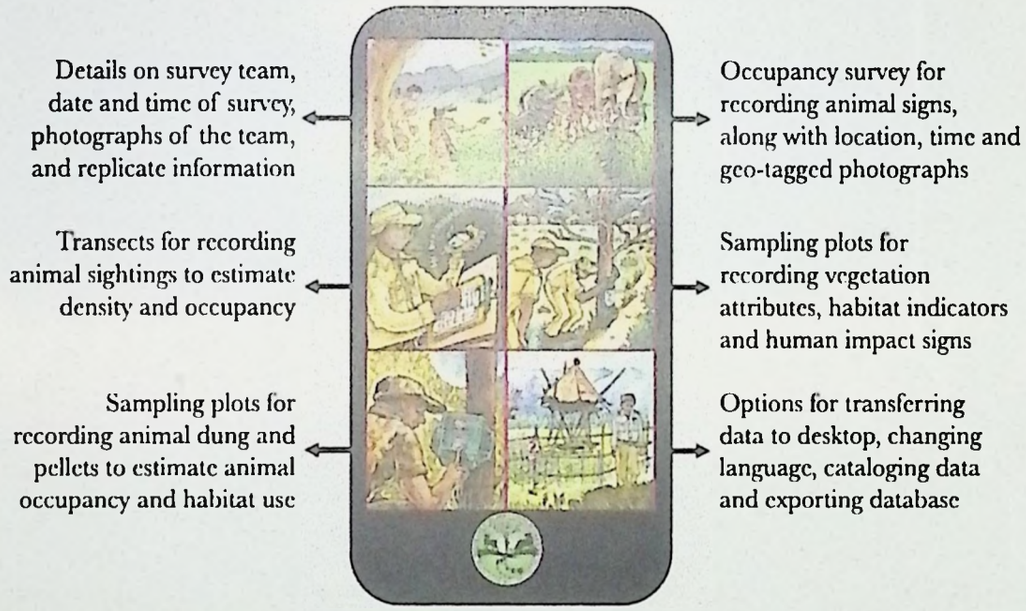

Figure 1: An open-access mobile app was developed within the MSTrIPES program to assist ground sampling for recording wildlife occupancy, density, habitat conditions and other ecological indicators. The app automatically geotags every record, trail and photographic evidence, along with time stamp. The app can be used in multiple languages, including the local language.

Phase I

The entire landscape was divided into grids of 10 x 10 km, as it represented average home range of snow leopards in the region. Multiple line surveys and plots were sampled within every such grid to capture variability within the grid. To systematically distribute our sampling spatially within every grid cell, it was divided into a sub-grid of 5 x 5 km. From every such sub-grid of 25 km2, we conducted assessment of carnivore occupancy, herbivore occupancy, herbivore density, vegetation conditions and human impacts. The survey was conducted as follows:

1. **Carnivore occupancy**: in every grid, 1 to 3 occupancy trails of around 5 km each were surveyed for recording the signs of carnivores. Animal trails, ridge lines, and wildlife trails were targeted to maximize the chances of sign encounter. Signs like pugmarks, scat, spray marks, etc. that can be assigned to the species were recorded along with geographic location, date, time, and photograph within a customized mobile app.

2. **Herbivore occupancy**: On every occupancy trail, a plot of 2 x 20 m was sampled at every 500 m to record the count of pellets and dung of all wild and domestic herbivores, along with geographic and photographic information.

3. **Herbivore density**: At every 500 m, a point transect of variable length was sampled to record the sightings of herbivores using a calibrated binoculars that measure the distance and bearing of the herbivores from the sampling point. At every plot, the region was scanned for at least 5 minutes to ensure detections. Upon detection, species, group size, distance, bearing, detection time and plot location was recorded.

4. **Vegetation conditions**: At every 500 m, 10 m circular plot was sampled to record the percent cover of shrub species, grass species, forb species, along with photographic and geographic information.

5. **Human impacts**: Along the occupancy trails, signs of human use like livestock presence, signs of vegetation harvest, livestock corrals, vehicle tracks, people seen, settlement, etc. were recorded, along with photographic and geographic information.

The data was recorded via 'MSTrIPES polygon' mobile application customized for the snow leopard population assessment (Jhala et al. 2019). This is an open access mobile app, which automatically records spatial and time attributes of the entire occupancy trails and plots. It has easy to use option to record all the assessments using dropdown menu in local language (Figure 1). Every record is attached automatically with geographic location, time stamp and geo-tagged photographs. Information from users with this app can be easily transferred into a desktop software customized for data archiving and produce reports at any required spatio-temporal resolution. This ensures easy data entry, transparency, and long-term archiving in a digital infrastructure. We have made this app available for everyone, within the open-access policy. This digital platform provided us all with all ground survey data in ready-to-use format for occupancy and density modelling. We effectively sampled 35,100 km² habitat area and obtained 9525 signs of snow leopard across the landscape (Figure 2).

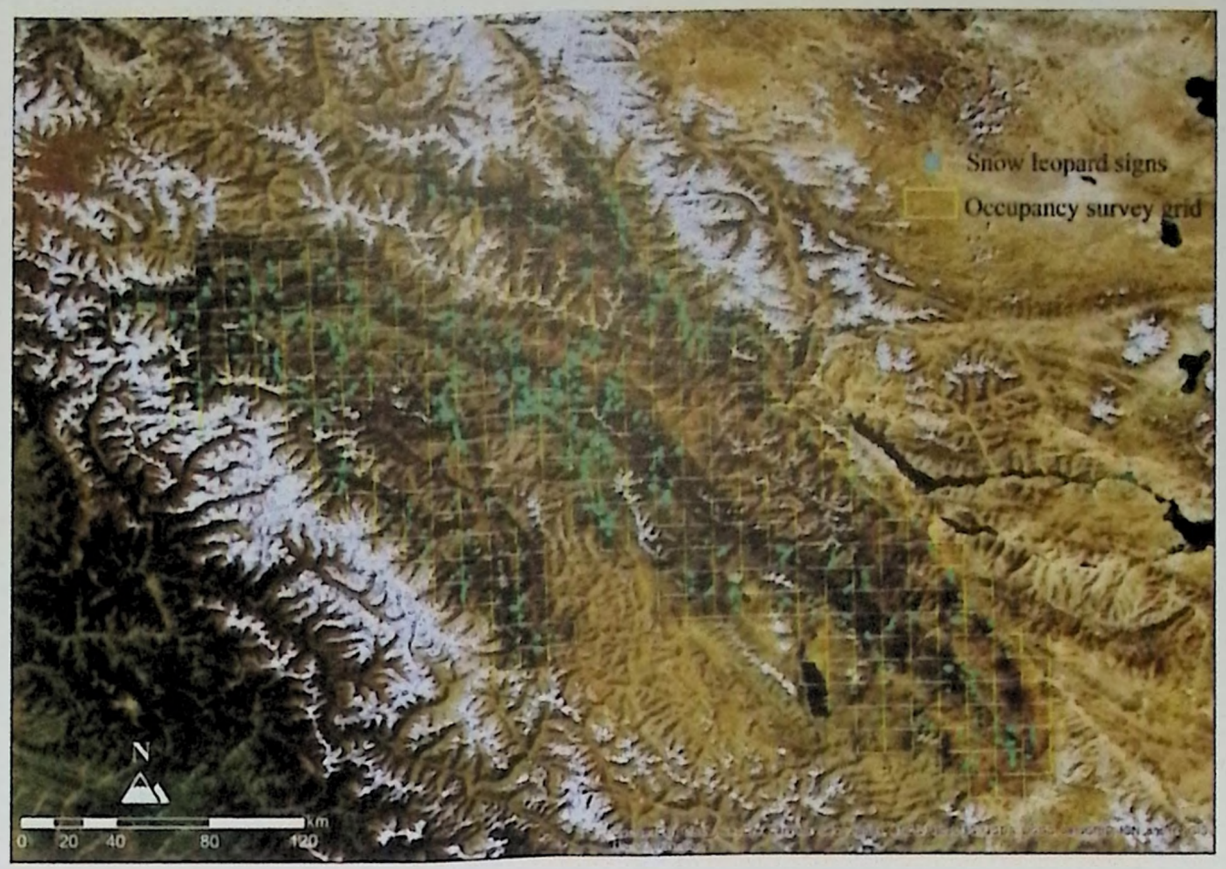

Figure 2: Sampling coverage across the landscape, where every grid (n=351) was sampled to obtain 9525 signs of snow leopard.

Phase II

Phase II included intensive camera trapping across the snow leopard habitat use (derived from the phase I data). Camera trap surveys have become a widely accepted approach for estimating the abundance and density of carnivore populations. The advancement of spatial capture-recapture techniques (Borchers and Efford 2008; Sharma et al. 2021) has significantly enhanced the accuracy and precision of density estimation by incorporating the spatial location of animal photo-captures, and model with suitable covariates for estimating abundance in a large landscape (Qureshi et al. 2023, Boulanger et al. 2018; Gogoi et al. 2020). We distributed sampling blacks across snow leopard density using the 10x10 km grid. At least 4 grids were sampled in a block, for intensive camera trapping. For spatially covering the area within every grid of 100 km2, it was subdivided into 2 x 2 and 3 x 3 km micro-grids for placing camera traps in each of these sub-grids. The camera trap was placed on trails used by snow leopards

and identified during the Phase I, such that the capture of snow leopards was maximized. We used motion detected and thermal detected cameras of Reconyx model. The camera traps were positioned to capture the forehead and flanks of the snow leopards. The camera traps were kept active for maximum 125 days. We effectively sampled 8604 km^2 in seven blocks, using 956 camera trap locations and 97313 trap nights (Figure 3).

Every camera trap photograph was geo-tagged and stamped with time and date information in the metadata. The species within every photograph were identified using the program CaTRAT that uses artificial intelligence and machine learning to identify species. It was subsequently checked by multiple biologists and personnels. Snow leopard photographs were obtained from this data archive. We used a customized machine learning program within Extract-Compare to digitize and archive pelage pattern of forehead for every snow leopard photograph. The program develops a unique key based on these patterns and assigns it to snow leopard individuals and uses it to identify unique snow leopards captured across camera traps. We used 26130 geo-tagged images of snow leopard and identified unique individuals using the program. The identity was independently validated by set of trained researchers using visual cues. The species identification program (CaTRAT) (Cheema et al. 2018) and individual identification program (Extract-Compare) were specifically customized for the snow leopard regions and are available as open-access. This has led to development of India's first photographic archive of snow leopards, which can be used for population monitoring, poaching cases, etc.

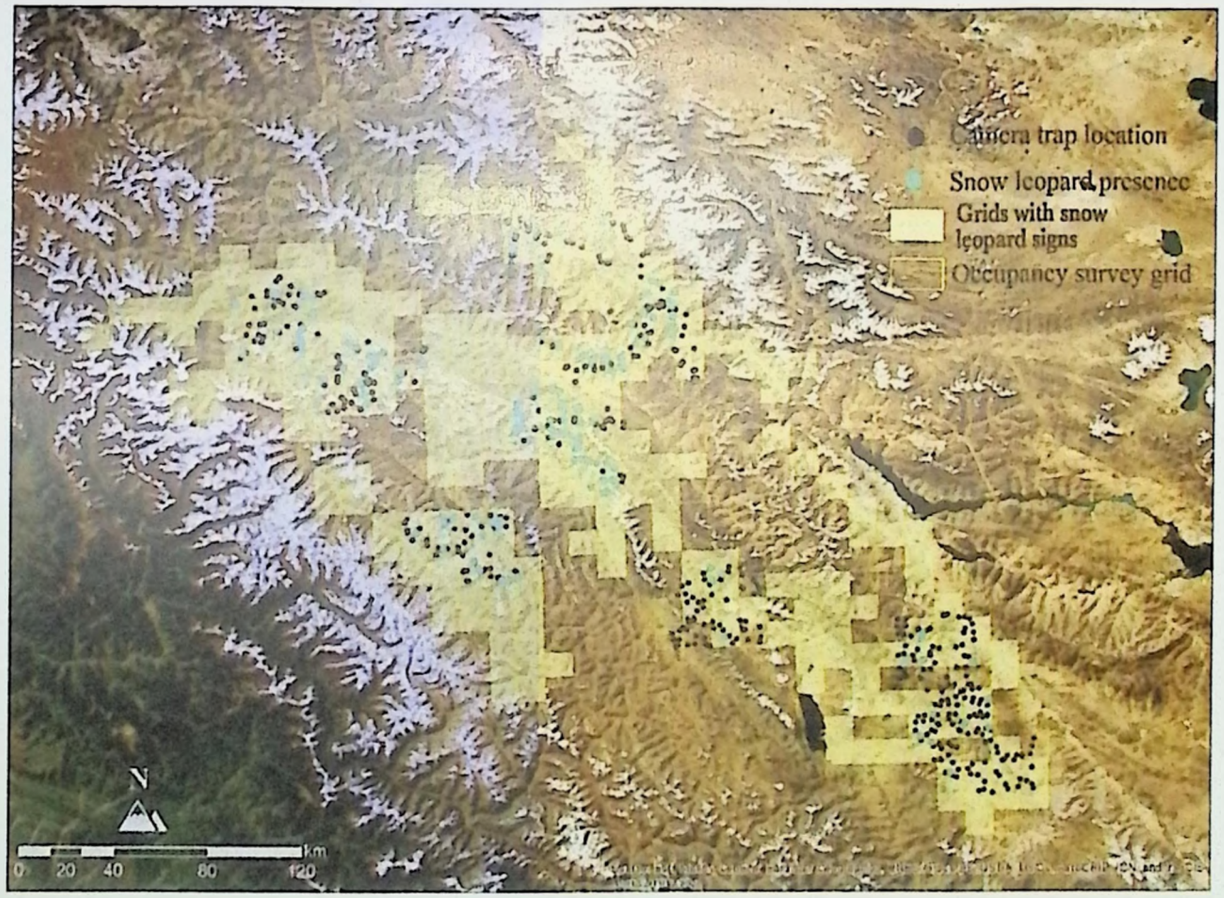

Figure 3: Sampling coverage of camera traps (n = 956) across the landscape in seven sampling blocks.

Phase III

Snow leopard occupancy:

The extent of habitat occupied by a species is often used as a one of the state parameters for evaluating its status. Detection of a species or its signs is inferred as an area being occupied, while non-detection could either result from absence of the species from the area or failure to detect the species in an occupied area. Occupancy modelling uses multiple surveys to compute detection probabilities and correct for imperfect detection to infer occupied area. We used a likelihood-based approach to estimate detection probability and occupancy (MacKenzie et al. 2017). The grid of 10 x 10 km was considered for deriving occupancy, as it best represents snow leopard home range. Every carnivore occupancy survey within the grid was considered

as a single replicate, where sign detection was considered as presence, and non-detection as absence. We further used ecological variables representing site characteristic that can influence snow leopard occupancy. These site variables were availability of wild prey, availability of domestic animals, availability of cattle, elevation, terrain ruggedness, slope, proportion of permanent snowy area, open grassy habitat area, minimum temperature of winters, distance from valleys, and proportion of dense human settlements.

The variables were standardized, and only non-correlated variables were used within a model (Pearson's correlation -0.7 > r > 0.7). Occupancy models using Maximum Likelihood were fitted to the data in PRESENCE Ver. 2.13.47. Models were evaluated using Akaike Information Criteria (AIC) and parameter estimates from alternative models that differed by < 5 AICs were averaged based on model weights to account for model uncertainty (Akaike 2011). It provided us null occupancy and covariate modelled occupancy for snow leopards in the region.

Snow leopard occurrence:
As snow leopards could occur in regions that were not sampled in Phase I, we modelled the potential distribution of snow leopards across the region using Maximum Entropy (MaxEnt) (Phillips et al. 2017). MaxEnt is one of the most widely used algorithms for potential distribution modeling, which calibrates environmental variables from species presence locations and compares them with a set of random background locations from the study area (presence-background model). We used a suite of remotely sensed datasets on climate (mean temperature of summer, mean temperature of winter, annual precipitation, precipitation of the driest and wettest season), terrain (elevation, slope, proportion of valleys, and terrain ruggedness), vegetation (proximity dry grass dominated areas, moist grass dominated areas, and areas under natural open ecosystems, difference between Enhanced Vegetation Index (EVI) of wet season and dry seasons), water (proximity to water sources), and disturbance factors (proportion of built up area) important for determining species occurrence. Furthermore, we excluded permanent snowy areas (>5200 m elevation), dense human settlements, water bodies, and all restricted areas. We conducted a Pearson's correlation test, and included only those variables in a model that were not correlated (-0.7 > r > 0.7).

Being a presence-background model, the extent of the background environment influences the species-environment relationship (Phillips et al. 2017), which necessitates appropriate ecological criteria to define the background. Since we only consider natural habitats for this study, model extent and background were restricted to natural areas in which the species were known to occur. To address the autocorrelation within presence points, we spatially thinned the presence location at 1 km scale, so that every pixel (1 km) will have only one presence location. Even though sampling was systematically distributed using a grid, the intensity of sampling in a grid may vary. To account for this variability, we used bias correction by including sampling density map. MaxEnt uses this bias file to derive the information on the representation of different covariates variability through sampling. For assessing model performance, we divided the presence data for each species into training (80%) and testing (20%) sets, for MaxEnt modeling and independent accuracy assessment, respectively. This was done using k-fold (k=5) partitioning with proportionate representation of elevational gradient, where we used each k-partitioned set, for every species, as an input data for MaxEnt.

We used the partitioned presence locations for every species and developed habitat suitability models using linear, quadratic, hinge, and product features and 100 bootstrap simulations. We performed Jackknifing simulations for estimating the contribution and effects of different covariates on species habitat suitability and used the logistic output of MaxEnt (Phillips et al. 2017). For every species, results of all the k-partitioned model runs were averaged, which provided probability of potential distribution for every pixel that varies from 0 to 1. All pixels greater than a threshold that yield highest True Skill Statistics (TSS), were considered potentially suitable for species. This TSS was used as the primary index of accuracy for effectively mapping species potential distribution (Allouche et al. 2011). The averaged Area Under the receiving operating characteristic Curve (AUC) of MaxEnt model was considered as an additional criterion to assess the ability of MaxEnt to model species potential distribution.

For deriving the prey prevalence index, we used potentially suitable pixels for all three herbivores species (blue sheep, ibex, and urial) that were above the highest TSS value. The probabilities per pixel for all herbivores

were spatially summed to derive the prey prevalence index, which was used for modelling snow-leopard potential distribution. The potential distribution model for snow-leopard was used as a habitat mask for further population estimation analyses.

Snow leopard population:
Maximum likelihood based spatially explicit capture recapture (SECR) was used to estimate snow leopard abundance/density from the camera trap data. In SECR, we assume that individuals have home ranges and the 'activity centres' of these home ranges are distributed in a spatial Poisson point process and are independent and identically distributed. Detection probability at the activity centre is 'g_0' and this detection probability declines as we move away from the activity centre which is modelled as spatial scale of detection 'σ' using Gaussian, hazard, etc. functions akin to Distance sampling. However, these activity centres are unobserved and hence considered latent variables. By marginalizing over the entire available space, we then need to estimate only g0 and σ to assess the density (Borchers & Efford 2008).

As snow leopard occurrence is jointly influenced by prey availability, elevation, human impacts, etc, we used MaxEnt derived potential distribution probability as a covariate to model the influence of environmental settings. We conducted analysis in R program environment with package secr 4.6 (Efford 2023).

Results

Snow leopard occupancy:
We found a total of 9525 signs of snow leopards across the landscape (Figure 2). The naïve occupancy of region was 23,000 km^2. The detection corrected null occupancy was 25,709 km2 (CI: 25,201 – 26,263), whereas occupancy modelled using site covariate was 25,308 km2 (CI: 22,726 – 28,091) (Figure 4). The best amongst competing models (Table 1), highlighted positive impacts of wild prey availability and domestic animal availability, whereas it showed negative impacts of elevation and human settlement (Table 2).

Table 1: Competing models used for deriving occupancy (Ψ) and detection (p) of snow leopards in Ladakh. The model with least AIC was considered best explanatory model (bold).

Model	AIC	deltaAIC	no.Par.
Ψ (wp, ele, dom, hs),p(.)	**1584.55**	**0**	**6**
Ψ (wp, ele, dom),p(.)	1600.8	16.25	5
Ψ (wp, ele),p(.)	1623.55	39	4
Ψ (wp, ele, catt),p(.)	1624.57	40.02	5
Ψ (wp, ele, catt, hs, vall, open),p(.)	1624.71	40.16	8
Ψ (dom, ele),p(.)	1630.19	45.64	4
Ψ (dom),p(.)	1636.59	52.04	3
Ψ (prey),p(.)	1639.34	54.79	3
Ψ (ele),p(.)	1712.23	127.68	3
Ψ (wtemp),p(.)	1721.38	136.83	3
Ψ (catt),p(.)	1727.08	142.53	3
Ψ (open),p(.)	1734.16	149.61	3
Ψ (hs),p(.)	1736.28	151.73	3
Ψ (.),p(.)	1736.34	151.79	2

Abbreviations: Wp: wild prey encounter rate, ele: elevation, dom: domestic animal encounter rate, hs: human settlement density, catt: cattle encounter rate, vall: distance from valley, open: open grassy area, wtemp: minimum temperature of coldest quarter.

Table 2: Model statistics explaining the influence of ecological variables on snow leopard occupancy (Ψ) and detection (p) in Ladakh.

Parameter	Variable	Estimate	SE
Ψ	Intercept	616.31	0.29
Ψ	Wild prey encounter rate	16.48	0.79
Ψ	Elevation	-1.2	0.33
Ψ	Domestic animals encounter rate	2349.71	1.1
Ψ	Human settlement	-3.03	1.28
p	Detection - Intercept	-0.02	0.07

Snow leopard occurrence:
MaxEnt modelling highlighted a strong positive influence of wild prey occurrence on snow leopard potential occurrence (model contribution 95%). Other variables influencing snow leopards were intermediate elevation, moderate ruggedness, and areas with less permanent snow cover (Figure 5). The estimated occurrence of snow leopard in the landscape was 47,572 km2 (Figure 6). The modelling had reliable accuracy with TSS = 0.79, and AUC = 0.86 (SD 0.001).

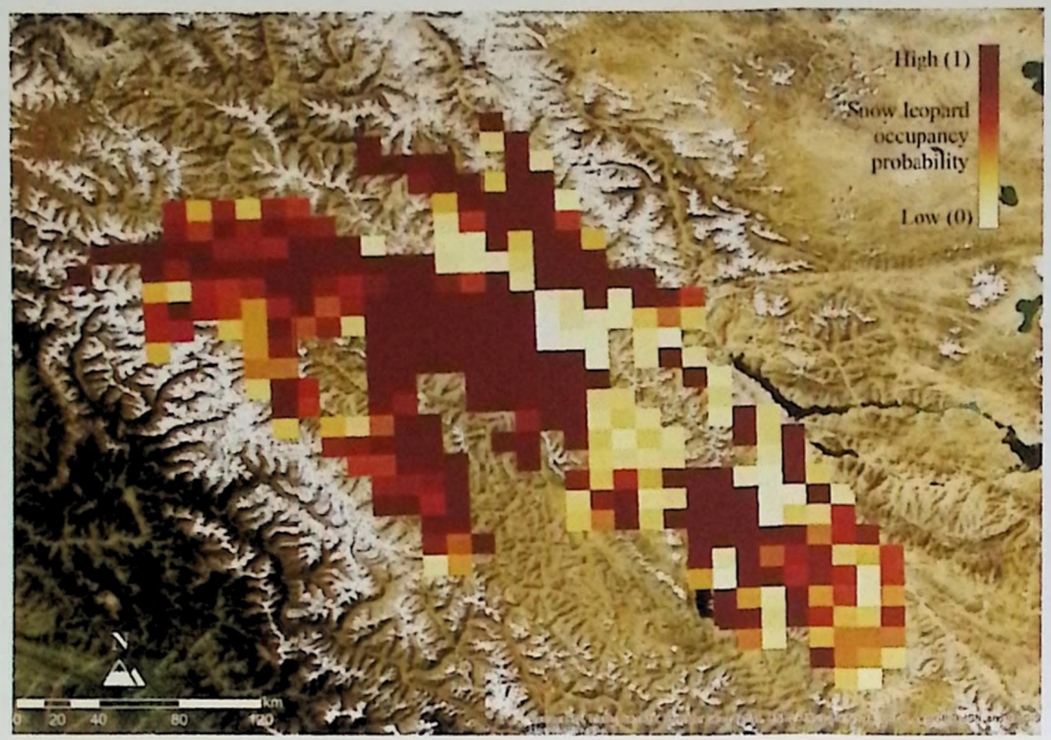

Figure 4: Snow leopard occurrence probability in Ladakh

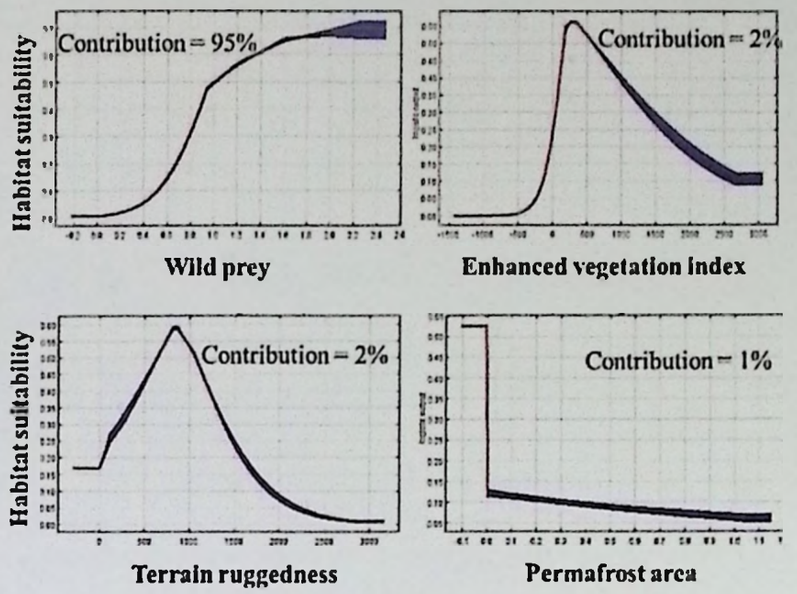

Figure 5: Relationship between snow leopard presence and ecological variables, used in deriving the presence area of snow leopard in Ladakh.

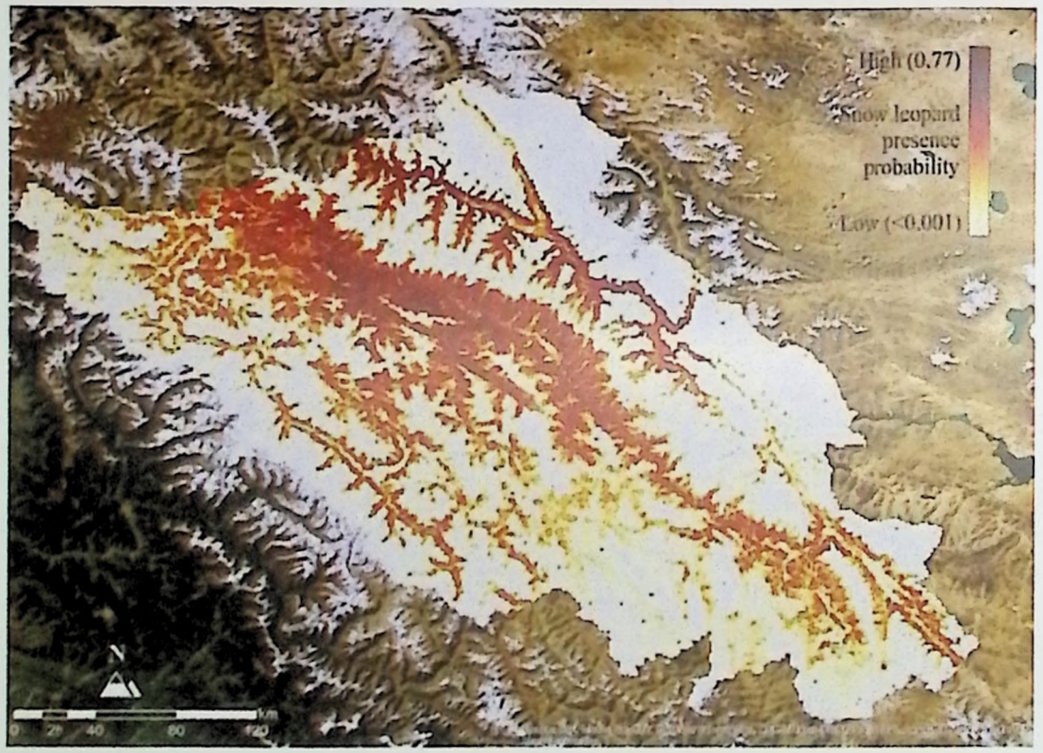

Figure 6: Potential presence of snow leopard in Ladakh.

Table 3: Competing models for explaining density (D), activity centre (g_0), and activity range (σ) of snow leopards in Ladakh.

Model	Detection	No.Para	AICc	dAICc
D(habitat suitability) g_0 (.) σ(.)	Halfnormal	4	3098.87	0
D(.) g_0(.) σ(.)	Halfnormal	3	3118.33	19.46

Snow leopard population:
We photo-captured 26,130 images of snow leopards and identified 159 unique individuals, out of which 126 unique adult individuals were used for population estimation using their forehead patterns. The population was modelled based on the SECR covariate model for the suitable habitat in Ladakh landscape (47,572 km2). The average density estimate was 1/100 km2. The population was estimated to be 477 (± 51.16) (Figure 7). Model parameters and estimates are provided in the Table 3 and 4.

Table 4: Parameters for the SECR based density estimation of snow leopards in Ladakh.

Parameters	Estimate
Camera points	956
Trap nights (effort)	97313
Unique snow leopards photo-captured	126
Detections	440
Model	D(habitat suitability) g_0(.) σ(.)
$\hat{D}$ SECR (per 100 km2)	0.34 (± 0.14) at the base level
σ (SE) (km)	4.09 (± 0.15)
g_0 (SE)	0.003 (± 0.0003)
Population estimated based on covariate model	477 (± 51.16)

Note: The covariate model density estimate is the density at the base level of covariate not the density of entire landscape. The entire landscape density has to be calculated by predicted population/ area of prediction which is around 1per 100 km²

SE: Standard error (±)
$\hat{D}$ SECR: Density estimate from Maximum Likelihood based spatially explicit capture recapture
$\hat{\sigma}$ (Sigma): Spatial scale of detection function
$\hat{g}_0$: Magnitude (intercept) of detection function

Study implications

The snow leopard status assessment done for Ladakh provides a hierarchical approach of integrating occupancy surveys, relevant ecological covariates of prey, terrain, and vegetation into spatially explicit density estimates of snow leopards across the entire landscape. It is the first landscape scale assessment for the species done with this level of effort and precision. The results show that Ladakh is home to a relatively large population of snow leopards and is perhaps one of the largest source populations in the world. There are relatively few apparent threats to this population except that of prey depletion, direct poaching, and conflict due to livestock predation. Careful planning and weaving mitigation measures of compensation and law enforcement into the policy of the newly formed Union Territory of Ladakh can enhance the contribution of snow leopard based economics in the region. The Snow Leopard is a tourist magnet, the knowledge that Ladakh has one of the largest populations of the species can attract more ecotourists. Suatainable nature based economies are the best solution for conserving the fragile Himalayan ecosystems and providing communities with livelihoods. The snow leopard and its ecosystem provide a unique oppertunity that needs sensitive policy, planning, and management for supporting a sustainable long-term ecotourism program.

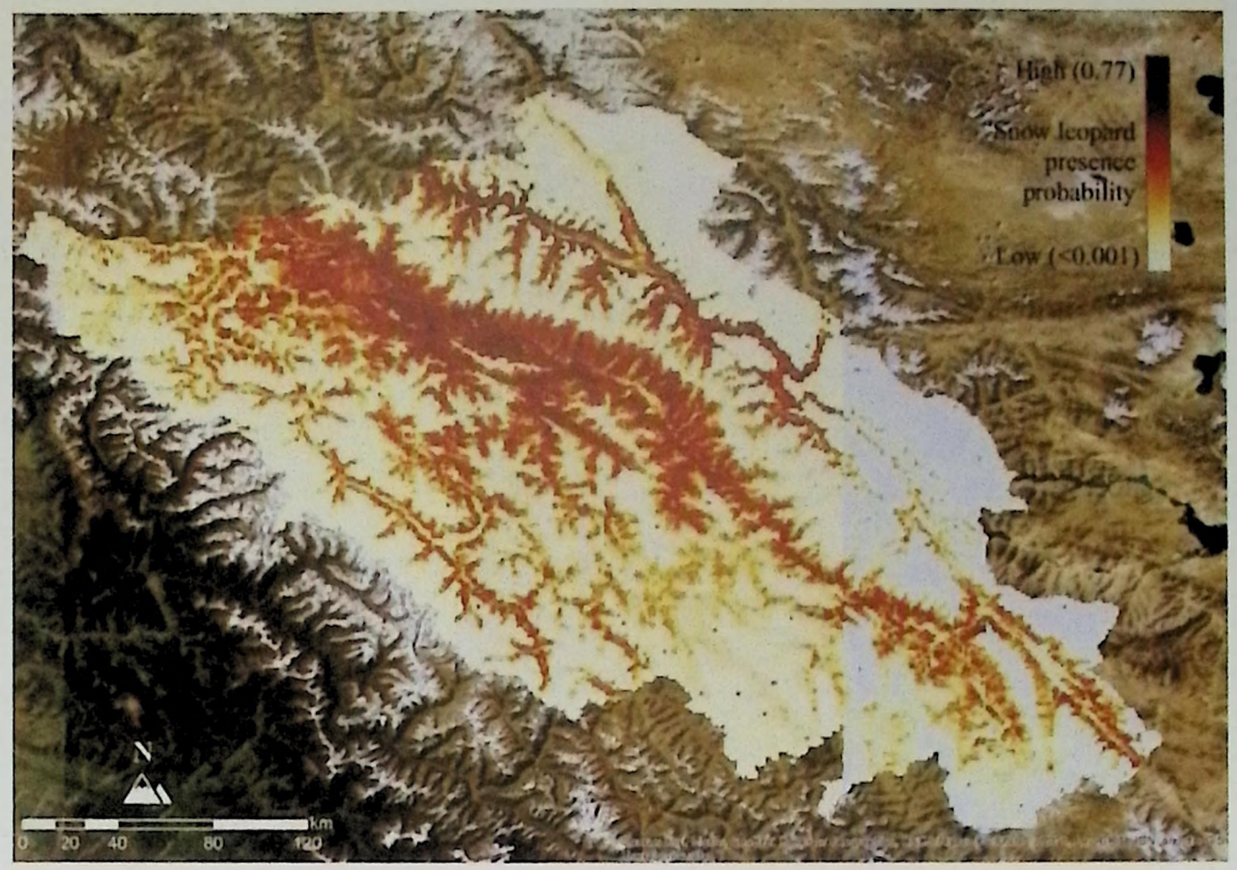

Figure 7: Population density of snow leopard in Ladakh.

Bibliography

Bagchi S, Mishra C, Bhatnagar YV (2004) Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan mountains. In: Animal Conservation forum. Vol. 7 Cambridge University Press pp. 121–128.

Borchers DL, Efford MG (2008) Spatially Explicit Maximum Likelihood Methods for Capture-Recapture Studies. Biometrics 64:377–385

Boulanger J, Nielsen SE, Stenhouse GB (2018) Using spatial mark-recapture for conservation monitoring of grizzly bear populations in Alberta. Scientific Reports 8:5204

Cheema GS, Anand S, Qureshi Q, Jhala YV (2018) CaTRAT: Camera Trap Data Repository and Analysis Tool.

Chundawat RS, Qureshi Q (1999) Planning wildlife conservation in Leh and Kargil districts of Ladakh, Jammu & Kashmir. Wildlife Institute of India, Dehradun, India

Efford M (2023) secr 4.6-spatially explicit capture–recapture in R.

Fox JL, Chundawat RS (1995) Wolves in the Transhimalayan region of India; the continued survival of a low-density population. In: Ecology and Conservation of Wolves in a Changing World. Edmonton : University of Alberta Press.

Gogoi K, Kumar U, Banerjee K, Jhala YV (2020) Spatially explicit density and its determinants for Asiatic lions in the Gir forests. PloS one 15:e0228374

Jhala YV, Qureshi Q, Gopal R, Bonal BS, Swain D, Nayak AK, Yadav SP, Negi HS, Kumar S, Garawad R, Mathur V, Singh RR, Verma N, Bankhwal DP, Somasekar P, Kamdi H, Mungi NA, Pradhan AK, Prasad A, Kumar A, Mishra K, Latafat K, Laha DR, Sadhu A, Dutt A, Bhasin A, Khatonier P, Banerjee K, Kumar U, Kollipakam V, Saini S, Bist S, Solanki R (2019) Development and implementation of MSTrIPES in Tiger Reserves. National Tiger Conservation Authority, Government of India, and Wildlife Institute of India, Dehradun, New Delhi.

MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey L, Hines JE (2017) Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier

McCarthy T, Mallon D, eds. (2016) Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes. In: Academic Press.

Mishra C (2001) High altitude survival: conflicts between pastoralism and wildlife in the Trans-Himalaya. Wageningen University and Research

Nowell K, Li J, Paltsyn M, Sharma RK (2016) An Ounce of Prevention: Snow Leopard Crime Revisited. TRAFFIC, Cambridge, UK

Phillips SJ, Anderson RP, Dudík M, Schapire RE, Blair ME (2017) Opening the black box: An open-source release of Maxent. Ecography 40:887–893

Qureshi Q, Jhala YV, Yadav SP, Mallick A (2023) Status of Tigers, co-predators and prey in India 2022. National Tiger Conservation Authority, Government of India, and Wildlife Institute of India, Dehradun, India

Schaller GB (1977) Mountain monarchs. Wild sheep and goats of the Himalaya. University of Chicago Press.

Sharma RK, Sharma K, Borchers D, Bhatnagar YV, Suryawanshi KR, Mishra C (2021) Spatial variation in population-density of snow leopards in a multiple use landscape in Spiti Valley, Trans-Himalaya. PLoS One 16:e0250900

Suryawanshi KR, Khanyari M, Sharma K, Lkhagvajav P, Mishra C (2019) Sampling bias in snow leopard population estimation studies. Population Ecology 61:268–276

Photo repository of individually identified snow leopards in Ladakh

Hemis National Park

Individual captures for 2018-2019

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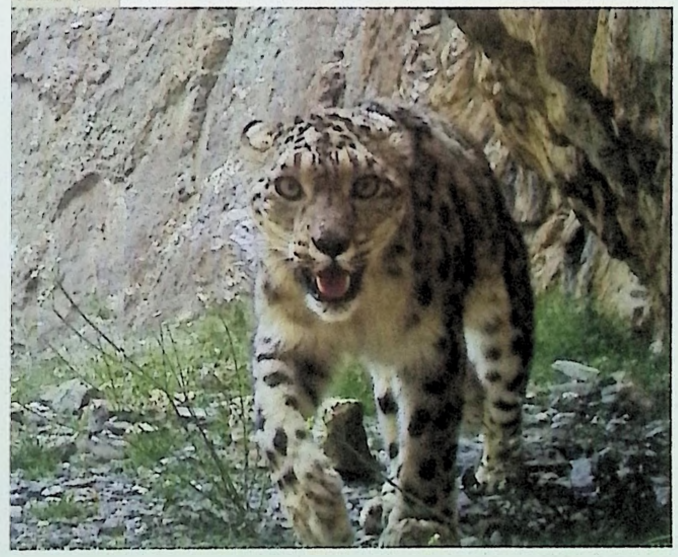

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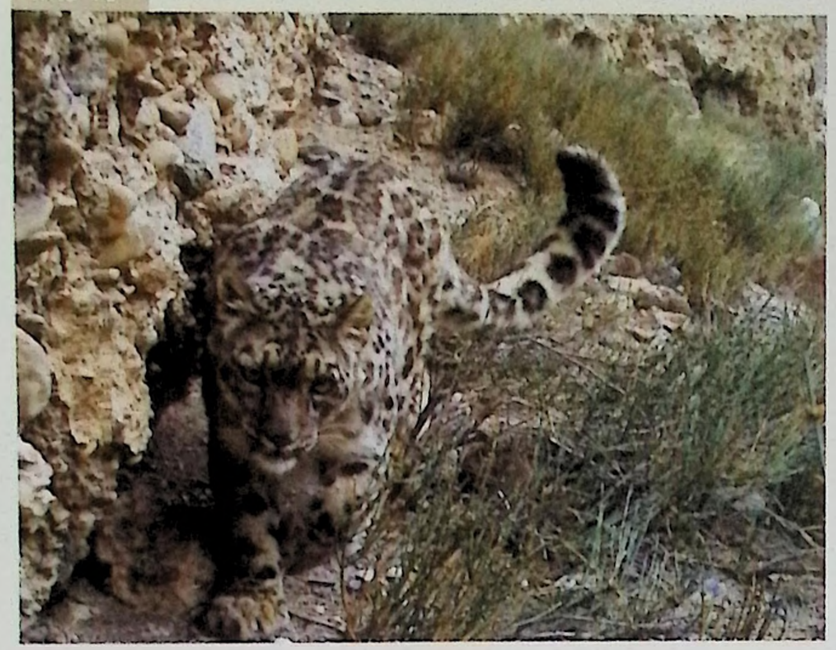

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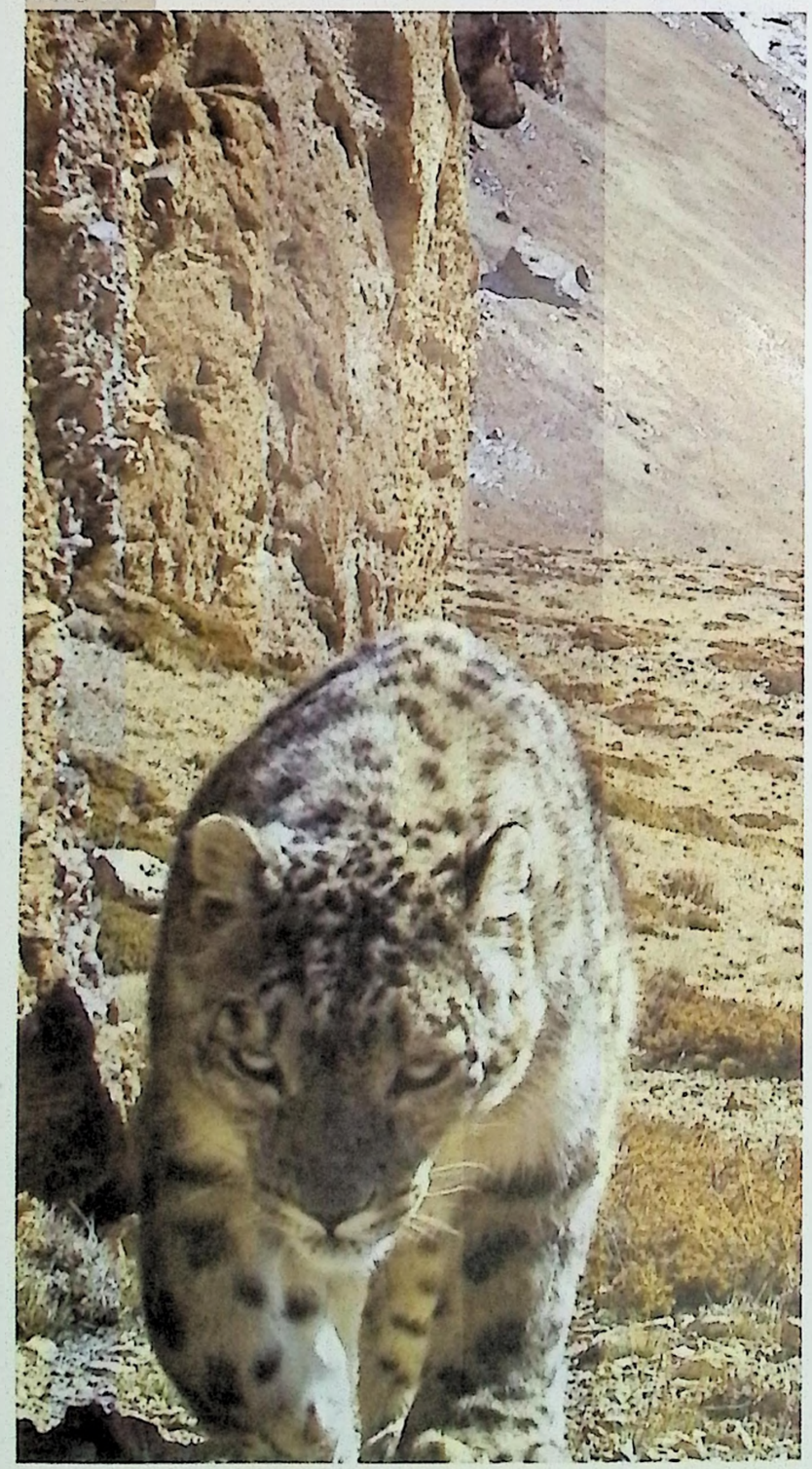

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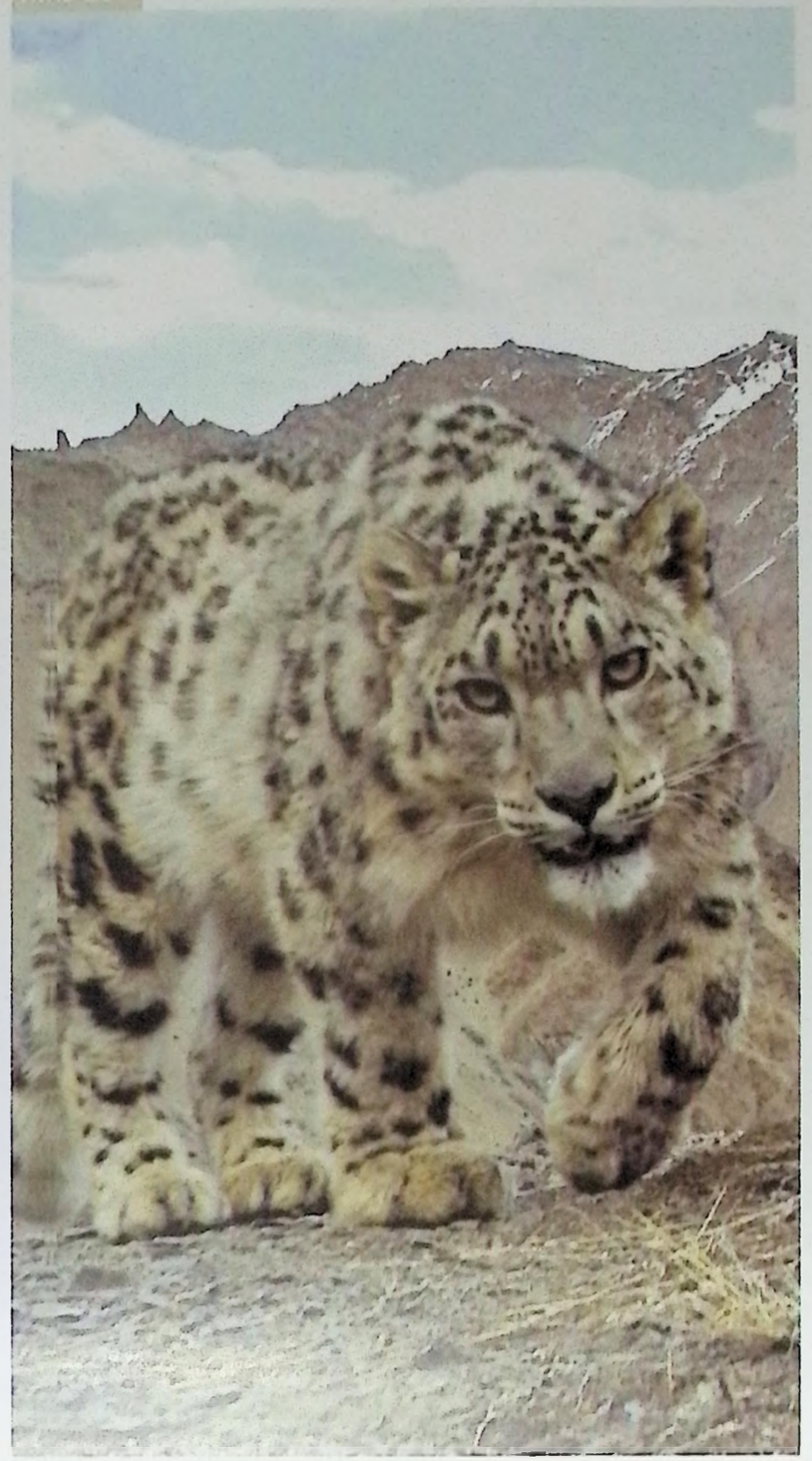

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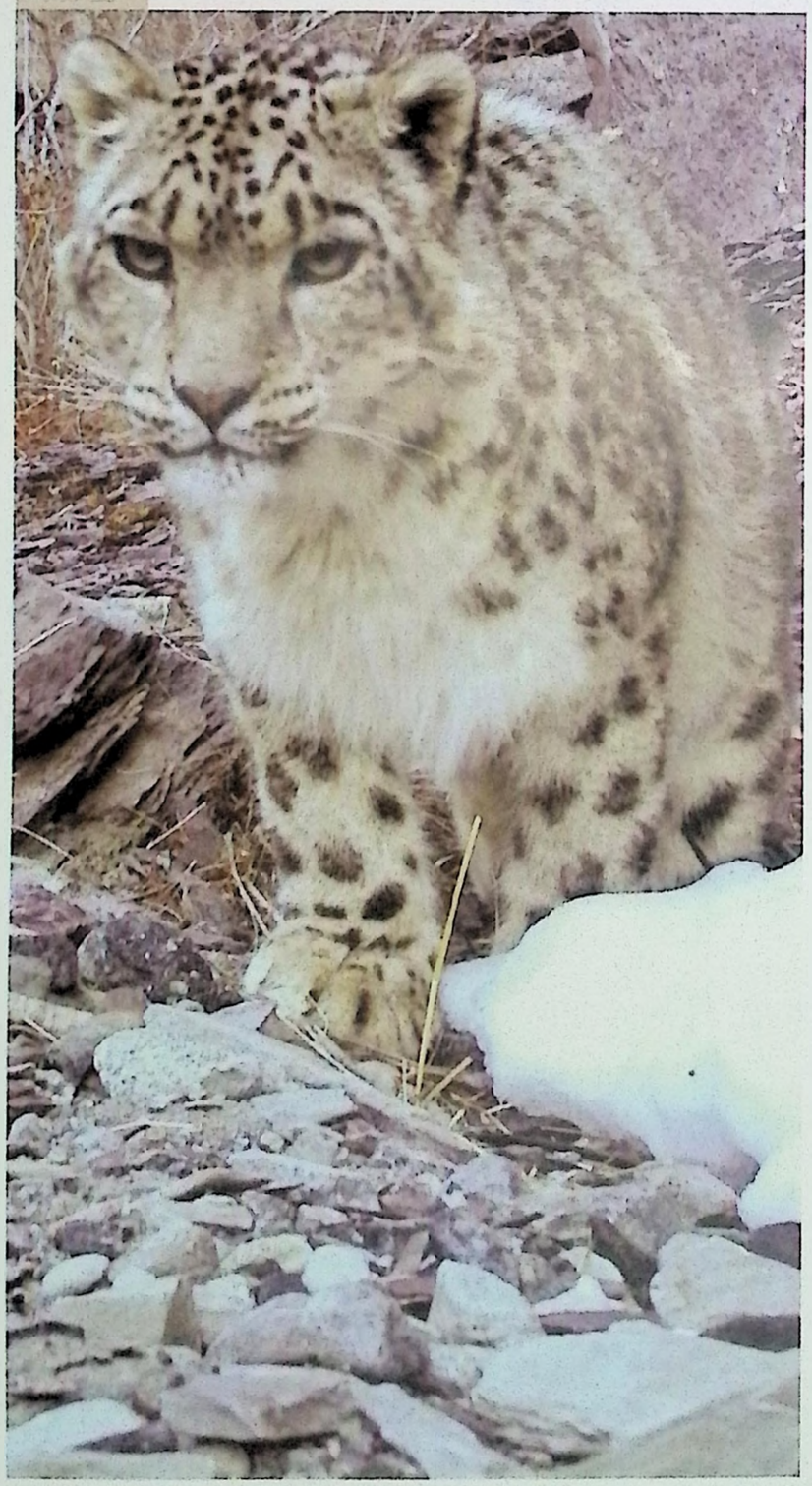

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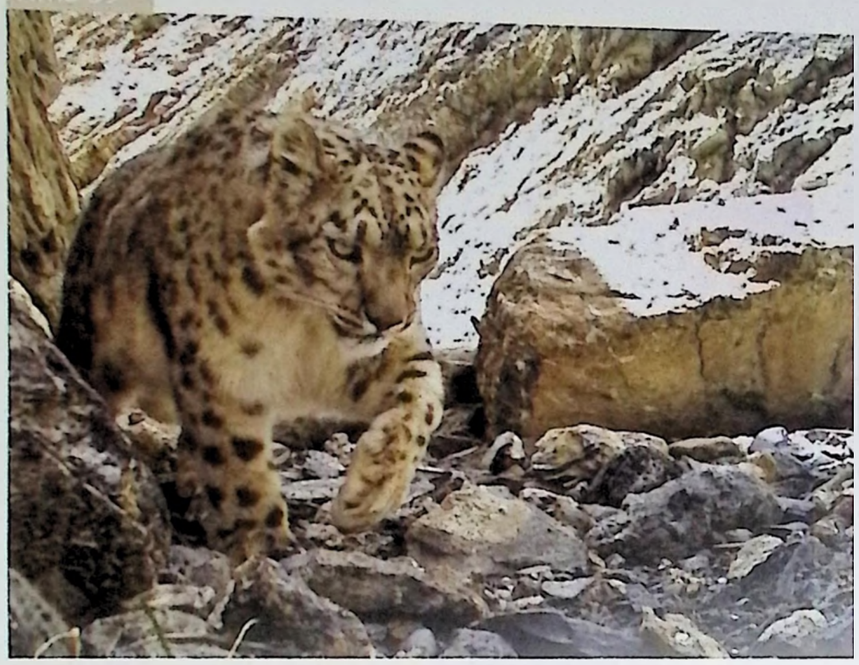

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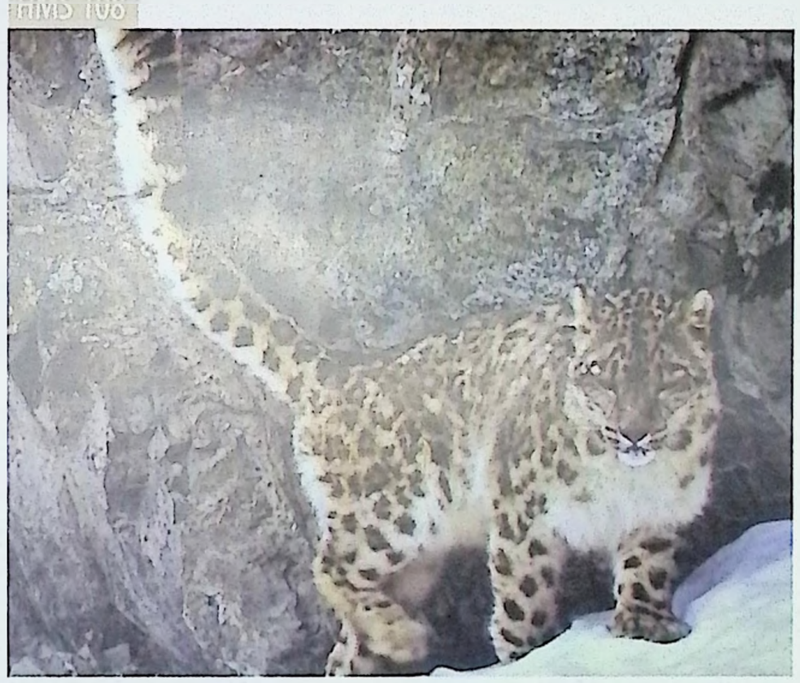

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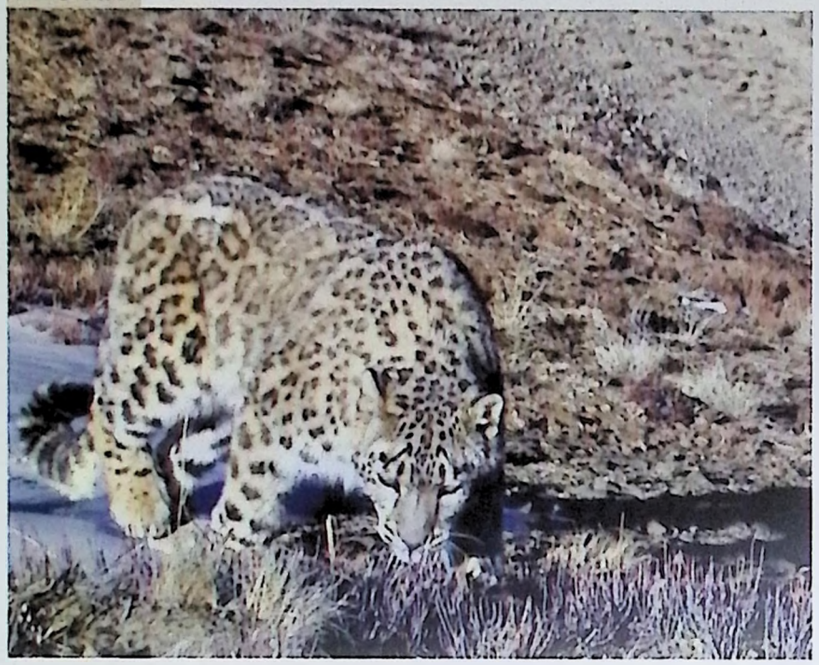

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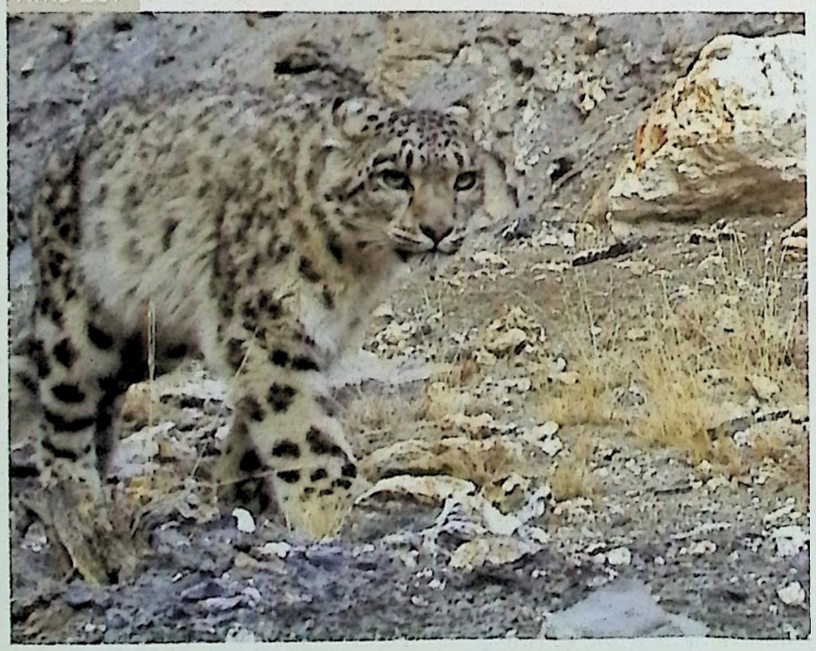

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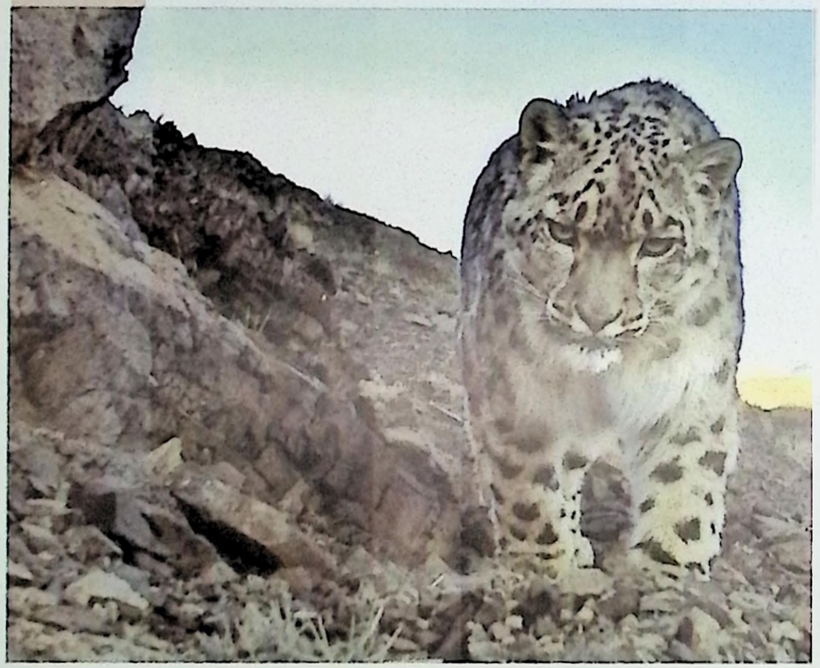

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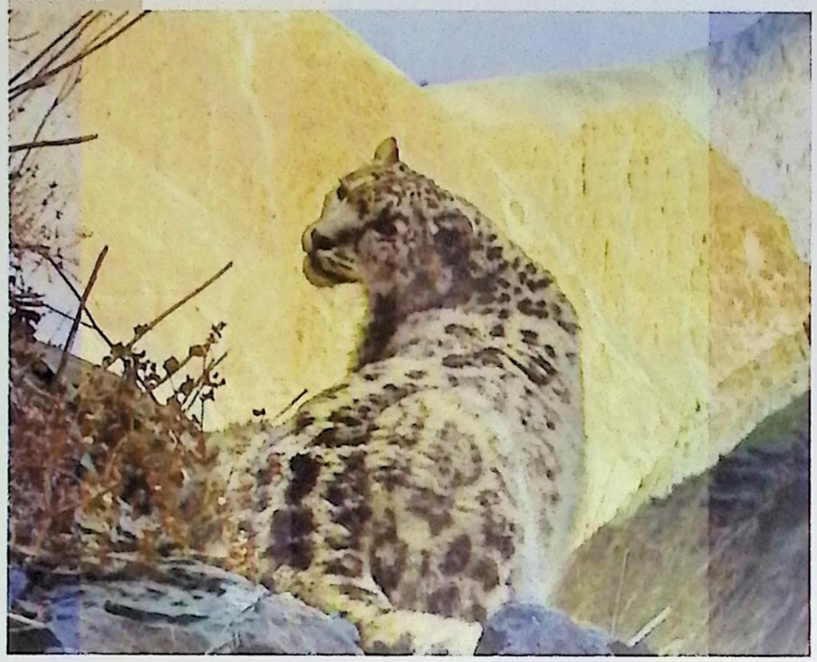

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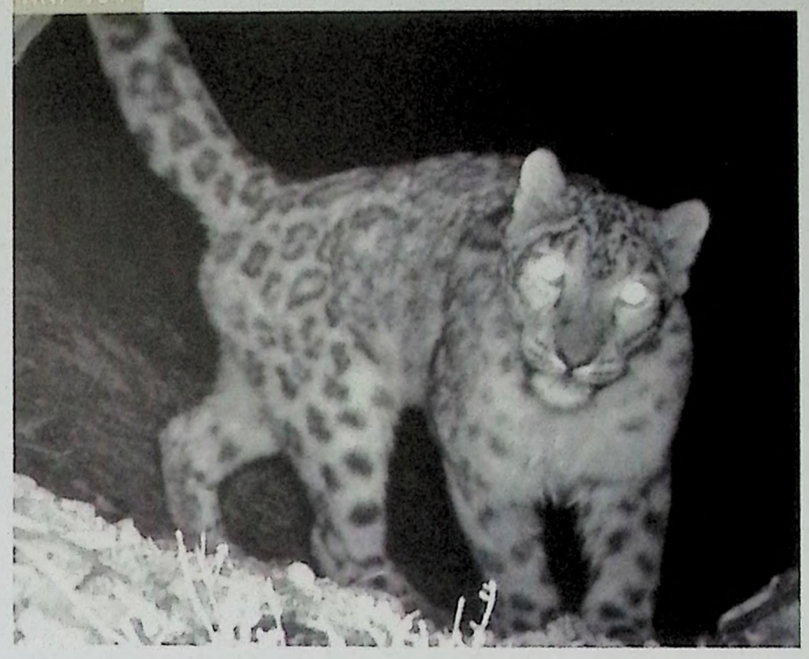

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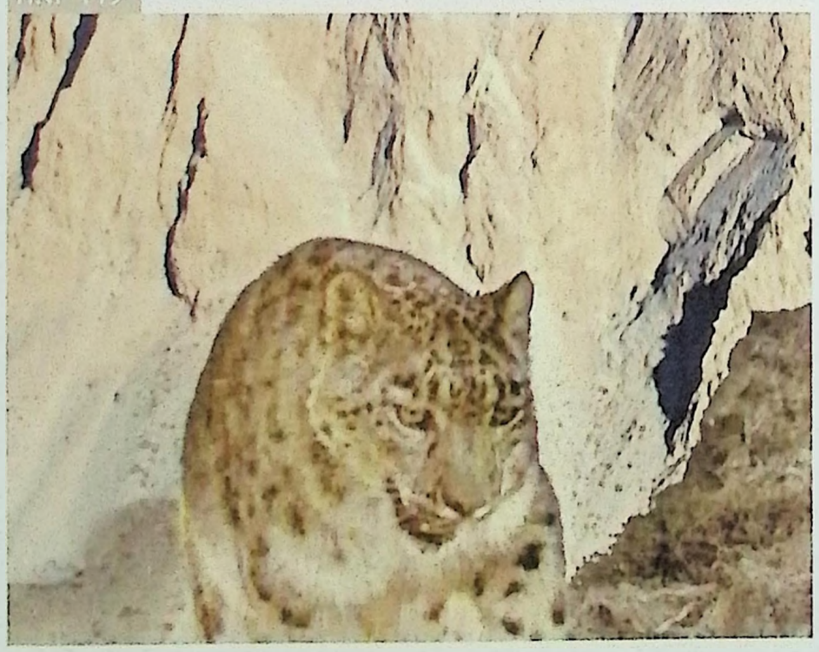

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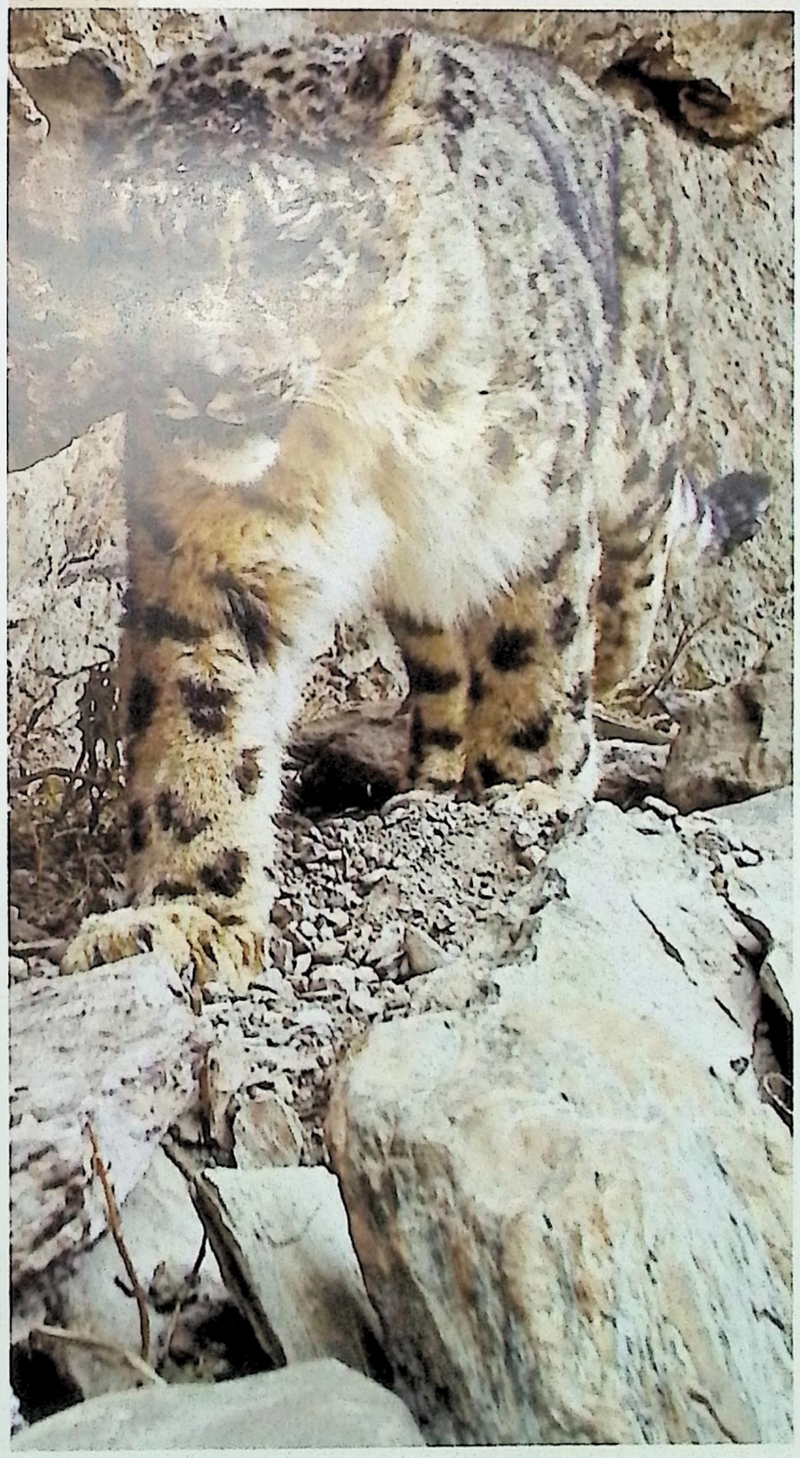

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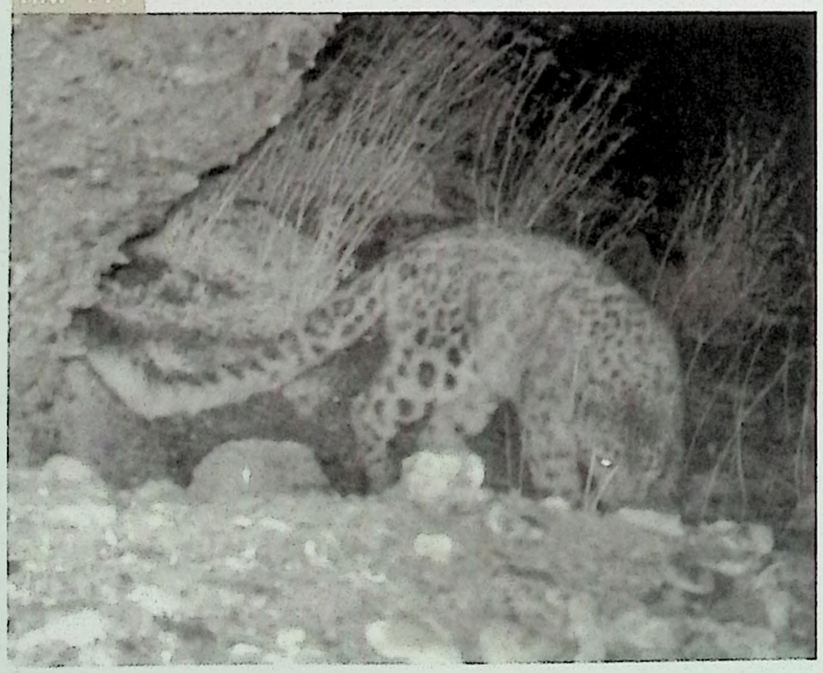

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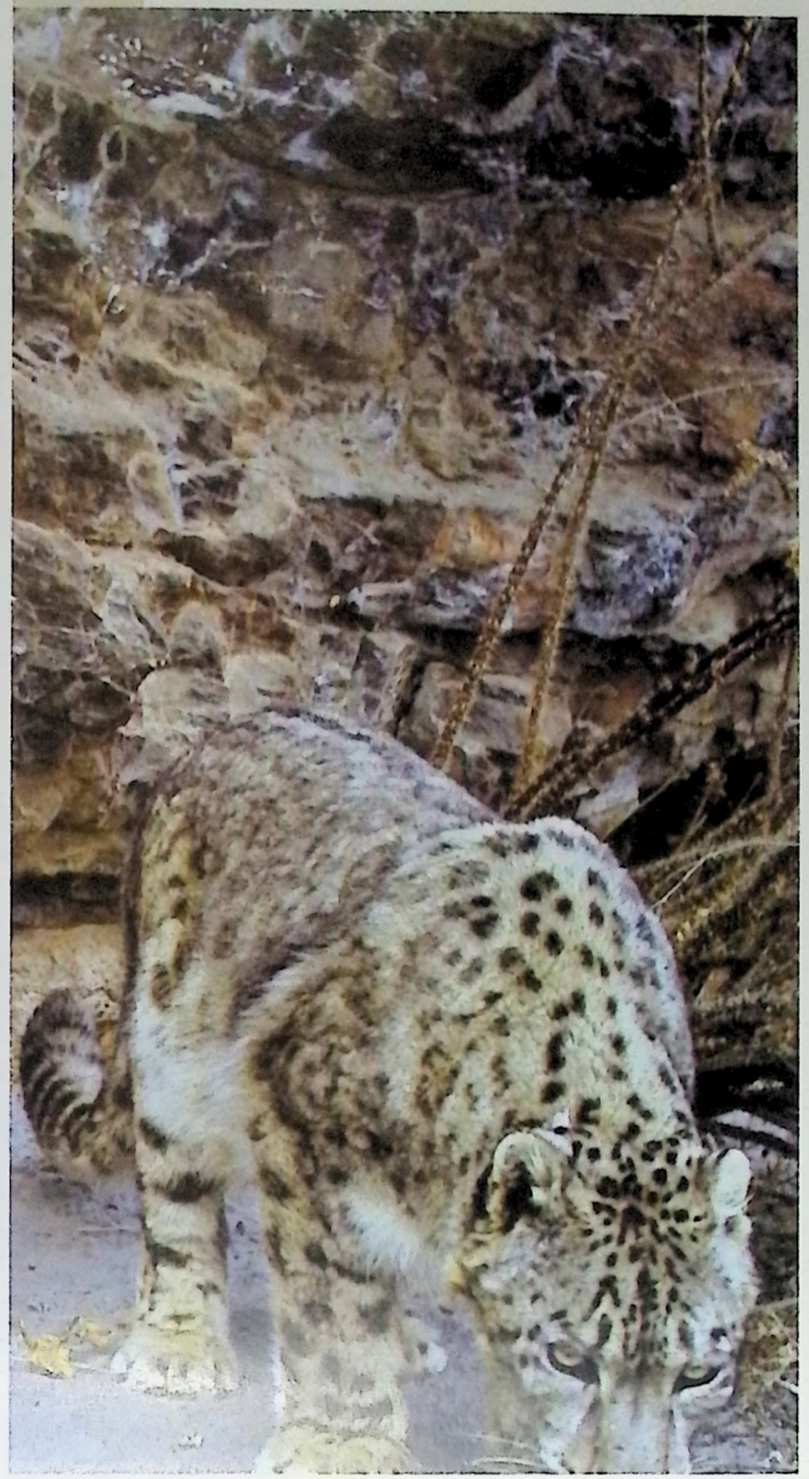

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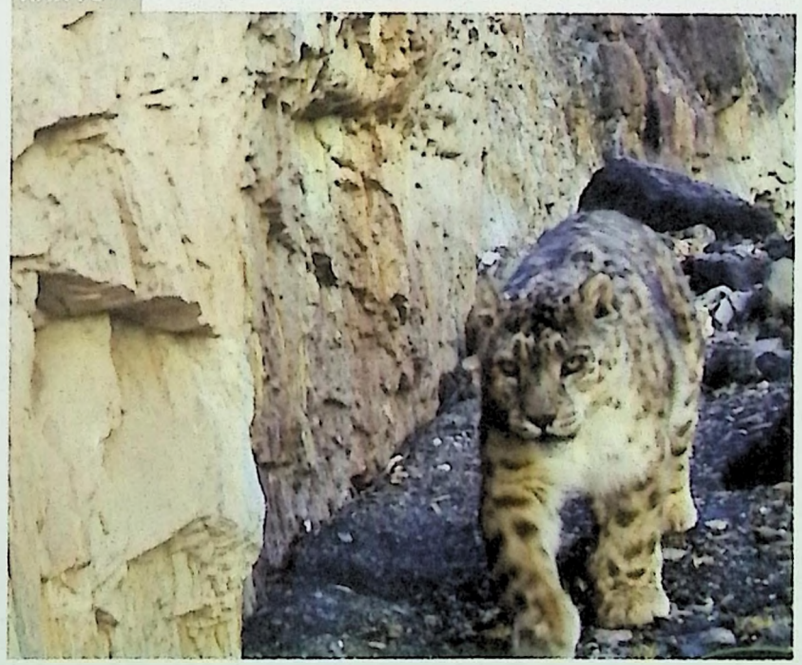

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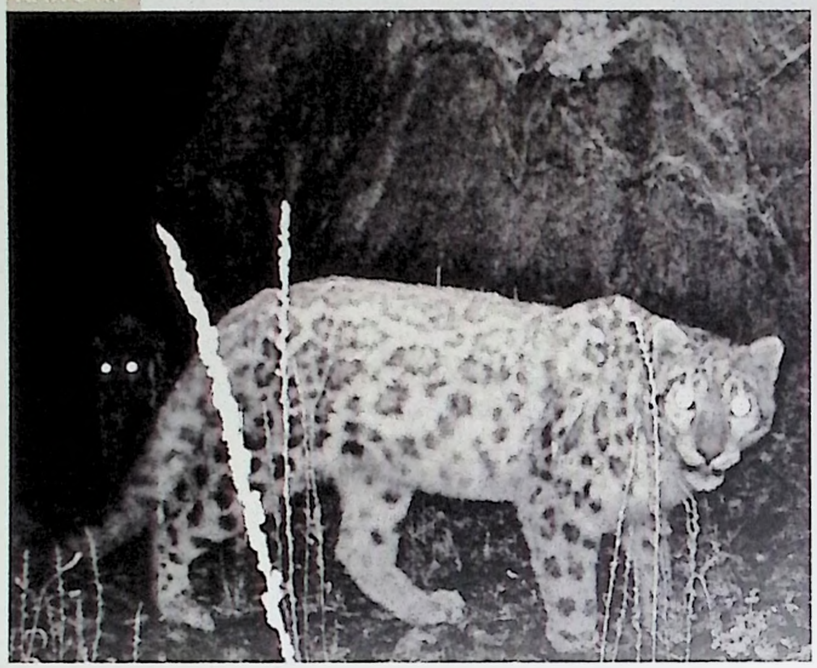

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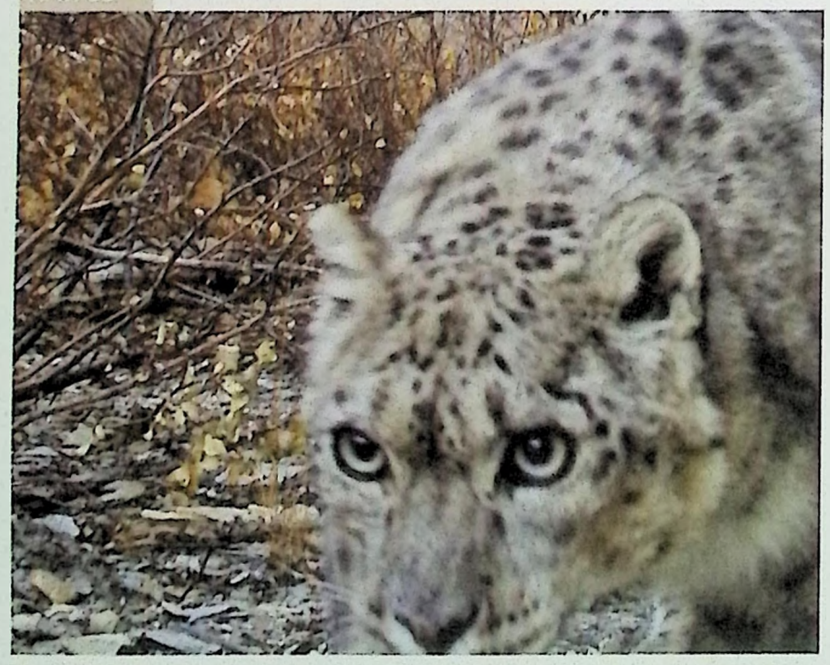

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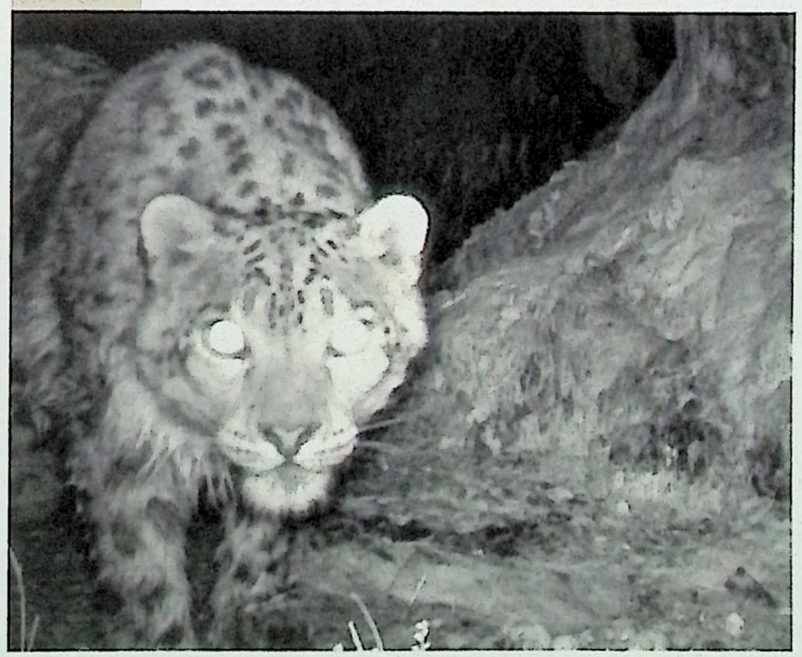

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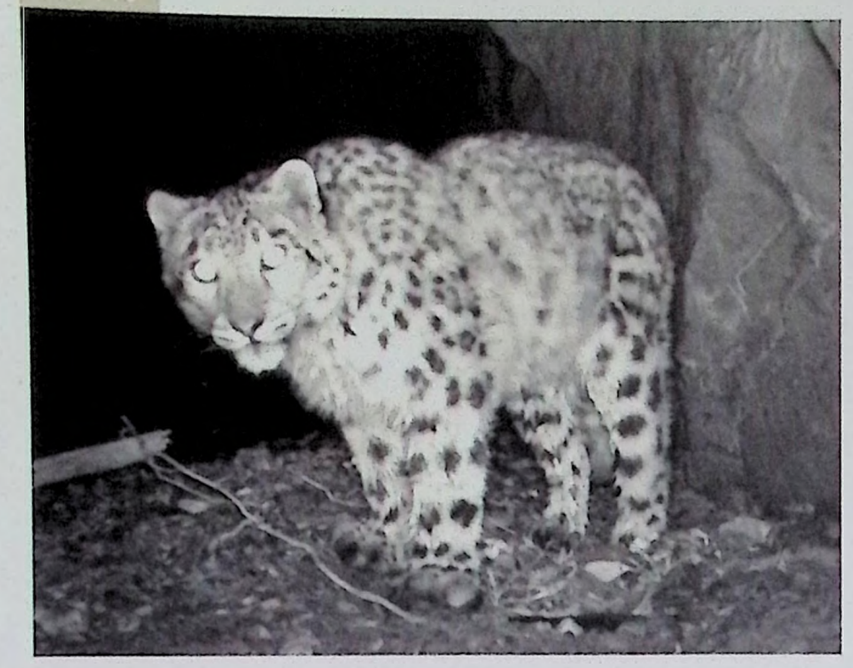

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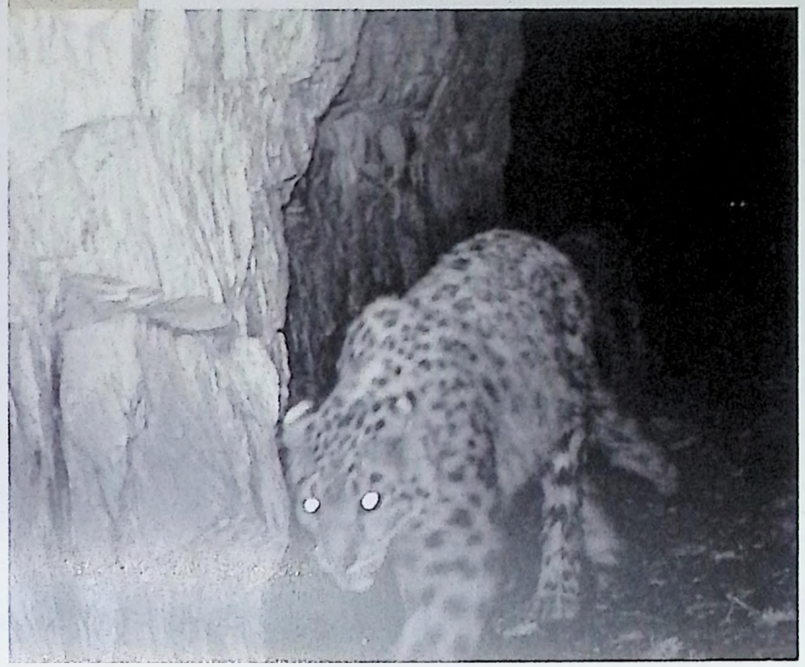

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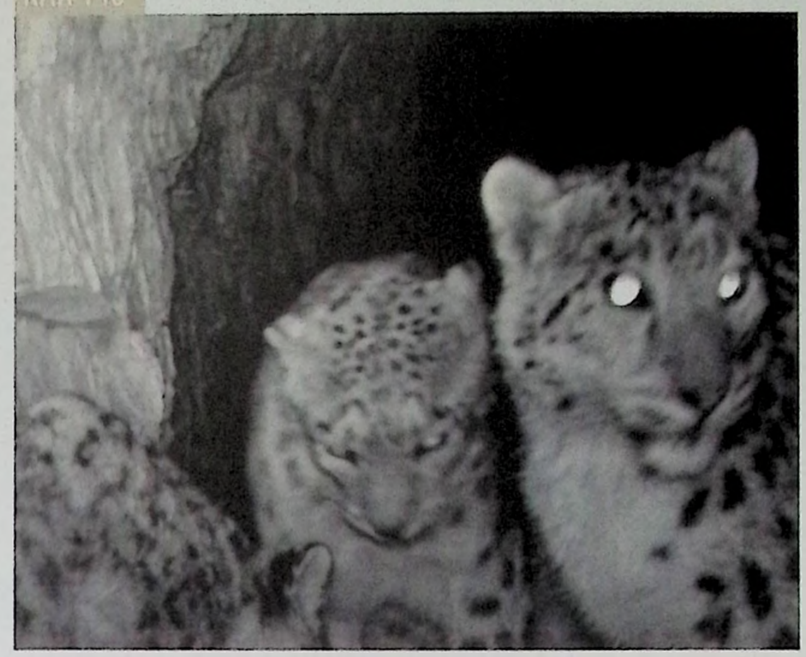

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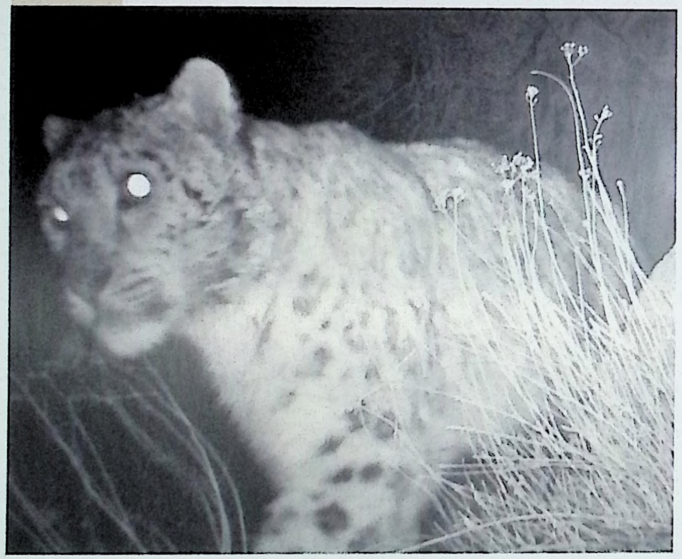

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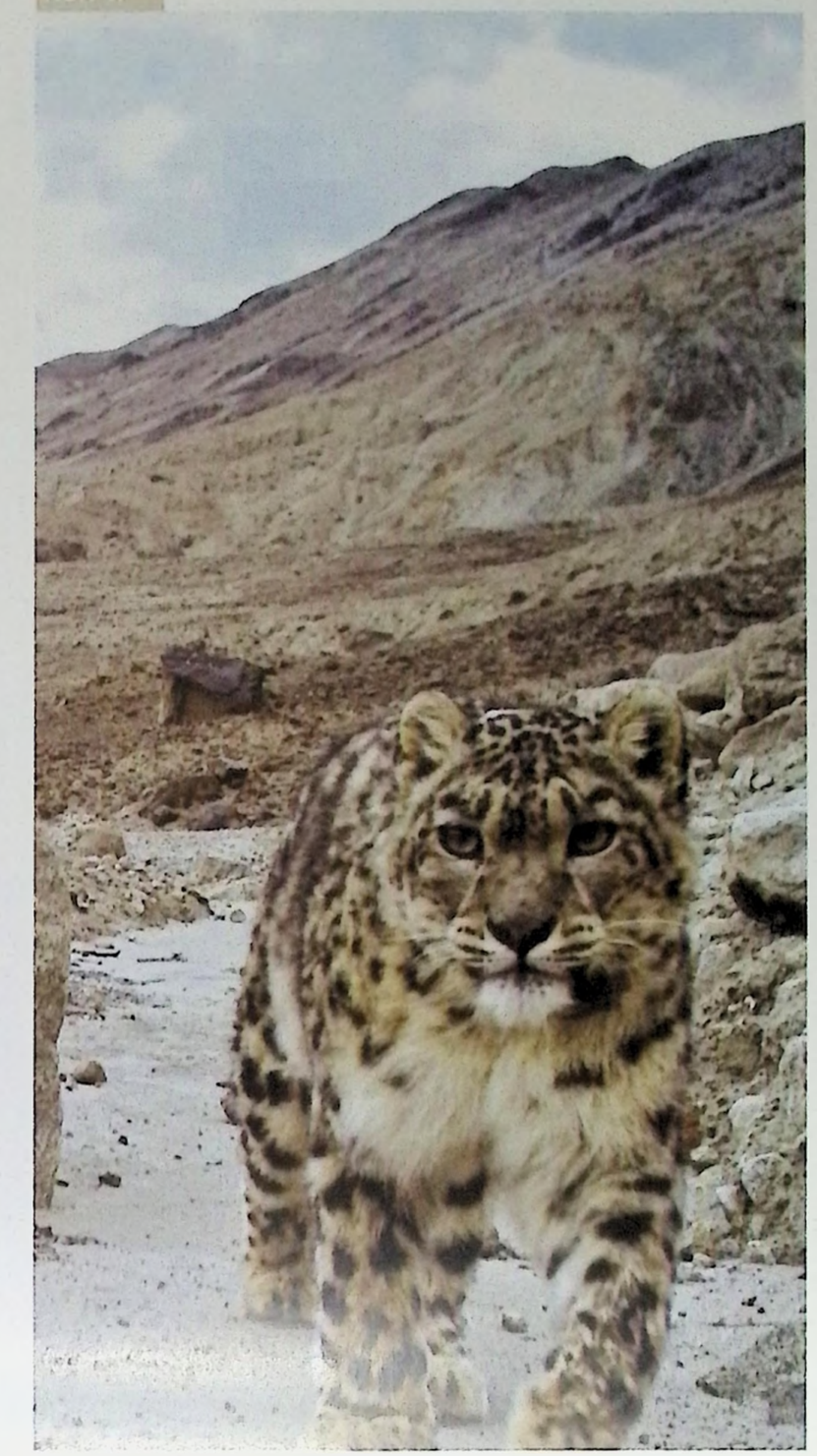

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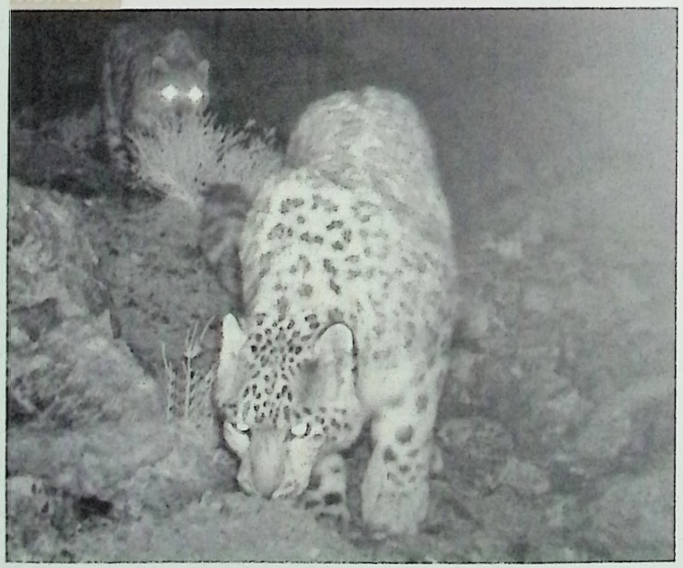

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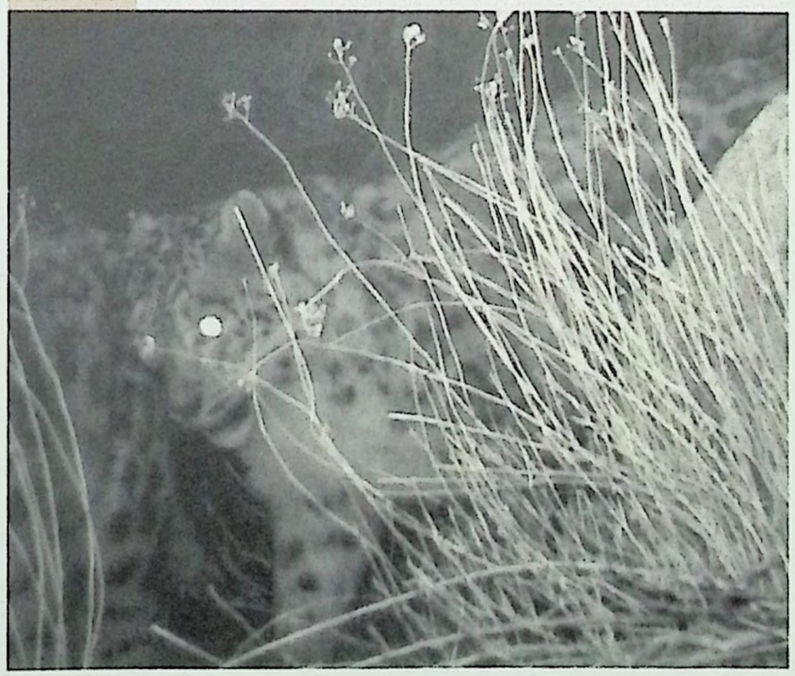

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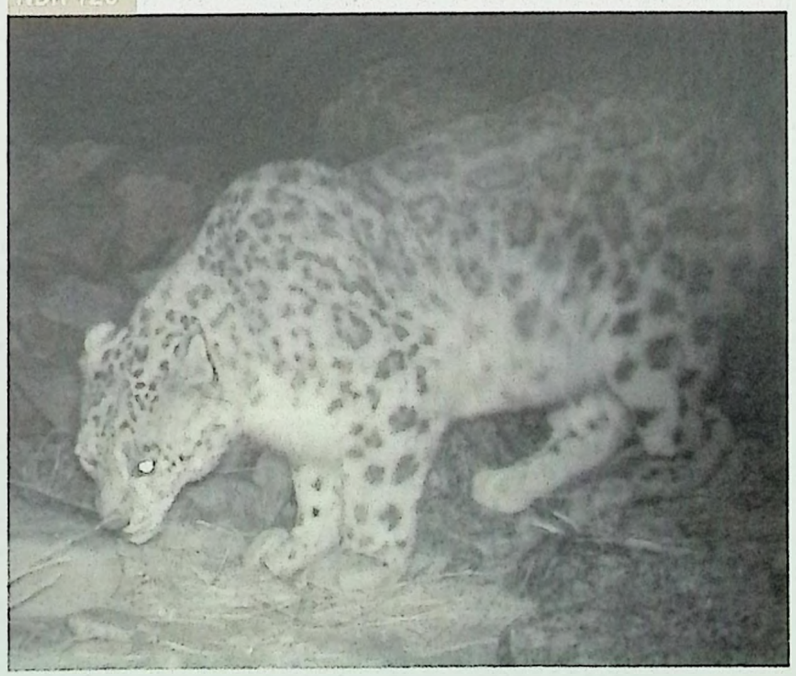

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(Appendix II)

Snow leopard population assessment in Jammu and Kashmir

INTERIM PROJECT REPORT

(Assessment Year 2016-17 & 2021-23)

Submitted to

Ministry of Environment, Forests and Climate Change

(Government of India)

Executing Agency

Department of Wildlife Protection

Govt. of Jammu and Kashmir

PROJECT PARTNERS

niversity of

SKUAST

National Development

d on

Nature Conservation

F

Wildlife Trust of India

EXECUTIVE SUMMARY

The majority of snow leopard surveys in the erstwhile Jammu and Kashmir were limited to Ladakh. Institute of Mountain Environment (IME), University of Jammu pioneered the snow leopard surveys with the goal to understand the spatiotemporal change in snow leopard distributions in Kishtwar high altitude National Park (KNP) in 2016. This was the first attempt of an assessment on occupancy and human – snow leopard interactions at the landscape level in the region. Post reorganization of Jammu and Kashmir, the Department of Wildlife Protection, Govt. of Jammu and Kashmir formally initiated the surveys for assessing the distribution and population estimates of snow leopard in the Lesser and Great Himalayan landscapes in J&K in the year 2021. The techniques used during the surveys aligned with the protocols prescribed by the Ministry of Environment, Forest and Climate Change under Snow Leopard Population Assessment in India (SPAI) as adopted across all Himalayan States where snow leopards occur. The project, currently in its third year, is being executed by many partners, including local research institutes and reputed scientific organizations, under the aegis of the Department of Wildlife Protection, J&K. The study employed various data collection methods, including interviews and sign-based occupancy surveys, camera trapping, and genetic sampling. The report presents the results based on occupancy and spatial capture-recapture.

The summary of the results obtained for this project:

1. This is the first systematic effort at a regional scale to estimate snow leopard population over an area of 12,700 km^2 following two step strategy prescribed under SPAI. The first step included occupancy surveys that provided a probabilistic distribution map of survey units (grids) utilized by snow leopard occurrence across two time periods (25 years apart) based on questionnaire surveys of local communities residing around Kishtwar high altitude National Park (henceforth Kishtwar National Park). Step two, involved the intensive camera trap surveys carried out in whole landscape covering Greater and Lesser Himalayas. Greater Himalayas is roughly divided in three regions, namely the northern Zojila-Thajwas-Baltal circuit, the middle Wadwan-Marwah-Dachhan (Kishtwar national Park) circuit, and south-eastern Paddar circuit. The lesser Himalayan landscapes including Kailash ridge in south and Pir Panjal range reaching far west bordering Pakistan were also surveyed for snow leopards.
2. The probability of site-use (occupancy) by snow leopard was defined as a quadratic function of elevation indicating that snow leopards were likely to use moderately higher elevations. The models suggested on upward shift of snow leopard with pronounced local abandonment near human settlements at lower elevations. This was higher than the colonization rate for the species implying a decline in its spatial distribution over a period of 25 years.
3. The sample counts based on camera trap were used to compute abundance and density of snow leopard. A grid size of 5*5 km^2 was chosen to ensure that it was less than the typical snow leopard home range to allow for recaptures. A total of 225 grids (sampling units) were delineated using randomized grid search method while optimizing the spatial coverage.

4. A total of 278 Infra-red cameras were deployed at 135 locations involving 80 grids (75 in Greater and 5 in lesser Himalayas) randomly across the entire landscape at an elevation of 1700-4780 meters. The entire survey effort totalled 20,207 active camera trap nights.
5. The snow leopard was photo captured in 25 of the 135 locations with two frames recording a female with two sub-adults and a pair, respectively. While most snow leopard sightings have occurred in Kishtwar National Park, the animal has only been captured twice outside the protected area. This includes a single detection each from Kashmir's Thajwas-Baltal Wildlife Sanctuary (PU-2) and Wadwan Valley, Kishtwar (PU-3). The animal has been detected at an altitude of 2970–4120 meters.
6. We identified nine individual snow leopards, seven adults and two sub-adults from 25 detections. Four individuals were excluded from the analysis owing to poor image quality and bad capture angle. This dataset is however inadequate to estimate the size of the snow leopard population across the entire landscape.
7. Most detections were observed in Renai (n=6) followed by Kiyar (n=17) in Kishtwar National Park. Seven of the nine individuals were re-captured at more than two occasions. PU-5 was captured on 11 occasions followed by PU-1 (four occasions) and PU-6 and PU-7 (three occasions, each). PU-2 and PU-3, the ones outside the protected area were detected once only during the entire sampling. Snow leopard PU-5 exhibited a significant level of activity and mobility, as evidenced by its repeated recapture in both the Renai and Kiyar watersheds.
8. The current sampling efforts have yielded a moderately high snow leopard density of 0.75 individuals per 100 km^2, based on SECR. With only two detections observed beyond Kishtwar National Park during the entire effort, the SECR based density was evaluated for the park only. The low sigma values indicate 'valley confined' populations and this is ascertained by high recapture rates in Renai and Kiyar watersheds. The robust density estimates for the entire landscape shall be obtained following multi session SECR commencing this season.
9. Other carnivores detected during the sampling include Himalayan brown bear, Asiatic black bear, Tibetan wolf, red fox, yellow throated marten, leopard cat, Siberian weasel, stoat while the prey-base primarily comprised of Asiatic Ibex, musk deer, Himalayan Gray langur, long tailed marmot, Kashmir flying squirrel, pikas and a few Galliformes. The abundance, density and activity pattern of associate predators and prey base has not been computed and shall be projected in the final report due next year.

Given the efforts, the first of their kind in the region, the results are incredibly encouraging and indicative of immense snow leopard research potential of the landscape. The results provide a strong baseline that will be further refined following the rigorous surveys aimed to arrive at robust snow leopard population estimates for entire Jammu and Kashmir. The department is committed to extending its efforts as a long-term monitoring initiative aimed at tracking the population of snow leopards and their wild prey species across the whole snow leopard landscape in Jammu and Kashmir.

INTRODUCTION

A camera trap image of snow leopard in Kishtwar National Park

Snow Leopard *Panthera uncia*, the smallest member of the genus Panthera is the most elusive and sought over cat inhabiting cold and rugged mountain landscapes of Great and Trans Himalayas in north western Himalayas. Its secretive behaviour, camouflage, and adaptation to extreme environmental conditions makes it one of the most charismatic species in the world. The snow leopard is found across the high mountains of twelve countries of South and Central Asia and India has the third largest share of snow leopard distributional range. In India, the snow leopard is found in the Union Territories of Ladakh and Jammu and Kashmir, the states of Uttarakhand and Himachal Pradesh in the Western Himalayas and the states of Arunachal Pradesh and Sikkim in the Eastern Himalayas.

The erstwhile Jammu and Kashmir enjoyed being one of the richest abode of snow leopard in the Himalayas. After the reorganization of Jammu and Kashmir, while Ladakh retained the vast and well-known snow leopard habitat in the north, the Union Territory of Jammu and Kashmir (herein after Jammu and Kashmir) encompasses a potential north-eastern (Greater Himalayas) and the central arc (the Lesser Himalayas) that makes around 12,700 km^2 of the potential snow leopard landscape (Fig. 1). Nearly one-fourth of the geographic area of Jammu and Kashmir is located in the Great Himalayan region, the preferred habitat of the snow leopard, which borders Drass in the north and Zanskar in the east. Highly fragile, topographically complex and rugged, this landscape is mostly un-inhabited and disturbance free except for summers that witness the livestock migration of transhumant and local herders. The region is rich with unique animal species including the associate carnivores like Himalayan brown bear, Asiatic black bear, Tibetan wolf, red fox and the preferred prey base including Asiatic ibex, Himalayan tahr, musk deer and Himalayan marmot. The intactness and ecological integrity of the landscape is supported with the presence of two protected areas, Thajwas-Baltal Wildlife Sanctuary and Kishtwar high altitude National Park (here after Kishtwar National park), the largest protected area in J&K.

A typical snow leopard habitat in Haghsu Valley bordering Zanskar

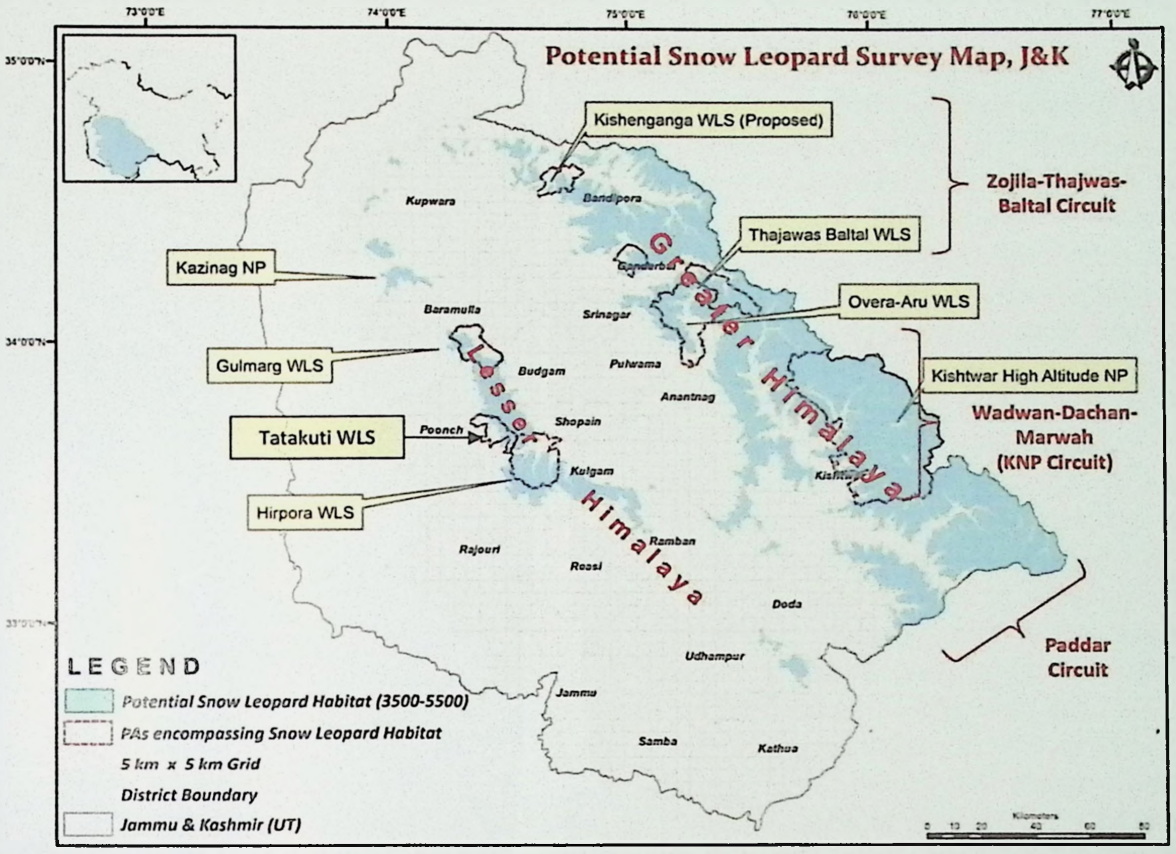


Fig- 1 Potential snow leopard habitat map overlaid with Protected area network in Jammu and Kashmir

The Lesser Himalayas (the Pir-Panjal), which separate the Kashmir Valley from Jammu, also contain a number of protected areas, the most notable of which are Kazinag National Park, Hirpora Wildlife Sanctuary, and Gulmarg Wildlife Sanctuary (Fig 1). These landscapes provide immense ecosystem services and sustains the subsistence of millions of people living downstream.

Though no reliable global snow leopard population estimates exist on date, their number seems to fluctuate between 3900 to 8745 (McCarthy et al 2016). The IUCN recently down listed the snow leopard from Endangered to Vulnerable (McCarthy et al 2017). To get the number right, there is a need to sample large contiguous heterogenous landscapes including the protected areas and multi-use landscapes. The governments of the twelve snow leopard range countries agreed to a collaborative effort called PAWS, or Population Assessment of World's Snow Leopards (The Bishkek Declaration 2017). The Indian government responded by releasing the methodological guidelines for a countrywide Snow leopard Population Assessment in India (MOEF 2019). Now with the recreation of boundaries, the Department of Wildlife Protection, Jammu and Kashmir initiated a new APO and adopted the modalities for assessing the distribution and population estimates of snow leopard in northern Greater Himalayan landscapes bordering Kargil and Zanskar and the central Lesser Himalayas bisecting Jammu from Kashmir region. For the sake of administrative convenience, the vast northern landscape is roughly divided into three regions, the northern Zojila-Thajwas-Baltal circuit, the middle Wadwan-Marwah-Dachan (Kishtwar National Park) circuit, and south-

eastern Paddar circuit in Greater Himalayas. The lesser Himalayan landscape including Kailash ridge in the east and Pir Panjal range reaching far west bordering Pakistan have been considered as a single spatial entity for sampling (Fig -1).

The J&K's conservation efforts can be gauged by the fact that the current SPAI exercise is not restricted to protected areas but spread across the entire landscape with an equal thrust to the habitats outside the protected areas. As Ladakh had been the epicentre of snow leopard research, this region of erstwhile Jammu and Kashmir received little attention and remained deprived of any such surveys in the past until 2016, when researchers from Sher-e-Kashmir University of Agricultural Sciences and Technology – Kashmir used camera traps to establish the presence of the snow leopard in the Baltal-Thajwas Wildlife Sanctuary (Ahmed and Ahmed, 2016). Recent surveys conducted by the Institute of Mountain Environment, University of Jammu provided fascinating insights into the spatial and temporal distribution of snow leopards using an occupancy framework (Ahmed, 2021; Kichloo et al., 2023).

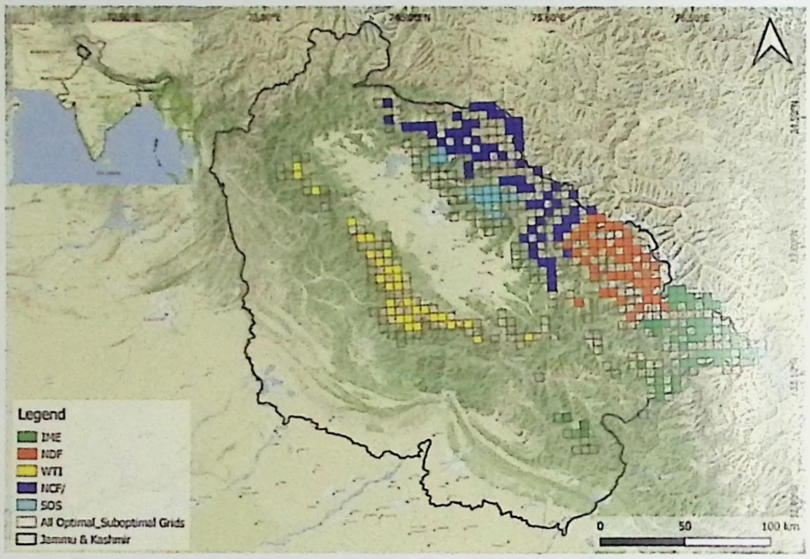


Fig-2 Map showing the grids allocated to different partners

In November 2021, the Department of Wildlife Protection, Government of Jammu and Kashmir, launched its ambitious Snow leopard population survey in J&K by involving a group of collaborators comprised of established scientific organizations and local institutes. The Ministry of Environment Forests and Climate Change (MoEFCC), Govt. of India designated Nature Conservation Foundation (NCF), Mysore as its technical partner and mentor for the snow leopard population assessment in the Union Territory. NCF in collaboration with National Center for Biological Sciences, Bangalore, and Snow Leopard Trust, organized a series of capacity building workshops on PAWS guidelines and SPAI protocols for local partners, researchers, and wildlife support staff. The partner institutes identified for SPAI J&K included Institute of Mountain Environment, Sher-e-Kashmir University of Agricultural Sciences and Technology – Kashmir, National Development Foundation, Nature Conservation Foundation, and Wildlife Trust of India. Each partner was assigned a patch of sampling grids that represented a specific region in Lesser and Great Himalayas (Fig 2).

Picturesque Gandhari Valley, Paddar

The snow leopard population estimates can be obtained through the use of appropriate sample counts using camera trap (Karanth, 1995) or molecular genetics (Mondal et al., 2009). The cameras are deployed in microhabitats preferred by snow leopards, spread across the study area using a uniform grid system or a random spatial design (Alexander et al., 2015; Jack- son et al., 2006; Sharma et al., 2014). Individual snow leopards are identified from photographs using their distinctive pelage patterns, and the data are analyzed by generating individual capture histories in order to estimate population density and size (Alexander et al., 2015; Sharma et al., 2014). Recent advances in Spatially Explicit Capture-Recapture (SECR) methods have increasingly put camera traps at the forefront of population monitoring programs.

Population density is a useful parameter for many ecological purposes. SECR methodology is a widely accepted population density estimation tool to monitor populations of large carnivores and it incorporates animal movement in the statistical estimation process. Some applications require estimates of population size rather than density, and population size in a defined area may be obtained as a derived parameter from SECR models. SECR based density estimation was developed independently by Borchers and Efford (2008) and Royle and Young (2008). What separates SECR density estimation from closed capture-recapture models is the incorporation of an explicit spatial component to each individual's detection history, as well as a defined state-space over which density is estimated (Efford and Fewster, 2013; Royle et al., 2014). SECR models explicitly use the spatial information of detection location at the camera traps, accounting for the heterogeneity in captures due to animal activity center location. Decline in detection probability with the distance between a detector and a home range center can likewise be inferred from the clumping of locations at which each individual is observed. This requires that some individuals are detected at multiple locations. Due to a lack of adequate multi session data and number of recaptures in the given data set, we performed single session SECR to estimate snow leopard population densities in the current sampling effort.

Upper Hagshu Valley, Paddar bordering Zanskar range

Though most of the snow leopard surveys in the region focused on assessing distribution, habitat suitability and human-animal interactions, no rigorous field studies have been conducted on estimating abundance and density of snow leopards in the Union Territory. These estimates are pre-requisite for establishing the baseline, assessing the efficacy of conservation efforts, and formulating management plans. SPAI-JK partners initiated the scientific investigations adopting a two-step sampling strategy, one involving occupancy-based snow leopard assessment (following questionnaire approach), and second, population sampling for regional density estimation of snow leopards using camera trapping.

The entire study area sprawled in 12,700 km^2 was divided into 490, 5*5 Km grids, which corresponded to the smallest snow leopard home range (reported in Nepal) and allowed for the most effective recaptures. The grids were further reduced to 225 using a random grid search approach yet retaining the spatial representativeness of the landscape (Fig 3). The report depicts the estimates of the distribution, abundance, and density of snow leopards, but not their prey base.

METHODOLOGY

The study used a two-step sampling process recommended by the PAWS guideline (Sharma et al. 2019) to ensure robust design and adequate coverage of the Union Territory. First the macro level sampling to identify the sites where camera-trapping and ungulate surveys were to be conducted, and second the micro level sampling to deploy cameras, transect walks, genetic sampling, and questionnaire surveys at each site (grid). The potential snow leopard habitats were identified on the assumptions that the animal prefers the elevation above 3000 m to 5500 m, avoids the forested areas with canopy cover more than 50%, and stay away from permanent glaciers and steep rocky terrain based on literature and recent surveys in KHNP (Kichloo et al. 2023).

A grid size of 5*5 km^2 was chosen to ensure that it was less than the typical snow leopard home range (12-39 km^2 to 124-207 km^2) to allow for recaptures. In view of the above, 225, 5*5 km grids (sampling units) covering 12,700 km^2 of potential snow leopard habitat was delineated using randomized grid search method while optimizing the spatial coverage (Fig 3). The grids were plotted in Google Earth (Google Inc., USA), and all known landscape features were identified and marked. While the report aimed to cover the Great Himalayan landscapes, the ideal snow leopard habitats, it did not rule out the possibility of animal's presence in lesser Himalayan landscapes that were also duly scanned for the signs of snow leopards.

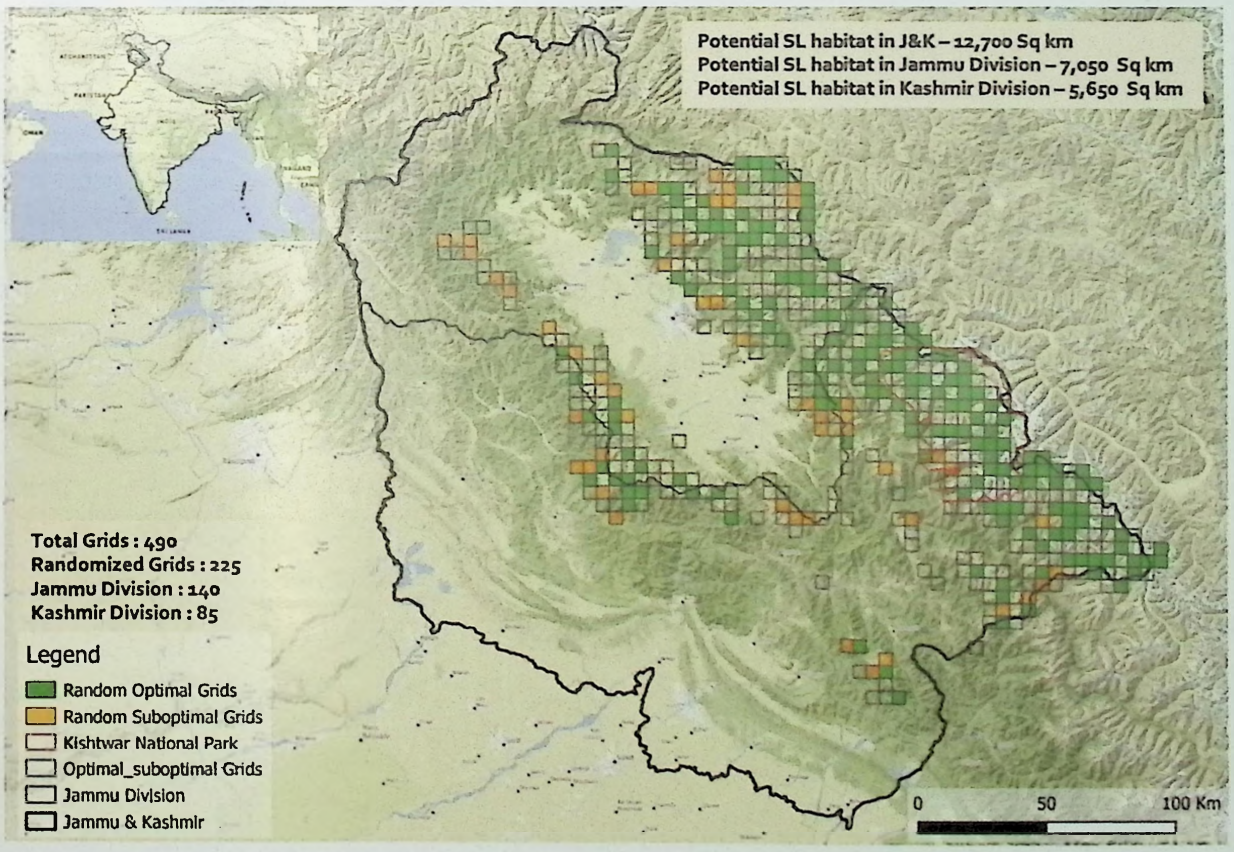


Fig - 3 Potential snow leopard habitat map of Jammu Kashmir overlaid with optimal and sub-optimal grids based on randomized grid search approach

1. Species site use (Occupancy)

Questionnaire based surveys were conducted with the locals who spent considerable time in the study area, the Kishtwar National Park (Fig. 4) and analyzed reports of detection and non-detection by interviewees using a multi-season occupancy framework (MacKenzie et al., 2006). Four broad target groups were identified, a) tribal shepherds (Bakerwals), b) forest and wildlife officials, c) gatherers, and d) others, that included forest resource gatherers or dwellers belonging to different professions. The information about grid-cells where interviewees reported snow leopard was arranged in a detection/non-detection (1/0) format. Occupancy estimates for the three species were considered as the probability of sites being used by each species in the respective time periods (1990s and 2016-17) by relaxing the assumption of closure of sites (MacKenzie and Nichols 2004; Taubmann et al. 2016; Mackenzie et al. 2018).

Data analysis :

Probability of local extinction (ε) was estimated as the probability of a site being used by the species in the past but not in the current period whereas the probability of colonization (γ) was considered the probability of a site being used in the current time period and not in the past (MacKenzie et al. 2018). Covariates that could influence the probability of a site being used by a species, its local extinction and colonization were incorporated in the models using logistic insertion. Six spatial layers *viz.,* elevation, slope, aspect, percentage area under glaciers, normalized differential vegetation index (NDVI), and least cost path distance from the nearest settlements were developed using Geographical Information System (GIS). Data on glaciers and waterbodies was downloaded from Geofabrik (https://www.geofabrik.de/data/shapefiles. html). The spatial datasets were averaged for each of the 25 km^2 sampling unit to be used as site covariates. The probabilities of site-use (ψ), detection (p), local extinction (ε), and colonization (γ) were modelled for the two time periods using package rPresence v 2.0 (Proteus, Dunedin, New Zealand) in the R programming interface (version 4.0.3, https://www.r- project.org/) using RStudio (RStudio Team 2022). The study developed candidate set of 24 single species multi-season models (MacKenzie et al. 2003) for snow leopard. Model outputs were ranked based on Akaike weights (Anderson & Burnham 2002) with top models representing minimum Akaike Information Criteria (AIC) values. Highly correlated covariates were not used in combination when defining a particular model. The analysis was performed in QGIS, version 3.14 (QGIS Development Team, 2023).

2. Micro sampling (Camera trapping)

The sites for the IR camera deployment were selected for the micro-habitats that are preferred by snow leopards but spread across the study area in a uniform grid system or distributed randomly in space (Alexander 2015; Jackson, 2006; O'Connell, 2010; Sharma et al., 2014). Camera-trapping was performed in 80, 5*5 km^2 grids spread across entire snow leopard habitat in the entire J&K. The Infrared cameras (Reconyx, Cuddeback make) were installed for 45-60 days, during which, cameras were checked once for battery condition and for replacement of memory cards. The IR cameras were placed between 30 and 50 cm above the ground (Jenks et al., 2011; Tobler et al., 2008) along paths, trails, overhanging rocks, cliffs, ridgeline saddles etc, based on prevalence of snow leopard signs such as hair, scat, scrape or urine spray marks and suitable microhabitats to maximize detection within each cell. The trap locations were spaced at least 800 - 1000 meters apart.

Image classification

Image classification was done in two phases – image identification phase followed by the review phase that involved two teams each from IME and NCF. Rosette patterns from the face, limbs, rump, shoulder, upper parts of the tail and cheeks of the snow leopard were used to identify different individuals. All the identified individuals were reviewed by team-2 at respective institutes and in case of insufficient evidence towards identification, the individual was discarded for further analysis. Following the individual identification for each site, image comparisons across sites were made to check if any of the individuals were detected at more than one site. All snow leopard images were tagged using the digiKam image management software (https://www.digikam.org/) and tags were read- out using the CamtrapR (Niedballa et al., 2016) package.

SECR based density estimates

A maximum-likelihood based single-session SECR model was used to estimate population densities of snow leopards (Efford and Fewster 2013). SECR models explicitly use the spatial information of detection location at the camera traps, accounting for the heterogeneity in captures due to animal activity centre location. Heterogeneity may arise because the probability of capture in a specific camera trap depends on its location relative to the animal's activity centre (Efford et al., 2009). A buffer size of 14 km was used around the traps to model the state-space. A habitat mask which excluded non-habitable areas above 5200 meters ASL was incorporated into the state-space. A half-normal detection function was used to model detection probability and trap response was assumed to be absent. The model was implemented using R Package 'secr' (Efford 2016) in R (version 3.2.3) (R Core Team 2023). Abundance was obtained using a buffer of 4-km which best represented the sampled region.

RESULTS

1. Site use (Occupancy)

In total, 102 interviews were conducted within and outside Kishtwar National Park (Fig 4). Average sampling area coverage reported by each respondent was 24 grids or 600 km^2 (range: 9–46 or 225–1150 km2; SD=10.7 or 268 km^2), and average active period in the area of knowledge was 30.5 years (range: 8–60 years; SD=13.5 years). Interviewees reported the presence of snow leopard in 38 (naïve occupancy = 0.34) sampling units. The study used 24 single species multi-season occupancy models for snow leopard.

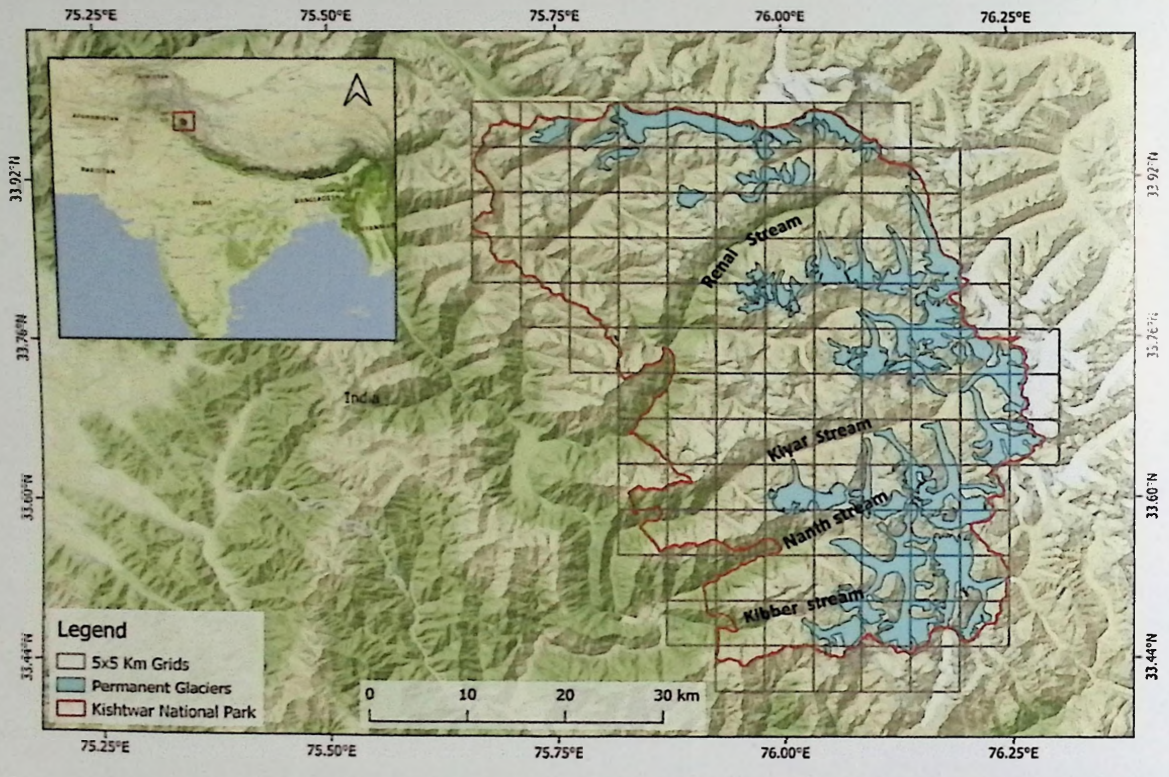


Fig - 4 Kishtwar high altitude National Park (KNP) and the sampling grids. A total of 73 (64.6%) grids were represented in 102 interviews conducted for this study (Kichloo et al, 2023).

The models were ranked for each species on the basis of their respective AIC weights in decreasing order (Supplementary Information, S2). Here the study present the top 10 models for each species (Table - 1).

Table 1 : Top ten models from the candidate model of 24 models for snow leopard

S. No	Model	ΔAIC	AIC weight	N par	Likelihood
1	psi(Elev + I(Elev^2)), p(Season + Occupation), gamma(), epsilon(Stlm)	0	0.493	11	1017.78
2	psi(Elev + I(Elev^2)), p(Season + Occupation), gamma(), epsilon(Stlm + Glacier)	1.18	0.2731	12	1016.96
3	psi(Elev + I(Elev^2)), p(Season + Occupation), gamma(), epsilon(Glacier)	3.65	0.0796	11	1021.43
4	psi(Elev + I(Elev^2)), p(Season + Occupation), gamma(), epsilon(Slope)	4.27	0.0583	11	1022.05
5	psi(Elev + I(Elev^2)), p(Season + Occupation), gamma(), epsilon()	4.93	0.0418	10	1024.71
6	psi(Elev + I(Elev^2)), p(Season + Occupation), gamma(), epsilon(Elev)	6	0.0245	11	1023.78
7	psi(Elev + I(Elev^2)), p(Season), gamma(), epsilon()	7.56	0.0113	7	1033.34
8	psi(Elev + I(Elev^2)), p(Season + Age), gamma(), epsilon()	7.88	0.0096	8	1031.66
9	psi(Elev + I(Elev^2)), p(Occupation), gamma(), epsilon()	8.73	0.0063	9	1030.51
10	psi(Slope), p(Season + Occupation), gamma(), epsilon(Glacier)	13.28	6.00E-04	10	1033.06

Detection probability

The top models indicated that the detection probability varied between two seasons by a factor of–0.53 (SE=0.24) on the logit scale for snow leopard. NFTP gatherers were more efficient at detecting and reporting snow leopard ($\beta_{SLp:gatherers}$=0.77, SE=0.38) followed by shepherds ($\beta_{SLp:shepherd}$=0.74, SE=0.37). Age and the period respondents remained active in the area of knowledge did not seem to affect the detection probability of the species (Table - 2).

Table – 2 Untransformed estimates of coefficient (β) from the top models of snow leopard

Covariate	Snow leopard β ± SE
Occupancy (Ψ) Elevation (Elevation)^2 Settlements NDVI	 -0.83 ± 0.34 -0.65 ± 0.24 - -
Detection Probability (ρ) Season NTFP gatheres Others Shepherds	 -0.53 ± 0.24 0.77 ± 0.38 -0.09 ± 0.57 0.74 ± 0.37
Abandonment (ε) Elevation Settlements	 - -1.21 ± 0.60
Local Colonization (γ) Elevation	 -

Species site-use, expansion, and contraction

The top model defined probability of site-use by snow leopards as a quadratic function of elevation ($\beta_{SLelevation}$=–0.83, SE=0.34; $\beta_{SLelevation^2}$=–0.65, SE=0.24) indicating that snow leopards were likely to use moderately higher elevations as opposed to high and low elevations (Fig 5). Probability of local abandonment was higher than the colonization rate for the species indicating an overall decline in its spatial distribution over the years. Further, the probability of snow leopard having faced local abandonment was greater closer to the settlements ($\varepsilon_{SLsettlements}$=–1.21, SE=0.60), than at higher altitudes.

Overall, while snow leopard showed an upward shift away from settlements with marked local abandonment at lower elevations (Fig 6). Sampling units with a major portion of their area under permanent glaciers were also less likely to have undergone local extinction of snow leopards ($\varepsilon_{SLglaciers}$ = – 0.42, SE = 0.51).

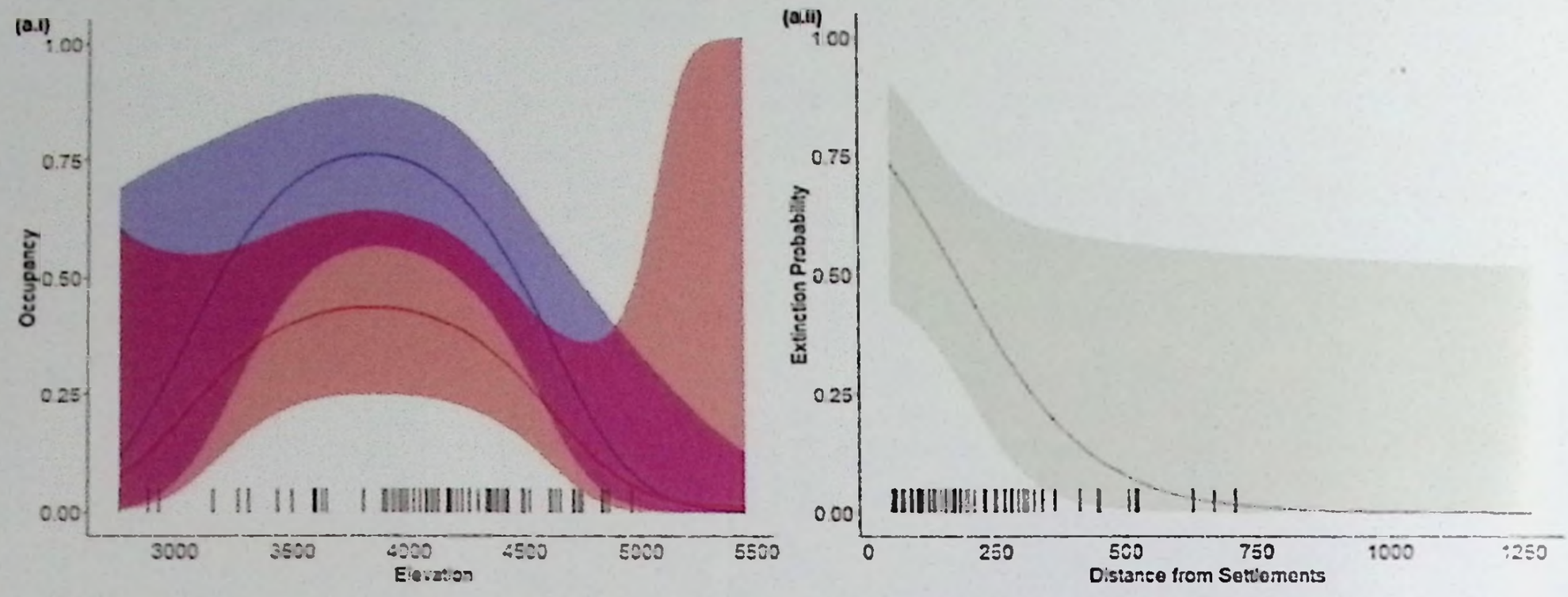


Fig. 5 Relationship between the probability of site-use (occupancy) in the past (blue) and present (red) time periods, and local extinction probability as a function of covariates included in the top model for (a) snow leopard [(i) occupancy~elevation; (ii) abandonment ~Distance from settlements] (Kichloo et al., 2023)

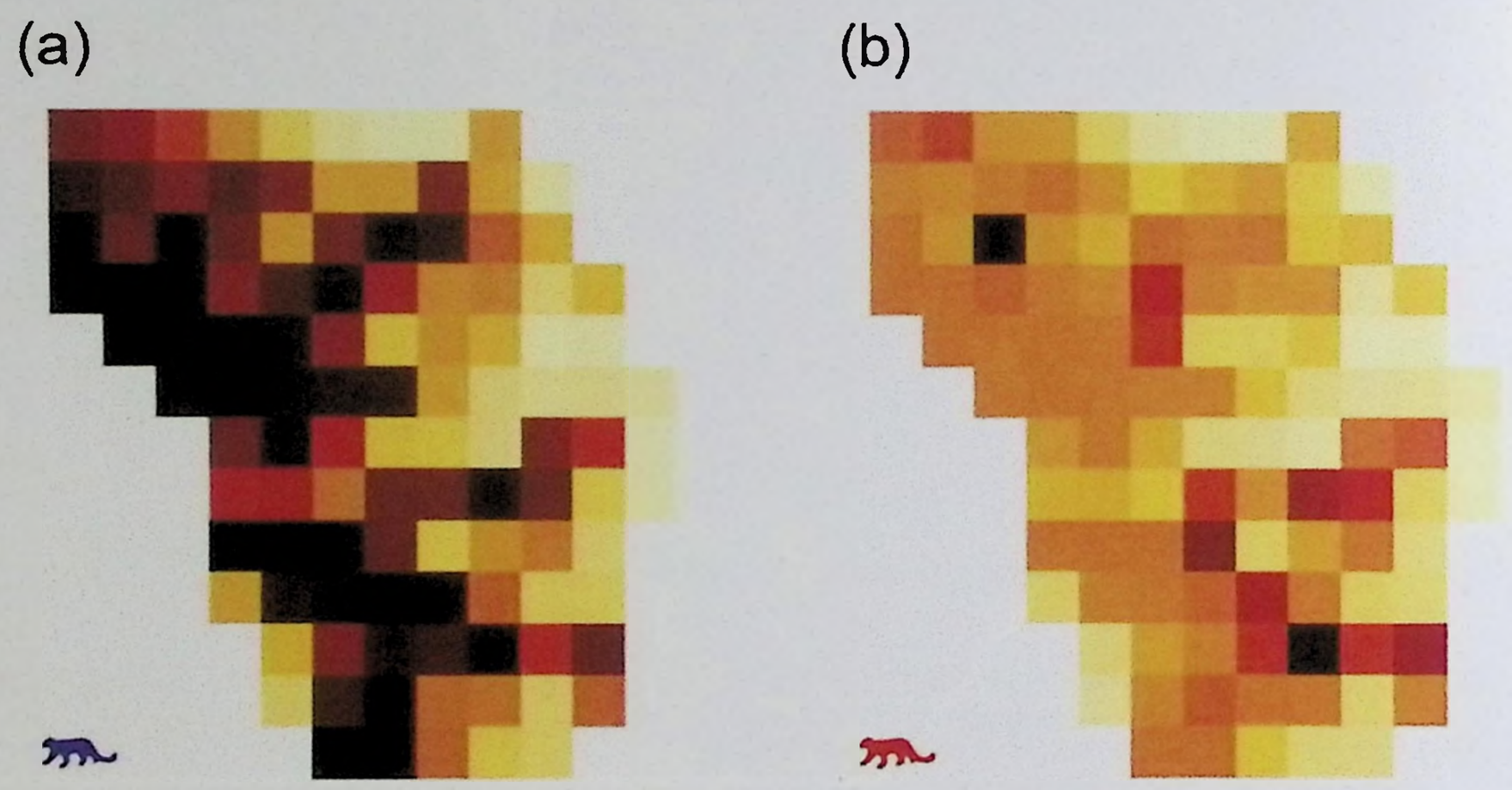


Fig. 6 Probability of sites being used by snow leopard (a, b) in the past (1990s), and current (2016– 2017) time periods respectively. Each past and current distribution of the species is estimated using the top model as selected by minimum AIC (Kichloo et al., 2023)

2. Camera trap based snow leopard abundance and density:

Snow leopards were detected in 25 of the 135 sites surveyed in 80 grids involving 278 cameras (Fig 7). Nine individual snow leopards, seven adults and two sub-adults have been identified.

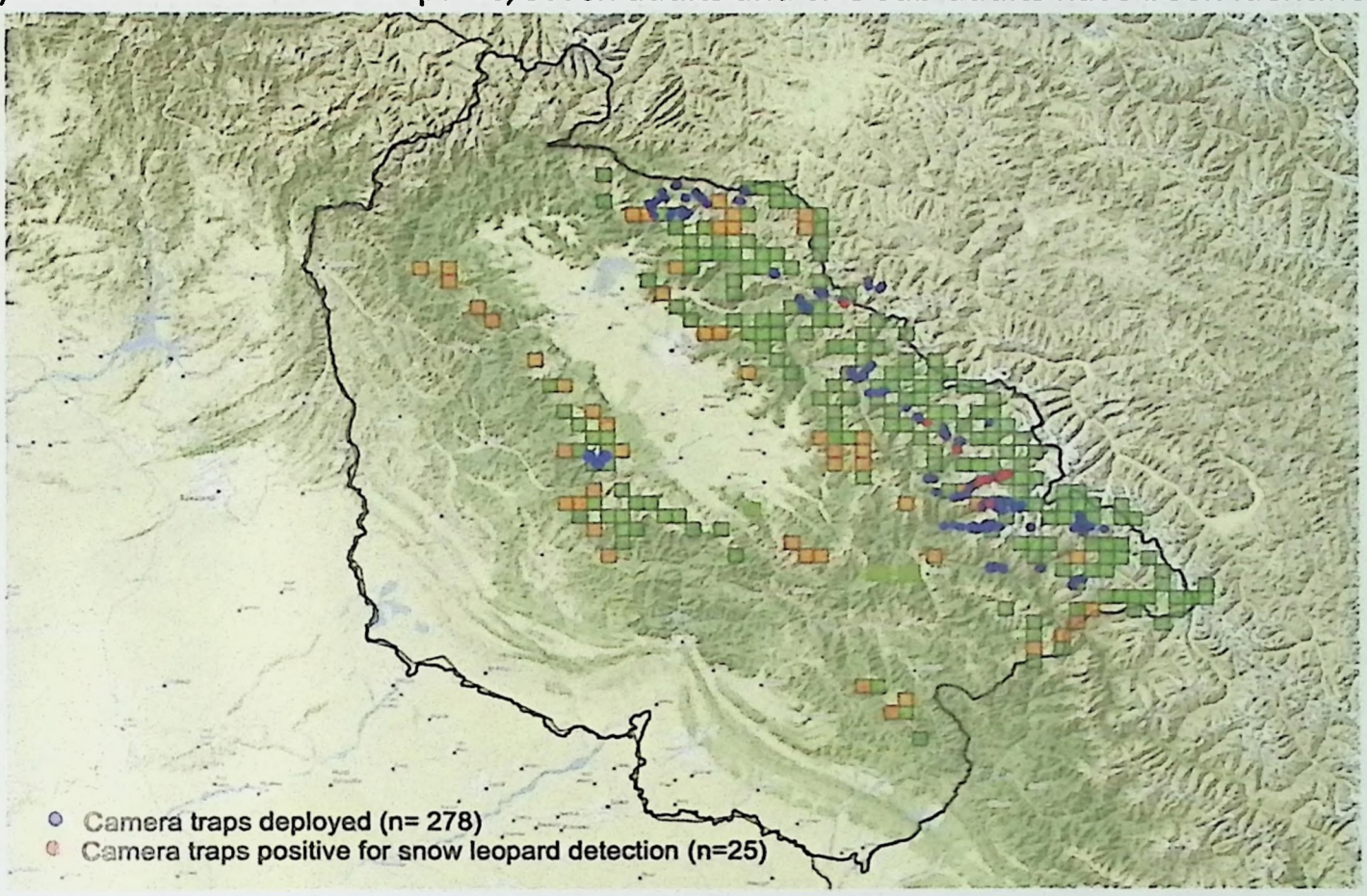


Fig 7. Map showing total camera traps deployed and camera traps positive for snow leopards. The grids in green are the optimal and those in orange are sub-optimal

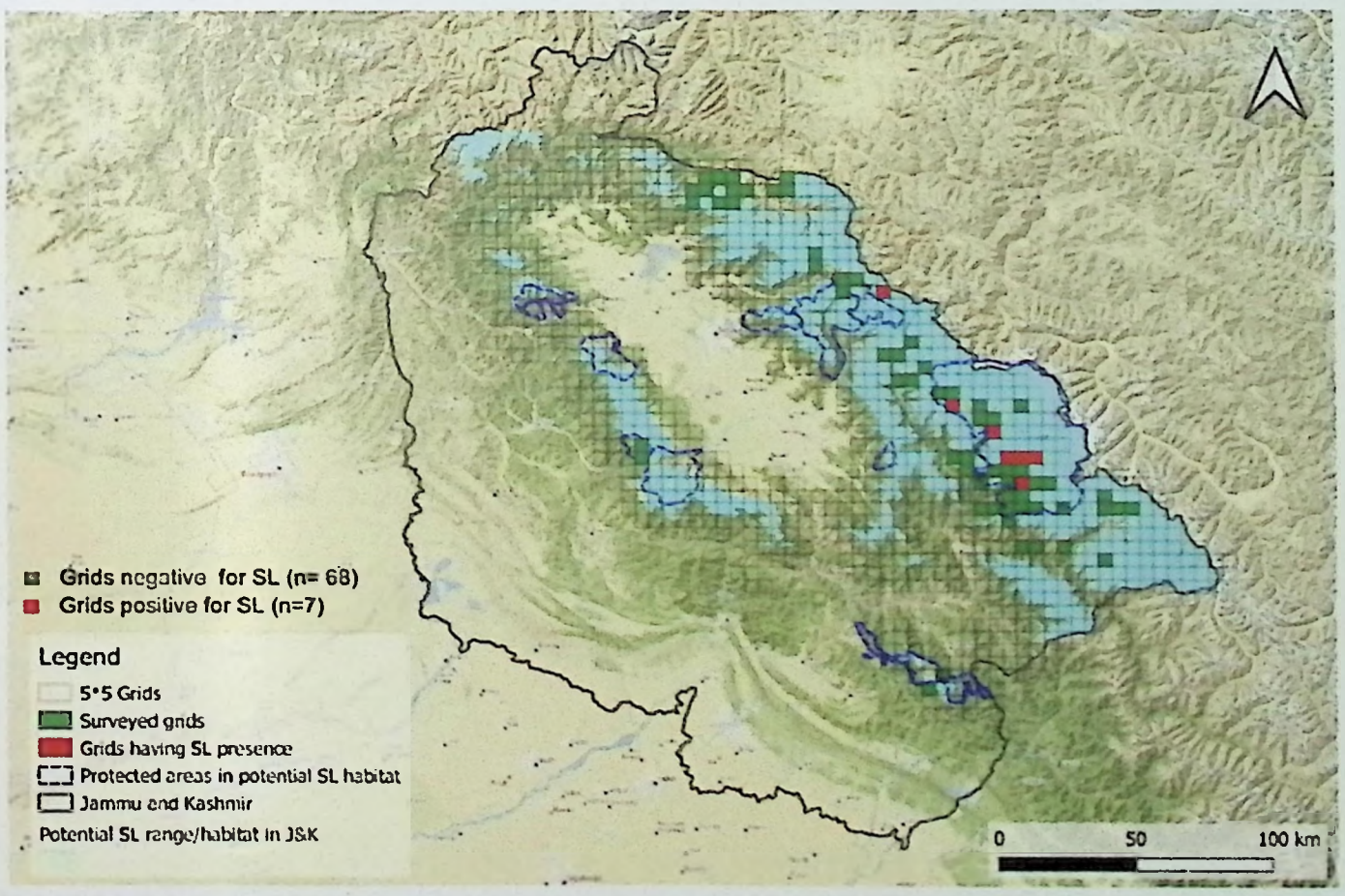


Fig 8 Map showing grids positive (red dots) and negative (blue dots) for snow leopard presence.

Estimated snow leopard population size (SECR based) in the current sampling effort is likely to be 13 individuals. Four individuals were excluded from the analysis owing to poor image quality and bad capture angle. This dataset is however inadequate to estimate the size of the snow leopard population across the entire landscape. Of the 75 grids camera trapped in the Greater Himalyas, seven were found postitve for snow leopard (Fig 8).

Image classification

The image classification yielded 9 individuals, seven adults and two sub-adults across 135 locations. The snow leopards have been named as PU (*Panthera uncia*) followed by arabic numeral, say PU-1, PU-2 and so on. One detection each comes from the Thajwas-Baltal Wildlife Sanctuary and Wadwan landscape, while the rest are confined to the Renai (n=6) and Kiyar watersheds (n=17) of Kishtwar National Park. Two of the images showed a female with two sub-adults and, a mating pair in Renai watershed. Seven of the nine individuals were re-captured at more than two occasions with PU-5 captured 11 times followed by PU-1 (four occasions) and PU-6 and PU-7 (three occasions, each). PU-2 and PU-3 were detected once only during the entire sampling (Table-3). Snow leopard PU-5 exhibited a significant level of activity and mobility, as evidenced by its repeated recapture in both the Renai and Kiyar watersheds. The animal has been detected at an altitude of 2970–4120 meters, with a few detections along the forest edges. Most of the detections are during the months of May and October.

Table 3 : Site wise details about camera trapping effort, date of detection and snow leopard id

S.No.	Sampling site	Region / PA	Date	ID
1.	Kainpathri 3	Thajwas-Baltal WLS	09/05/23	PU 3
2.	Dandoli pad	Wadwan, Kishtwar	19/05/23	PU 4
3.	Jayal top(Renai)	Kishtwar National Park	03/07/23	PU 1
4.	Jayal top(Renai)		03/11/22	PU 1
5.	Jayal top(Renai)		02/12/22	PU 7 and PU 8
6.	Jayal top(Renai)		19/02/23	PU 7, PU 8, PU 9
7.	Jayal top(Renai)		30/11/22	PU 5
8.	Jayal top(Renai)		12/05/22	PU 5
9.	Kiyar nallah		30/11/22	PU 1
10.	Kiyar nallah		21/10/22	PU 5
11.	Kiyar nallah		08/04/23	PU 5
12.	Kiyar nallah		10/04/23	PU 5
13.	Kiyar nallah		11/10/22	PU 7
14.	Dodtang		07/04/23	PU 1
15.	Drash		29/05/23	PU 4
16.	Sarbal top		11/05/23	PU 5
17.	Geem		27/05/23	PU 5
18.	Geem		15/06/23	PU 5
19.	Geem		25/05/23	PU 5
20.	Padhi cliff		28/05/23	PU 5
21.	Sarbal top		11/05/23	PU 5
22.	Sarbal top		23/05/23	PU 6
23.	Geem		13/05/23	PU 6
24.	Sarbal top		13/05/23	PU 6
25.	Sarbal top		13/05/23	PU 6

The first Snow leopard to be detected, PU-5 was photo captured on May 12, 2022 in Jayal Top, Renai, while PU-2 was photographed in Thajwas Baltal Wildlife Sanctuary on October 01, 2022. A classic frame of three individuals, a female with two sub-adults (PU-7, 8 & 9) captured on February 19, 2023 in the Renai watershed established an active breeding population within the park (Table-3).

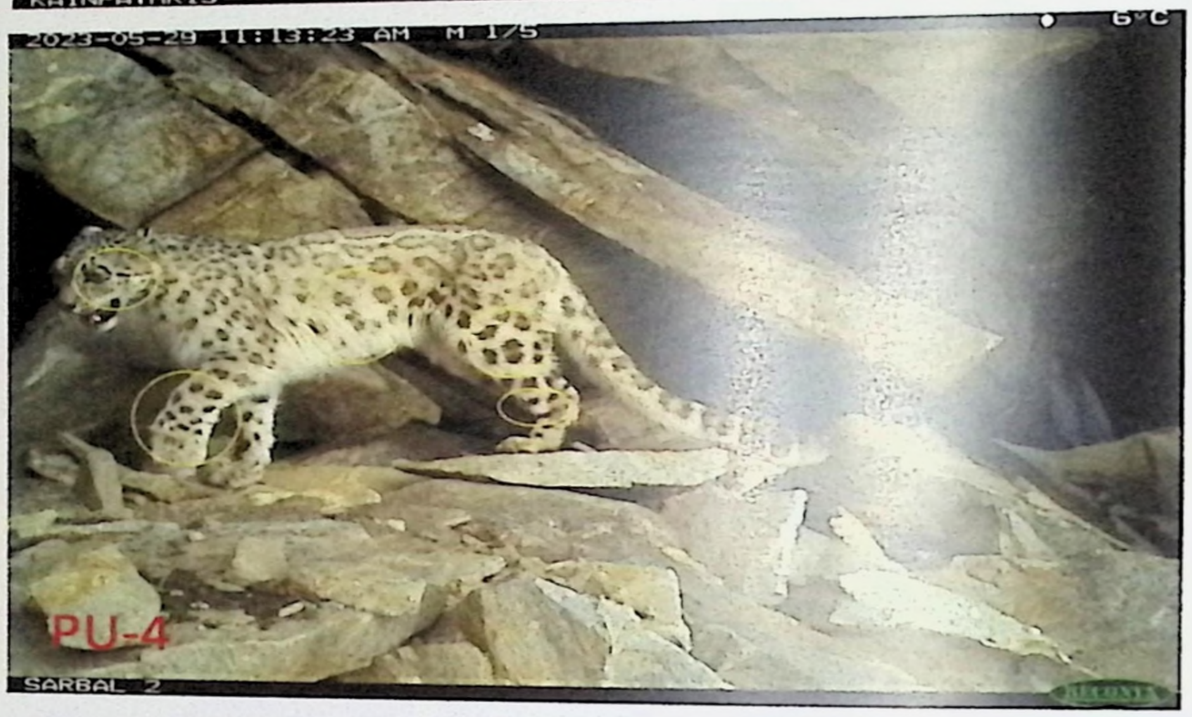
SECR based density estimates

Table 4 shows the SECR results. The estimated density was 0.75 individuals per 100 sq.km. (0.22-2.56). This resulted in an estimated abundance of 5 individual, with minimum 4 and up to 13 individuals present. In SECR models 'detectability' is modelled as a (typically halfnormal) function of distance, so the parameters g0 and sigma that together define that function replace 'p' (detection probability) in non-spatial models. 'Sigma' on its own can be interpreted as an index of home range size, but not directly as 'average distance moved': in some idealized conditions it may equal the sigma of a circular bivariate normal home range model. A sigma of 3383 m (1709 m – 6696 m) with a g0 of 0.013 seems to suggest that snow leopards here move lesser compared to snow leopards in more trans-Himalaya habitats like (who have estimated sigma of over 4,500m). This could indicate a population that is restricted to certain regions within a valley in and around Kishtwar National Park.

Table 4 SECR based estimate of Snow Leopards from Kishtwar National Park

Parameter	Estimate	SE	LCI	UCI
Density (per 100 sq.km.)	0.75	0.52	0.22	2.56
g0	0.013	0.007	0.004	0.038
Sigma (m)	3383	1215	1709	6696
Abundance (4km buffer)	5	1.46	4	13

SE = Standard Error, LCI = Lower Confidence Interval, UCI = Upper Confidence Interval.



Images PU-1 to 9 : Snow Leopard individuals identified in the current sampling effort

Non targeted mammal (carnivores and herbivores) species

While we did not attempt for computing the abundance and density of sympatric predators and prey species, we tend to highlight their co-occurrence based on photo captures. The carnivores detected during the sampling include brown bear, Asiatic black bear, Tibetan wolf, red fox, leopard cat, yellow throated marten, stone marten, Siberian weasel, stoat while the prey-base primarily comprised on Asiatic Ibex, musk deer, Himalayan Gray langur, long tailed marmot, pikas and a few Galliformes. The sympatric red fox was the most detected animal photo captured on 95 occasions followed by stone marten (77 occasions) brown bear (33 occasions) and Tibetan wolf (6 occasions). Among the prey species, Asiatic Ibex and Musk deer dominated the sampling area with 15 detections each (Table-5). The abundance, density and activity pattern of associate predators and prey base shall be projected in the final report due next year.

Table-5 Occurrence data on mammals (predators and prey base) based on the number Camera trap detections.

S.No.	Family	Species	Binomial name	Number of Detections	IUCN status
1	Cercopithecidae	Rhesus Macaque	*Macaca mulatta*	2	LC
2	Cercopithecidae	Himalayan Grey Langur	*Semnopithecus ajax*	1	EN
3	Moschidae	Himalayan Musk Deer	*Moschus leucogaster*	15	EN
4	Bovidae	Asiatic Ibex	*Capra sibirica*	15	NT
5	Felidae	Snow Leopard	*Panthera uncia uncia*	25	VU
6	Felidae	Leopard Cat	*Prionailurus bengalensis*	1	LC
7	Canidae	Tibetan Wolf	*Canis lupus chanco*	6	EN
8	Canidae	Red Fox	*Vulpes vulpes*	95	LC
9	Ursidae	Asiatic Black Bear	*Ursus thibetanus*	4	VU
10	Ursidae	Himalayan Brown Bear	*Ursus arctos isabellinus*	33	CE
11	Mustelidae	Stone Marten	*Martes foina*	77	LC
13	Mustelidae	Yellow-throated Marten	*Martes flavigula*	5	LC
14	Mustelidae	Mountain Weasel	*Mustela altaica*	5	NT
15	Mustelidae	Least Weasel	*Mustela nivalis*	5	LC
16	Ochotonidae	Royle's Pika	*Ochotona roylei*	48	LC
17	Sciuridae	Himalayan Marmot	*Marmota himalayana*	3	LC
18	Sciuridae	Long-tailed Marmot	*Marmota caudata*	29	LC
19	Sciuridae	Kashmir Flying Squirrel	*Eoglaucomys fimbriatus*	8	LC

Himalayan brown bear and red fox in snow leopard landscape of Kishtwar National Park

The prey base, Asiatic Ibex and Kashmir Musk deer in Kishtwar National Park

Long tailed Marmot and Himalayan snowcock in snow leopard landscape

Way forward

The results from this study provide a snapshot of snow leopard abundance and density estimates in the Greater Himalayan landscape mostly targeting Kishtwar National park and adjoining landscapes based on primary evidence. Though limited to site use (occupancy) and camera trapping, the study provides a significant baseline information to set up a long term monitoring project to track the population of snow leopard and its wild prey species. The department is committed to extending its efforts as a long-term monitoring initiative aimed at tracking the population of snow leopards and their wild prey species across the whole snow leopard landscape in Jammu and Kashmir.

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(Appendix III)

2021

STATUS OF SNOW LEOPARD AND PREY

in Himachal Pradesh

CITATION INFORMATION
Anon. 2021. Status of snow leopard and prey in
Himachal Pradesh, 2021.
Wildlife Wing - Himachal Pradesh Forest Department,
Government of Himachal Pradesh, Shimla.

COVER PHOTO BY
Prasenjeet Yadav

REPORT DESIGN BY
Aditi Elassery

Status of Snow Leopard & Prey in Himachal Pradesh

2021

nature conservation foundation

SNOW LEOPARD TRUST

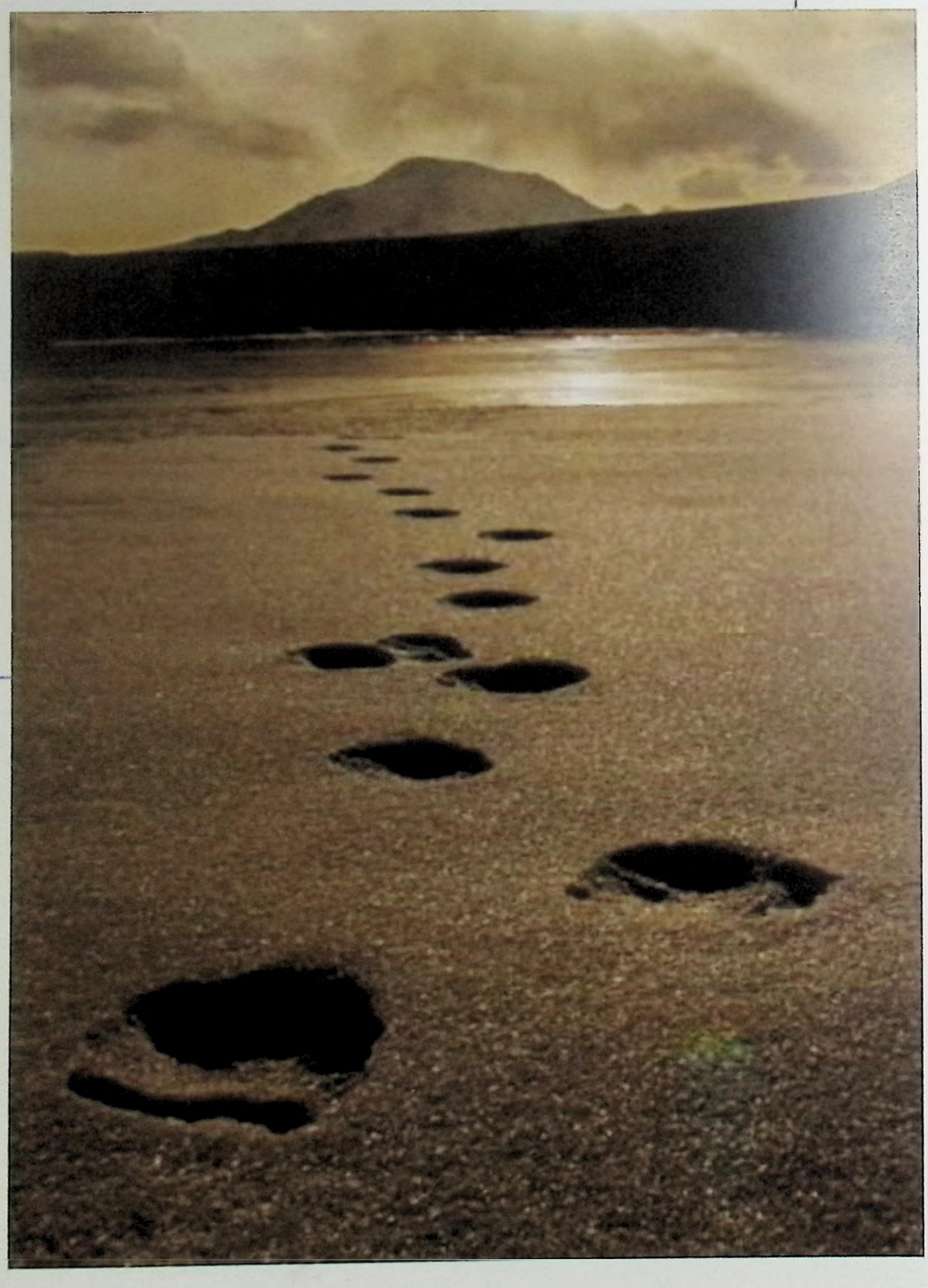

Photo by Prasenjeet Yadav

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Foreword

Archana Sharma (IFS),
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The State of Himachal Pradesh has a unique geography with nearly half of its area being high elevation Himalayan and trans-Himalayan region. This region is rich with unique animal and plant species that are found only in the high mountain regions of the Himalaya and parts of Central Asia. Himachal Pradesh is home to unique high altitude wildlife that includes bharal, ibex, and the most iconic species of these mountains – the snow leopard, known as the Ghosts of the Mountain. The snow leopard habitat of Himachal Pradesh are a source of local and regional ecosystem services such as fresh water used by millions of people living downstream and in the plains, and sustains unique high-altitude cultures.

Himachal Pradesh has played a pioneering role in the conservation of the snow leopard. The management planning of the ~4000 km² Upper Spiti Landscape was the first dedicated effort under the Project Snow Leopard. This has been the first – and still among a handful – effort towards conservation of a large carnivore species outside of the protected area network. India has the third largest share of the snow leopards global distribution range and the Indian Hemis-Spiti landscape has been identified as one of the 20 landscapes to secure healthy populations of snow leopards across the cat's range. The first step towards conserving snow leopards is to conduct robust assessments of snow leopard populations which can help identify areas of priority for snow leopard conservation. Taking a lead among Indian States, Himachal Pradesh embarked on this task in 2018 in partnership with Nature Conservation Foundation. Our goal was to use scientifically robust techniques to estimate the snow leopard population of Himachal Pradesh in a systematic effort that surveyed 26,000 km² of snow leopard habitat. This exercise was complemented with population assessments of the prey species (bharal and ibex) of snow leopard across Himachal Pradesh.

I am delighted that these assessments have been completed as planned despite the uncertainties of the pandemic. The results from the assessments are encouraging and prepare us for better management of conservation of the charismatic snow leopards of Himachal Pradesh and the high altitude landscapes they inhabit. I congratulate all the officers on the Wildlife Wing for ensuring that this project is a success.

Photo by Prasenjeet Yadav

Executive Summary

The snow leopard (*Panthera uncia*) is a top-predator of the Indian Himalaya. Its occurrence is regarded as an indicator of ecological health. The Greater and Trans-Himalayan ranges constitute an important habitat for snow leopard towards the southern limit of its global distributional range. Potential snow leopard habitat in the Indian Himalaya is not limited to protected areas (PAs), but overlaps considerably with human-use areas. These areas are also home to local communities whose cultures, traditions and livelihoods are deeply linked to these landscapes. Acknowledging the importance of these areas, the Government of India launched Project Snow Leopard in 2008 to safeguard and conserve India's unique natural heritage of high altitude wildlife populations and their habitats by promoting conservation through participatory policies and actions.

The snow leopard is also the State animal of Himachal Pradesh and its habitat covers a majority of the districts of Lahaul-Spiti and Kinnaur. Its potential habitat also extends into the upper regions of the districts of Shimla, Kullu, Chamba and Kangra. Most of these areas are remote with the added challenge of limited accessibility during winter. All this makes snow leopards a difficult species to study, not just in Himachal Pradesh, but across its Indian range.

In January 2018, the Wildlife Wing of the Himachal Pradesh Forest Department initiated a pioneering project to estimate snow leopard and its wild prey population in Himachal Pradesh.

This is among the first projects to be completed successfully, that has attempted an assessment at this scale. The techniques deployed for the project are scientifically robust and align with the protocols prescribed by the Ministry of Environment, Forest and Climate Change under Snow Leopard Population Assessment in India (SPAI). This protocol is being used to estimate snow leopard population across all five Himalayan States where snow leopards occur.

Over the last three years, the Wildlife Wing of the Himachal Pradesh Forest Department has partnered with the Nature Conservation Foundation (NCF) to execute this project. This included capacity building of frontline staff, extensive deployment of camera traps and retrieval and analysis of data that was compiled as a part of this massive exercise across snow leopard habitats of the State. This report provides the final results obtained from this exercise. Listed below is a summary of the main results obtained for this project:

1. This project is the first systematic effort at a large regional scale to estimate snow leopard population over an area of 26,112 km² that utilised a stratified sampling design. The entire snow leopard habitat of the State was first stratified into three categories: high, low or unknown snow leopard occurrence based on questionnaire surveys of local communities residing in these areas. Camera trap surveys were then carried out in areas under each of the categories. Thus this study ensures that there are no biases in sampling, which are otherwise common in snow leopard population studies.

2. Camera trapping surveys were conducted at 10 sites to representatively sample all the strata i.e. high, low and unknown. Snow leopards were detected at all the 10 sites suggesting that snow leopards are found in the entire snow leopard habitat in Himachal Pradesh – either as resident individuals of a population or as dispersing individuals navigating through these connecting habitats.

3. We detected 44 individual snow leopards on 187 occasions in this study. From this dataset of 44 individuals, we estimated that snow leopard population size is likely to be 51 individuals and this population can be reliably estimated to be upto 73 individuals.

4. Snow leopard density ranged from 0.08 to 0.37 individuals per 100 km² in Himachal Pradesh. The trans-Himalayan regions of Spiti and Pin valley recorded the highest densities of snow leopards.

5. For the entire snow leopard habitat, we assessed the populations of the primary wild ungulate prey of snow leopards – blue sheep *Pseudois nayaur* and ibex *Capra sibirica* using the double observer survey technique. Wild ungulate prey density ranged from 0.11 to 1.09 per km² . The trans-Himalayan region supports the highest densities of wild prey of snow leopards – the estimate of blue sheep population size was 891 for Spiti, and the ibex population size estimate was 224 for the Pin valley.

6. We find that the snow leopard density was positively correlated with the wild prey density indicating that higher wild prey densities corresponded to higher snow leopard densities. Spiti and Tabo recorded highest densities of both snow

Photo by Prasenjeet Yadav

leopards and their prey; while Chandra and Bharmour recorded the lowest densities of both snow leopards and their prey.

7. Our camera-trapping survey recorded 28 species that includes carnivores, such as the brown bear, black bear, yellow throated marten, stone marten, masked palm civet, Himalayan weasel; pheasants, such as the monal, cheer pheasant, koklass pheasant, snow partridge; and ungulates, such as the musk deer. We detected the common leopard and the snow leopard in the same camera trap at two stations in the Great Himalayan National Park suggesting a habitat overlap between the snow leopard and the common leopard.

8. The entire camera trapping exercise has been led by a team of 8 local youth of Kibber village in Spiti who have been working on such surveys across the Upper Spiti Landscape since 2010. They were adequately supported by NCF researchers, frontline staff of the Himachal Pradesh Forest Department and members of the local community where studies were carried out.

These results are extremely encouraging and representative of the positive conservation efforts being made by the Wildlife Wing. They also reiterate the fact that local communities are the strongest allies for conservation, if their concerns can be factored into conservation planning.

The results provide a robust baseline for the Wildlife Wing to set up a long term monitoring project to track the population of snow leopard and its wild prey species. Himachal Pradesh can pursue a process similar to that followed for tiger census in India which is reported once every four years, while field work is ongoing. Such long-term studies are a very useful way to track the efficacy of on-ground conservation efforts, which allows the State to further set an example for others to follow.

कार्यकारी सारांश

हिमालय के भारतीय भाग में स्नो लैपर्ड (पैंथेरा अनसिया) यानी हिम-तेंदुआ एक चरम षिकारी है। इसकी मौजूदगी पर्यावरण के स्वास्थ्य की सूचक होती है। हिम-तेंदुए की ग्लोबल डिस्ट्रीब्यूषन रेंज की दक्षिणी सीमा की ओर, ग्रेटर और ट्रांस-हिमालयन श्रृंखलाएं इसका एक महत्वपूर्ण पर्यावास हैं। हिमालय के भारतीय हिस्से में हिम-तेंदुए का संभावित पर्यावास संरक्षित क्षेत्रों तक ही सीमित नहीं है, बल्कि मानव के इस्तेमाल वाले इलाकों से भी इसकी सीमाएं काफी मिलती हैं। इन क्षेत्रों में स्थानीय समुदाय भी रहते हैं जिनकी संस्कृति, परम्पराएं और आजीविका इन भू-प्रदेषों के साथ गहराई से जुड़ी हैं। इन इलाकों के महत्व को समझते हुए भारत सरकार ने २००८ में प्रॉजैक्ट स्नो लैपर्ड की षुरूआत की, ताकि ऊंचाई पर रहने वाले वन्य जीवों और उनके पर्यावासों, भारत की अनोखी प्राकृतिक विरासत की सुरक्षा और उसका संरक्षण किया जा सके। इस संरक्षण के संवर्द्धन के लिए प्रतिभागितापूर्ण नीतियों और कार्रवाइयों की मदद ली गई।

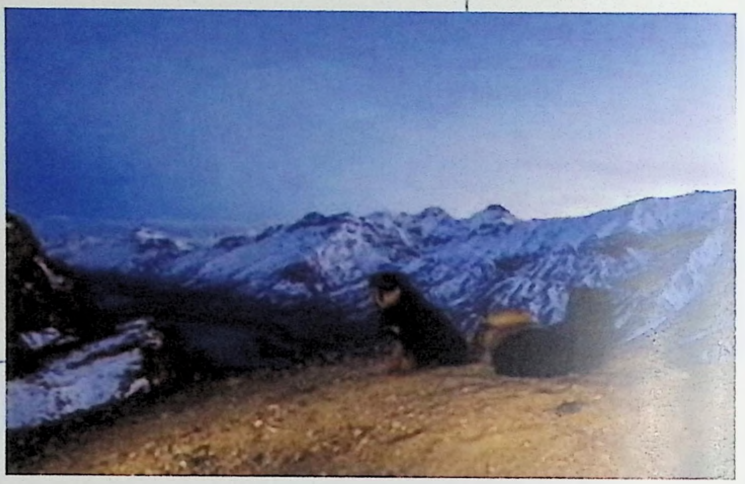
हिम तेंदुआ, हिमाचल प्रदेष का प्रतीक जीव भी है और इसका पर्यावास लाहौल-स्पीति और किन्नौर जिलों में अधिकतर स्थानों पर मिलता है। इसका संभावित पर्यावास षिमला, कुल्लू, चम्बा और कांगड़ा जिलों के ऊपरी हिस्सों तक भी फैला हुआ है। इसमें से ज्यादातर इलाके दूरदराज हैं, और सर्दियों के दौरान यहां तक पहुंच पाना काफी मुष्किल होता है। इसी वजह से हिम-तेंदुए का अध्ययन करना काफी मुष्किल है।

जनवरी, २०१८ में हिमाचल प्रदेष, वन विभाग के वन्य जीव संभाग ने हिमाचल प्रदेष में हिम तेंदुए और इसका षिकार बनने वाले जंगली जीवों का अनुमान लगाने की दृश्टि से एक अग्रणी परियोजना षुरू की। ये सफलतापूर्वक पूरी की जाने वाली आरंभिक परियोजनाओं में से एक है, जिन्होंने इतने बड़े पैमाने पर ये आंकलन लगाने की कोषिष की है। इस परियोजना के लिए जिन तकनीकों का इस्तेमाल किया गया, वे वैज्ञानिक रूप से दमदार हैं, और पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय के स्नो लैपर्ड पॉपुलेषन एसैसमैंट इन इन्डिया (एसपीएआई) के तहत प्रोटोकॉल से मेल खाती हैं। इस प्रोटोकॉल का इस्तेमाल हिमालय के उन सभी पांच राज्यों में हिम-तेंदुए की आबादी के आंकलन के लिए किया जा रहा है, जहां हिम तेंदुए मिलते हैं।

पिछले तीन वर्शों के दौरान, हिमाचल प्रदेष वन विभाग के वन्य जीव संभाग ने इस परियोजना को कार्यान्वित करने के लिए नेचर कन्जर्वेषन फाउंडेषन (एनसीएफ) के साथ मिल कर काम किया है। इसमें अग्रणी स्तर पर काम करने वाले स्टाफ का क्षमता निर्माण, व्यापक स्तर पर कैमरा ट्रैप लगाया जाना और बाद में आंकड़ों को हासिल करके उनका विष्लेशण षामिल रहा है, जिन्हें राज्य भर के हिम तेंदुआ पर्यावासों में चलाई गई व्यापक अभियान के दौरान संकलित किया गया था। यह रिपोर्ट इस अभियान के दौरान प्राप्त किए गए अंतिम परिणाम उपलब्ध कराती है। नीचे उन मुख्य परिणामों का सारांष मौजूद है, जो इस परियोजना से प्राप्त हुएः

१. इस परियोजना में स्ट्रैटिफाइड सैम्पलिंग डिजाइन का उपयोग करके २६११२ वर्ग किलोमीटर इलाके में पहली बार विषाल क्षेत्रीय स्तर पर एक योजनाबद्ध प्रयास किया गया। राज्य के हिम तेंदुए वाले पूरे पर्यावास को पहले तीन श्रेणियों में बांटा गयाः उच्च, निम्न और अज्ञात क्षेत्र जहान हिम तेंदुओं के दिखाई देने की संभावना है। और इस जानकारी को जुटाने के लिए इन इलाकों में रहने वाले स्थानीय लोगों के प्रष्न-आधारित सर्वेक्षण किए गए। फिर ऐसी हर श्रेणी में कैमरा ट्रैप सर्वे किए गए। तो ये अनुसंधान सुनिष्चित करता है कि इन नमूनों के साथ

Photo by Prasenjeet Yadav



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कोई पूर्वाग्रह जुड़ा नहीं है, जबकि हिम-तेंदुए की आबादी की अनुसंधान के मामले में ऐसा आम होता है।

२. १० जगहों पर कैमरा ट्रैपिंग सर्वे किए गए ताकि सभी क्षेत्रों के नमूने लिए जा सकें, उच्च, निम्न और अज्ञात क्षेत्रों में इन सभी १० जगहों पर हिम-तेंदुए पाए गए, जिससे पता चला कि हिमाचल प्रदेष के सभी हिम तेंदुआ पर्यावासों में हिम तेंदुए मौजूद हैं - ये या तो अपनी किसी आवादी का हिस्सा हैं, या फिर ये आपस में जुड़े पर्यावासों में आते-जाते रहते हैं।

३. इस अध्ययन में हमें १८७ अवसरों पर ४४ तेंदुए नजर आए। तेंदुओं के इन आंकड़ों से हमने अनुमान लगाया कि हिम तेंदुओं की संख्या ५१ होगी, और इनकी इस आवादी में इनकी संख्या ७३ तक हो सकती है।

४. हिमाचल प्रदेष में हिम तेंदुओं का घनत्व प्रति १०० वर्ग किलोमीटर में ०.०८ से ०.३७ पाया गया। स्पीति और पिन घाटी वाले ट्रांस-हिमालयन क्षेत्रों में हिम तेंदुओं का घनत्व सबसे ज्यादा पाया गया।

५. हिम तेंदुओं के पूरे पर्यावास में, हमने ये आंकलन लगाया कि हिम तेंदुए का षिकार वनने वाले, खुर वाले जीव हैं - ब्लू षीप (स्यूडोइस नायॉर) और आइबैक्स (कापरा सिबिरिका) इसके लिए डबल ऑबजर्वर सर्वे तकनीक का इस्तेमाल किया गया। षिकार बनने वाले, खुर वाले वन्य जीवों का घनत्व ०.११ से १.०६ प्रति वर्ग किलोमीटर रहा। ट्रांस-हिमालय क्षेत्र में हिम तेंदुए का षिकार बनने वाले वन्य जीवों का घनत्व सबसे ज्यादा है। स्पीति में ब्लू षीप की आबादी ८६१ थी, जबकि पिन घाटी में आइबैक्स की आबादी २२४ थी।

६. हमें ये पता चला कि हिम तेंदुए का घनत्व उसके षिकार बनने वाले जीवों के घनत्व से सीधा सम्बन्ध रखता है, यानी अगर षिकार बनने वाले जीवों का घनत्व अधिक होगा, तो हिम तेंदुए का घनत्व भी ज्यादा होगा। स्पीति और ताबो में हिम तेंदुए और उसके षिकार, दोनों का ही घनत्व सबसे अधिक पाया गया। जबकि चन्द्रा और भरमौर में हिम तेंदुए और उसके षिकार, दोनों का ही घनत्व सबसे कम मिला।

७. हमारे कैमरा ट्रैपिंग सर्वे में २८ प्रजातियों का पता चला, इनमें मांसाहारी प्रजातियां भी षामिल हैं, जैसे कि भूरा भालू, काला भालू, यलो थ्रोटेड मार्टिन, स्टोन मार्टिन, मास्क्ड पाम सिवेट, हिमालयन वीज़ल, फैजैन्ट, जैसे कि मोनाल, चीयर फैजैन्ट, कोकलाज फैजैन्ट, स्नो पार्ट्रिज, खुर

वाले जीव, जैसे कि कस्तूरी हिरण। हमें ग्रेट हिमालयन नैषनल पार्क में दो स्टेषनों पर एक ही कैमरा ट्रैप के जरिये सामान्य तेंदुए और हिम तेंदुए के होने का पता चला। इससे ये मालूम हुआ कि हिम तेंदुए और सामान्य तेंदुए का इलाका एक दूसरे को ओवरलैप करता है।

८. कैमरा ट्रैपिंग के इस पूरे अभियान का नेतृत्व स्पीति के किब्बर गांव में रहने वाले ८ स्थानीय युवाओं की टीम ने किया, जो २०१० से अपर स्पीति लैंडस्केप में इस तरह के सर्वे करते चले आ रहे हैं। इनकी मदद एनसीएफ के षोध ाकर्त्ताओं, हिमाचल प्रदेष वन विभाग के अग्रिम स्टाफ और स्थानीय समुदायों के सदस्यों ने की, जहां ये अनुसंधान किया गया था।

ये परिणाम अत्यंत प्रोत्साहित करने वाले हैं और वन्य जीव संभाग ने संरक्षण से जुड़े जो सकारात्मक प्रयास किए, ये उन्हें दर्षाते हैं। इन नतीजों ने इस बात की भी पुश्टि कर दी कि अगर संरक्षण की योजना बनाते समय स्थानीय समुदायों की चिंताओं को ध्यान में रखा जाए तो यही लोग संरक्षण के मामले में सबसे सषक्त साथी साबित होते हैं। परिणामों से वन्य जीव संभाग को इस पर दृढ विष्वास हो गया है कि हिम तेंदुए और इसका षिकार बनने वाले वन्य जीवों की आबादी पर नजर रखने के लिए लम्बी अवधि की एक निगरानी परियोजना कायम की जा सकती है। हिमाचल प्रदेष में भी एक ऐसी ही प्रक्रिया षुरू की जा सकती है जो भारत में बाघों की गणना के लिए इस्तेमाल हुई थी, जिसके तहत हर चार साल में इनकी गिनती होती है, और इस दौरान फील्ड में काम जारी रह सकता है। लम्बी अवधि की ऐसी स्टडीज, जमीनी स्तर पर संरक्षण के प्रभावीपन का पता लगाने में काफी उपयोगी साबित हो सकती है, और यह राज्य दूसरों के लिए एक उदाहरण भी बन सकता है।

Photo by Prasenjeet Yadav

Introduction

Photo by Prasenjeet Yadav

Snow Leopard (*Panthera uncia*) is the State animal of Himachal Pradesh. It is a flagship species for the conservation of the high Himalaya. The snow leopard is the smallest member of the genus Panthera, but it's secretive behaviour, camouflage, and adaptation to the cold and rugged mountain habitat captures public imagination, making it one of the most charismatic species in the world. Nearly half of the geographic area of Himachal Pradesh is located within the high elevation Himalayan and trans-Himalayan region, which is the preferred habitat of the snow leopard. This region is rich with unique animal and plant species that are found only in the high mountain regions of the Himalaya and parts of Central Asia, such as the musk deer, brown bear, goral, monal, and cheer pheasant. The snow leopard habitat of Himachal Pradesh is a source of local and regional ecosystem services such as fresh water used by millions of people living downstream and in the plains, and sustains unique high-altitude cultures (Murali et al. 2017).

The snow leopard faces many threats throughout its distribution range. It is threatened by large scale developmental projects such as mining and large infrastructure; rising livestock populations that can out-compete the wild herbivore prey of the snow leopard; increasing conflict with the herding community leading to their persecution; and an increase in poaching for snow leopard body parts.

Globally, the snow leopard is found across the high mountains of twelve countries of South and Central Asia and India has the third largest share of snow leopard distributional range. The state of Himachal Pradesh has played a pioneering role in the conservation of the snow leopard. The management planning of the ~4000 km² Upper Spiti Landscape was the first dedicated effort under the Project Snow Leopard. This is the first and still among a handful of efforts towards conservation of a large carnivore species outside the protected area network. The State's conservation efforts acknowledge that the wildlife in the high elevation region is not restricted to protected areas but spread across the entire landscape. The management plan of the Upper Spiti Landscape provides a framework for landscape level conservation that goes beyond protected area boundaries and integrates the needs of the local agro-pastoral communities as a part of the conservation effort. These ideas were foundational in setting the Management Plan Guidelines by the Global Snow Leopard and Ecosystem Protection Program (GSLEP) (Sharma et al 2019).

There are no robust global snow leopard population estimates, but they are believed to be 3900 to 8745 snow leopards (McCarthy et al 2016). Recently, the IUCN down-listed the snow leopard from Endangered to Vulnerable (McCarthy et al 2017) category. However, this change was questioned by many national governments and scientists (Bishkek statement 2017; Ale & Mishra 2017). The data used in these assessments has been shown to be biased and unsuitable for global assessments (Suryawanshi et al 2017). To work towards global estimates of snow leopards, there is a need to sample large contiguous landscapes which include newer areas and a diversity of habitat types and management regimes (protected areas and multi-use landscapes). The governments of the twelve snow leopard range countries agreed to a collaborative effort called PAWS, or Population Assessment of World's Snow Leopards (The Bishkek Declaration 2017). The Indian government responded by releasing the methodological guidelines for a countrywide snow leopard population assessment titled SPAI or, Snow leopard Population Assessment in India (MOEF 2019).

Robust methods of estimating snow leopard population sizes come from the use of sample counts based on camera trap (Karanth & Nichols, 1998) or molecular genetics (Mondal et al., 2009) and a model for imperfect detection. A standard camera trap based estimation involves setting up remote sensor cameras in the area of interest. The cameras are placed in the micro- habitats that are preferred by snow leopards but spread across the study area in a uniform grid system or distributed randomly in space (Alexander 2015; Jackson, 2006; O'Connell, 2010; Sharma et al., 2014). Individual snow leopards are identified from photographs using individually distinct spot patterns on the fur and the data are analysed using individual capture histories to estimate abundance and area sampled (Alexander et al., 2015; Sharma et al., 2014). The method assumes that individual snow leopards can be identified accurately from camera trap photographs. Johansson et al (2020) found that even experts make mistakes in identification of snow leopards from photographs leading to possible overestimation of the population. Similarly, samples of snow leopard faeces can be collected from the area of interest with relatively uniform spatial coverage across the study area. Individual snow leopards are

Photo by Prasenjeet Yadav

then identified by extracting and analysing DNA from these samples and the data are similarly modelled in a capture-recapture framework to estimate the abundance of snow leopards in the area sampled (Janecka et al., 2008; Mondal et al., 2009; Suryawanshi et al., 2017). The possibility of mis-identification of individuals exists in the genetic analysis as well (Janečka et al. 2008). Both these methods have become popular especially following their widespread adoption in monitoring tiger (Panthera tigris) populations (Karanth et al., 2004; Karanth & Nichols, 1998; Jhala et al 2019).

The primary objectives of this project were, 1. To estimate the population of snow leopards across the state of Himachal Pradesh. 2. To estimate the population of the prey species of the snow leopard (mainly bharal and ibex). This report presents the results of a state wide camera trapping exercise and prey survey exercise in the snow leopard habitat of Himachal Pradesh to address these objectives. We used the two-step method with an occupancy study based stratified design which has been proposed by the Ministry of Environment, Forest and Climate Change in the Snow Leopard Population Assessment of India guideline (SPAI) and the guidelines circulated by the Global Snow Leopard and Ecosystem Protection Program (GSLEP). We used simulations to estimate the impact of potential errors in the snow leopard photo identification process. We supported the camera trap based population estimates of snow leopards with estimates of prey density.

Photos by Prasenjeet Yadav

Methodology

Himachal Pradesh's snow leopard landscape is divided into valleys made by large rivers like Sutlej, Chenab, Beas, Parvathi and their tributaries which include Baspa, Kugti, Ravi, Spiti and others. Most watershed areas open into these main rivers. Large parts of this landscape are difficult to access given the breaks in the landscape caused by the numerous rivers and streams. The snow leopard inhabits landscapes of varied geology, starkly different climatic regimes, diverse vegetation and community structures. On account of the snow leopards being an elusive species that occurs in low densities, studies generally tend to target smaller areas with relatively high densities. Restricting estimation to small areas or solely to high density sites lead to bias in estimates by inflating densities (Suryawanshi et al. 2019). This bias is further amplified when extrapolated to larger regions of interest. Therefore, accurately estimating snow leopard density across the, requires adequate and representative sampling recognising the heterogeneity in the landscape. We use a two-step sampling process recommended by the PAWS guideline (Sharma et al . 2019/GSLEP) to ensure robust design and adequate coverage of the state. First is macro level sampling to identify the sites where camera-trapping and ungulate surveys are to be conducted and the second step is micro level sampling to deploy cameras and conduct surveys at each site.

Macro-sampling design

We first demarcated potential snow leopard habitat in the State by identifying areas that fall between 3000 meters and 6000 meters elevation, the typical elevation range of the species. Previous snow leopard occupancy estimates (Ghoshal et al. 2019) conducted in the regions of Kinnaur, Spiti, Lahaul and Chamba that cover a large fraction of the snow leopard habitat within the state, were used to categorise the region into 3 strata where camera trapping surveys were to be conducted. Regions with occupancy probability greater than 0.75 were recognised as potentially high-density, whereas regions with lesser occupancy probability were recognised to be of potentially low-density. Areas that are known to be snow leopard habitats but fell outside the purview of the occupancy survey were categorised as the third 'unknown' strata. We surveyed a total of 10 sites, 5 in the high-density strata, 3 in the low-density strata and 2 in the unknown strata.

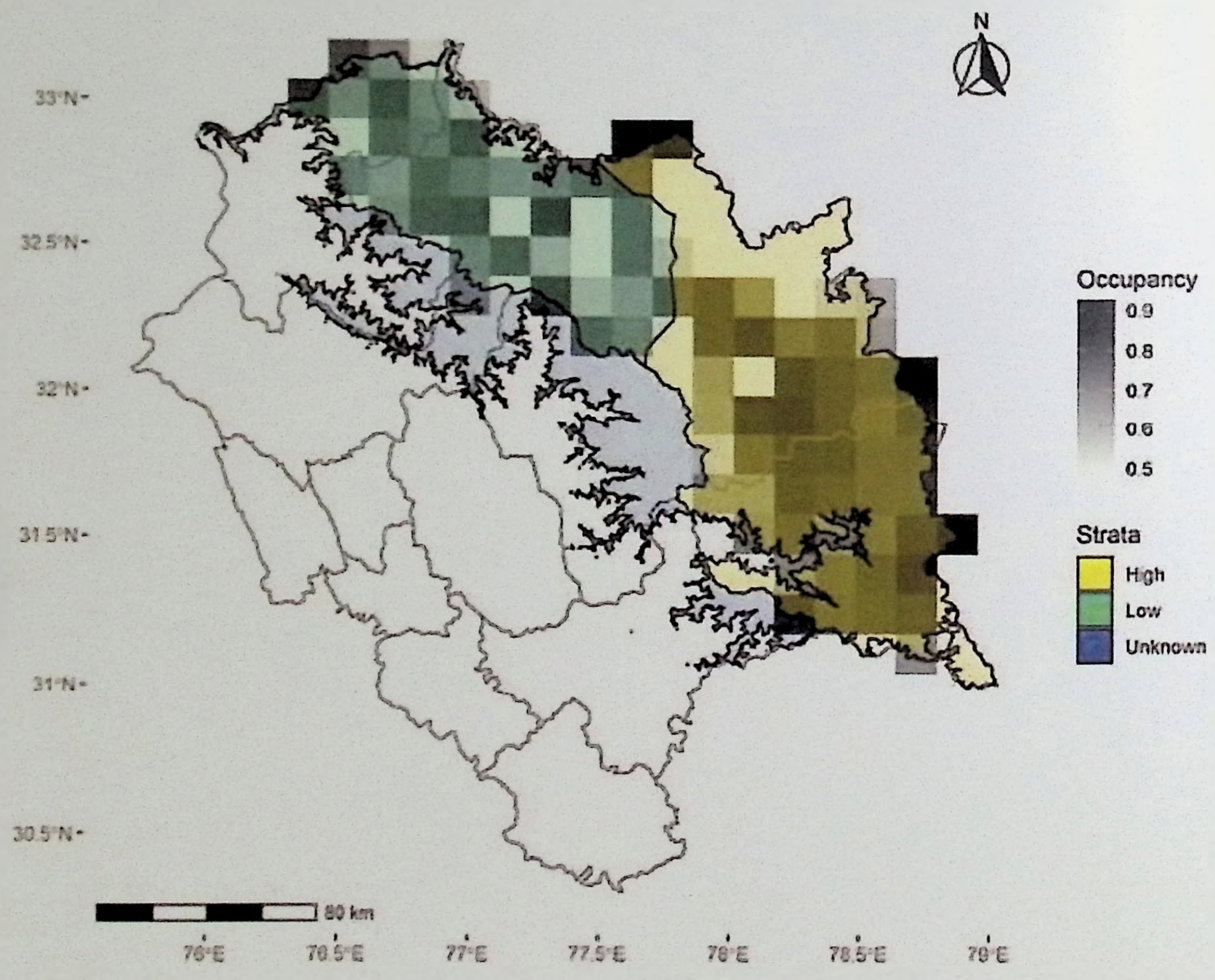


Figure 1: The potential snow leopard habitat in Himachal Pradesh stratified into 3 regions based on snow leopard occupancy – high (>0.75 occupancy), low (<0.75 occupancy) and the previously unsampled unknown stratum.

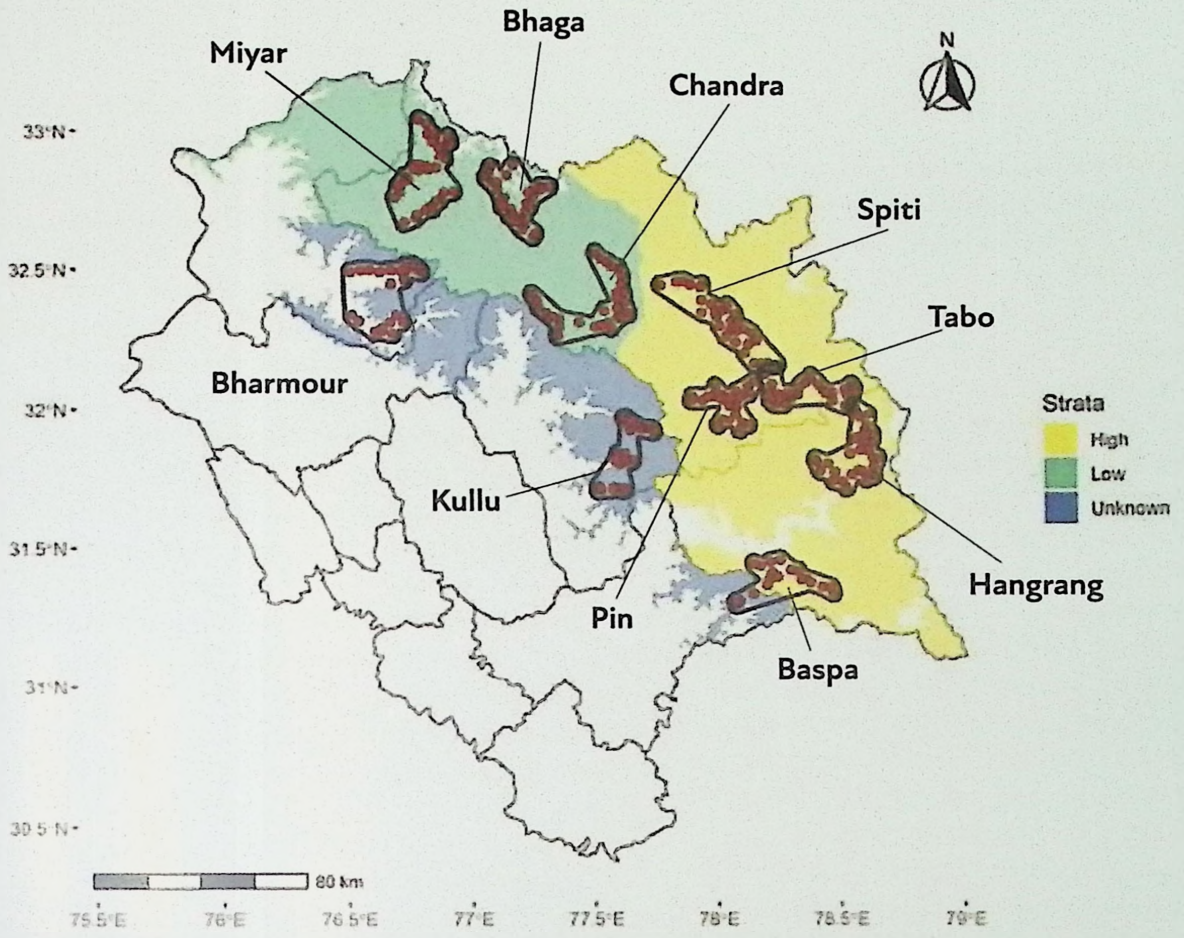


Figure 2: Camera trapping sites covering the three strata – high: Spiti, Hangrang, Tabo, Pin, and Baspa; low: Bhaga, Chandra, and Miyar; unknown: Bharmour and Kullu.

Micro-sampling design

Camera trapping survey

Areas with potential snow leopard habitats were demarcated in each site. These predominantly spanned ranges along the main river valley and ranges along valleys of larger tributaries. Slopes on both banks of the rivers, that were within the demarcated area were gridded into 4 x 4km cells. Snow leopard home ranges are known to vary greatly with estimates ranging from 12-39 km² in Nepal (Jackson and Ahlborn 1989, Jackson 1996) to 124-207 km² in Mongolia (Johannson et al. 2016). The camera-trap locations were selected to capture as many individuals as possible by multiple cameras, while optimising spatial coverage. Keeping this in mind, a grid size of 4 x 4km was chosen to ensure that it was less than the typical snow leopard home range to allow for recaptures across cameras. Since a clustered trapping design is difficult to implement given accessibility, we employed a uniform sampling design in all the 9 sites, except for Kullu. Cells that fell far below the elevation limits of snow leopard habitat (< 2000 m) and those covered in permafrost were excluded from the survey. Apart from a few cells which were completely inaccessible, one camera was deployed in each cell. Field teams deployed cameras, based on snow leopard signs such as hair, scat, scratch or spray marks and the presence of suitable microhabitats to maximise detection within each cell.

Double-observer survey

Each of the 10 sites was further divided into smaller blocks for the ease of survey. Each block was surveyed keeping three main assumptions in mind: 1) that entire visual coverage of each block was possible during the survey, 2) two individual teams surveyed the area independently, and 3) the ungulate groups could be identified individually based on the age-sex composition of a herd, its location, and any other peculiarities that the teams could note. This method is based on the principles of mark-recapture theory. It is difficult to identify individual mountain ungulates, however, their groups, even if temporary, can be identified during sampling based on characteristics such as group size, age-sex composition, and location. The unit being "marked" and "recaptured" in the double-observer technique is the individual group.

Image processing and data analyses

Camera-trapping was done at 10 sites spread across snow leopard habitat in the entire State of Himachal Pradesh. We used Reconyx HC500 cameras that were installed for 60 days, during which, cameras were checked once for battery condition and for replacement of memory cards (see table 1 for camera-trapping effort for each site).

All snow leopard images were tagged using the digiKam image management software (https://www.digikam.org/). Errors in snow leopard image identification have been shown to bias estimates of density and population size (Johansson et al 2020). To minimise this bias, we conducted image identification and tagging in two stages – first identification stage followed by the review stage. In the first stage, one or two researchers carefully catalogued all the camera trap photos of snow leopards from each site. Rosette patterns from the face, limbs, rump, shoulder, upper parts of the tail and cheeks of the snow leopard were to identify different individuals. In the second stage, two different researchers reviewed all the individuals that were captured only once. In case of insufficient evidence for tag assignment as a new individual, we reverted the image as "unidentified" or in case of a misidentification, we assigned a new tag to the image. The changes were verified by a third reviewer independently and discrepancies were resolved by using a conservative approach. Following the individual identification for each site, we conducted image comparisons across sites.

After individual identification, images were assigned tags which were saved in their respective image metadata, from where they were read using the CamtrapR package (recordTable and recordTableIndividual) to generate a database of snow leopard capture history information. The CamtrapR package (built for the R statistical and programming environment) was used to create separate csv files for individuals captured for each site.

Photos by Prasenjeet Yadav

Table 1: Effort for camera-trapping survey at 10 sites

Name of site	Estimated Area (km2)	No. of camera traps deployed	No. of occasions (days)
Bhaga	480	30	60
Bharmour	352	21	60
Chandra	496	31	60
Kullu	480	30	60
Miyar	576	36	60
Pin	370	25	60
Baspa	320	20	60
Tabo	464	29	60
Hangrang	484	31	60
Spiti	760	31	60

Data analyses

Snow leopard density and population size were estimated using multi-session SECR (Spatially Explicit Capture-Recapture) models (Borchers 2012). SECR models explicitly use the spatial information of detection location at the camera traps, i.e., these models account for the heterogeneity in captures that arises because probability of capture in a specific trap depends on its location relative to the movement of the animal (Efford et al. 2009). The number of wild prey per site was estimated using the two survey mark-recapture method employing a Bayesian framework using the 'BBRecapture' package in the R statistical and programming environment (Fegatelli and Tardella 2013, Version 3.3.4, R Core Team, 2020).

Results

1. *44 individual snow leopards were detected on 187 occasions. Estimated snow leopard population size is likely to be 51 individuals and this population can be reliably estimated to be upto 73 individuals.*

2. *Snow leopards were detected at all the 10 sites suggesting that snow leopards are found in the entire snow leopard habitat in Himachal Pradesh – either as resident individuals of a population or as dispersing individuals navigating through these areas.*

3. *The trans-Himalayan regions of Spiti and Pin valley recorded the highest densities of snow leopards and snow leopard density ranged from 0.08 to 0.37 individuals per 100 km².*

4. *Wild ungulate prey density (blue sheep Pseudois nayaur and ibex Capra sibirica) ranged from 0.11 to 1.09 per km². The trans-Himalayan region supports the highest densities – the estimate of blue sheep population size was 891 for Spiti, and the ibex population size estimate was 224 for the Pin valley.*

Snow leopard population density and abundance

Sites varied in the number of detections - Spiti from the high occupancy stratum had 61 detections with 9 individuals; Chandra from the low occupancy stratum had 18 detections of 3 individuals, and Kullu from the unknown stratum had 22 detections with 2 individual snow leopards.

Snow leopard densities varied across sampling sites with a seven-fold difference between the highest and lowest density sites. Tabo, Hangrang, and Spiti had the highest densities of 0.37 (95%CIs: 0.18 – 0.72), 0.36 (95%CIs: 0.18 – 0.73), and 0.3 (95%CIs: 0.15 – 0.59) snow leopards per 100 km², while Bhaga from the low stratum recorded the lowest density of 0.05 (95%CIs: 0.01 – 0.24) snow leopards per 100 km² (Table 2). Snow leopard densities estimated for each stratum corresponded to the occupancy surveys – the high occupancy stratum showed a high density of 0.3 (95%CIs: 0.21 - 0.42) snow leopards per 100 km²; low occupancy stratum had a low density of 0.08 (95%CIs: 0.05 - 0.12) and the previously unsampled stratum had a density of 0.08 (95%CIs: 0.08 - 0.14) snow leopards per 100 km².

Table 2: Site wise details about camera trapping effort and results from 10 sampled sites in the Indian state of Himachal Pradesh. Estimated area is the number of 4 x 4 km grids with cameras times the area of the grid.

Name of site	Estimated Area (km2)	No. of camera traps deployed	No. of occasions (days)	No. of snow leopard detections	No. of individual snow leopards	Estimate snow leopard density per 100km² (95% CI)
Bhaga	480	30	60	9	1	0.05 (0.01-0.24)
Bharmour	352	21	60	1	1	0.06 (0.01-0.31)
Chandra	496	31	60	18	3	0.1 (0.03–0.29)
Kullu	480	30	60	22	2	0.1 (0.03–0.35)
Miyar	576	36	60	5	2	0.07 (0.02–0.26)
Pin	370	25	60	19	6	0.27 (0.12–0.61)
Baspa	320	20	60	7	3	0.18 (0.06–0.51)
Tabo	464	29	60	27	9	0.37 (0.18–0.72)
Hangrang	484	31	60	18	8	0.36 (0.17–0.73)
Spiti	760	31	60	61	9	0.3 (0.15–0.59)

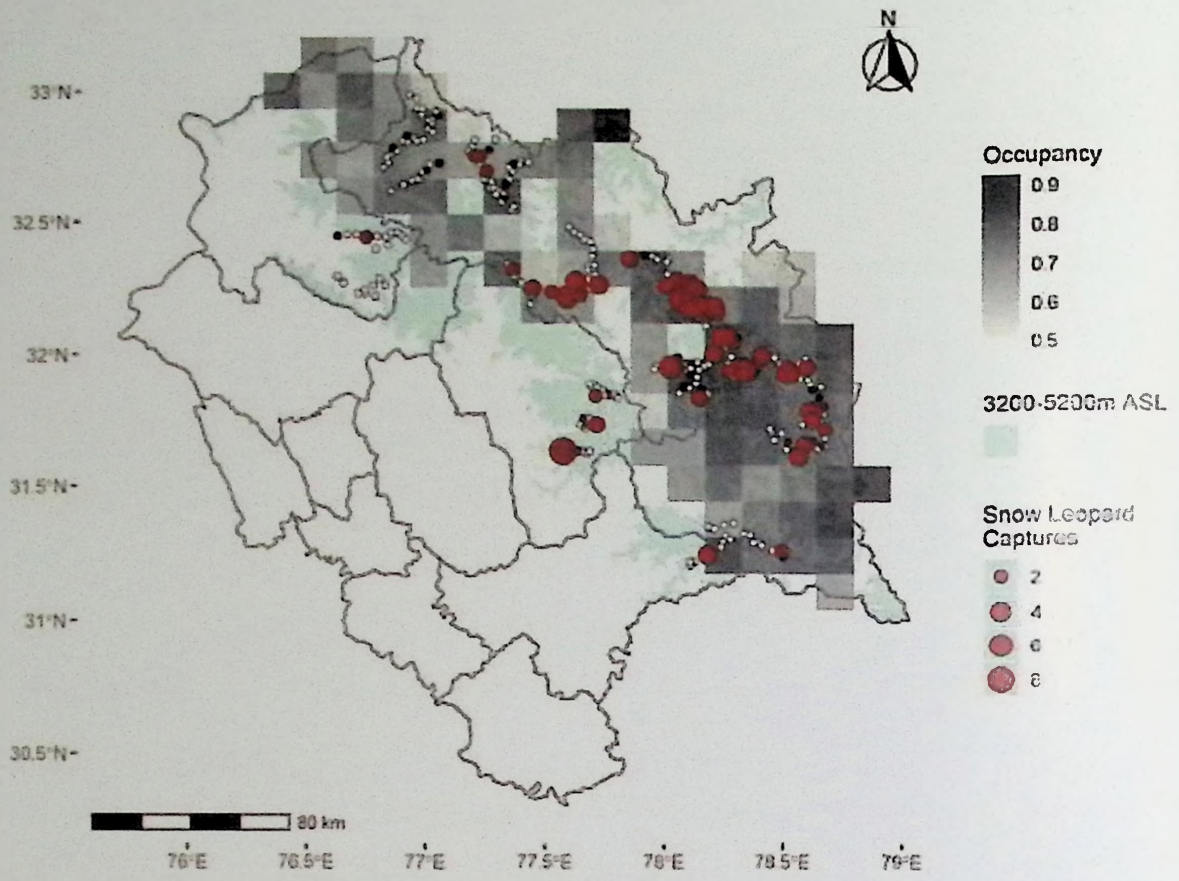


Figure 3: Snow leopard captures in each of the 10 sites surveyed. Red dots represent cameras where snow leopards were photographed. Larger dots indicate a higher number of occasions where snow leopards were captured. White dots represent cameras where no snow leopards were photographed. Black cells show snow leopard occupancy within a 15 x 15km grid as estimated by Ghoshal et al. 2019. The light blue region depicts the potential snow leopard habitat elevation range

This study used a robust sampling design that representatively sampled all types of snow leopard habitats unlike previous estimates that were based on sampling only from high density areas. For this study region, the population size is estimated to be between 44 to 73 snow leopards with a mean of 51 (95% CI 44 - 73) snow leopards. For our study region, the detection probability at the activity centres λ (lambda) was estimated to be 1.8 x 10-2 (95%CI: 1.3 x 10-2 - 2.5 x 10-2). The indicator of home range δ (sigma) from our study was estimated to be 8.5 km (95% CI: 6.9 – 10.41 km).

Ungulate density

The total area of all the 10 sampled sites was 4,489 km² and it was surveyed on foot, covering 749 km of transects which were walked two times by the two observer teams. Blue sheep was recorded in Spiti, Tabo, Hangrang, and Baspa, whereas ibex was recorded in all sites except in Kullu, Tabo and Baspa. We also recorded tahr in Kullu and Bharmour regions. The highest wild prey density was recorded in Spiti (1.09 individuals km^{-2}; 1.074 individuals km^{-2} – 1.14 individuals km^{-2}) and the lowest in Chandra (0.11 individual km^{-2}; 0.08 individuals km^{-2} – 0.22 individuals km^{-2}). Solely for blue sheep, the site with the highest density was Spiti (0.99 individuals km^{-2}; 0.97 individuals km^{-2} – 1.040 individuals km^{-2}) and the lowest was Baspa (0.19 individuals km^{-2}; 0.13 individuals km^{-2} – 0.44 individuals km^{-2}). Solely for ibex, the site with the highest density was Pin (0.75 individuals km^{-2}; 0.75 individuals km^{-2} – 0.86 individuals km^{-2}) and the lowest was Chandra (0.11 individual km^{-2}; 0.08 individuals km^{-2} – 0.22 individuals km^{-2}). Table 3 below summarises results from all the 10 sites.

Table 3: Results from ungulate double-observer surveys from 10 sites

Block	Year	Species	Effort Km	Area km²	Abundance (95% CI)	Density (95% CI)
Pin	2016	Ibex	45.5	298	224 (224-256)	0.75 (0.75-0.86)
Spiti	2017	Blue Sheep	96.5	816	810 (790-850)	0.99 (0.97-1.04)
		Ibex			94 (82-127)	0.12 (0.10-0.16)
		Combined			891 (872-932)	1.09 (1.07-1.14)
Tabo	2017	Blue Sheep	43.5	341	351 (342-392)	1.03 (1.00-1.15)
Hangrang	2017	Ibex	119.4	589	99 (84-156)	0.17 (0.14-0.26)
		Blue Sheep			454 (435-505)	0.77 (0.74-0.86)
		Combined			547 (519-600)	0.93 (0.88-1.02)
Bhaga	2018	Ibex	124	456	229 (200-290)	0.5 (0.44-0.64)
Miyar	2018	Ibex	88	604	164(142-254)	0.27 (0.23-0.42)
Chandra	2018	Ibex	47.4	447	47 (35-100)	0.11 (0.08-0.22)
Baspa	2019	Blue Sheep	66.2	480	93 (62-212)	0.19 (0.13-0.44)
Kullu	2019	Blue Sheep	51.42	256	177 (163-229)	0.69 (0.64-0.89)
		Tahr			79 (59-163)	0.31 (0.23-0.64)
Bharmour	2019	Tahr	67.3	202	109 (87-177)	0.54 (0.43-0.88)
		Ibex			33 (25-81)	0.16 (0.12-0.40)

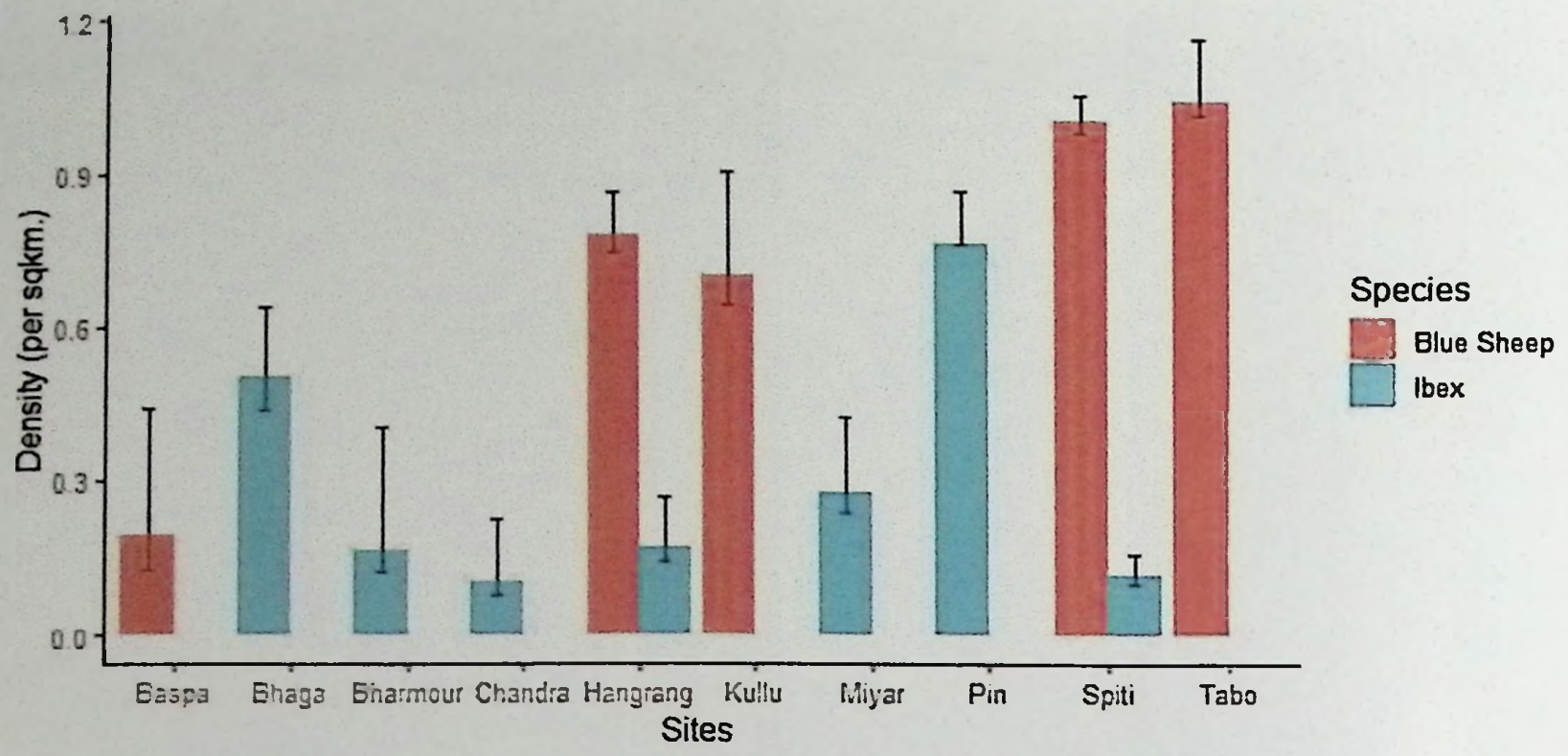


Figure 4: Results from double-observer surveys for prey density from 10 sites

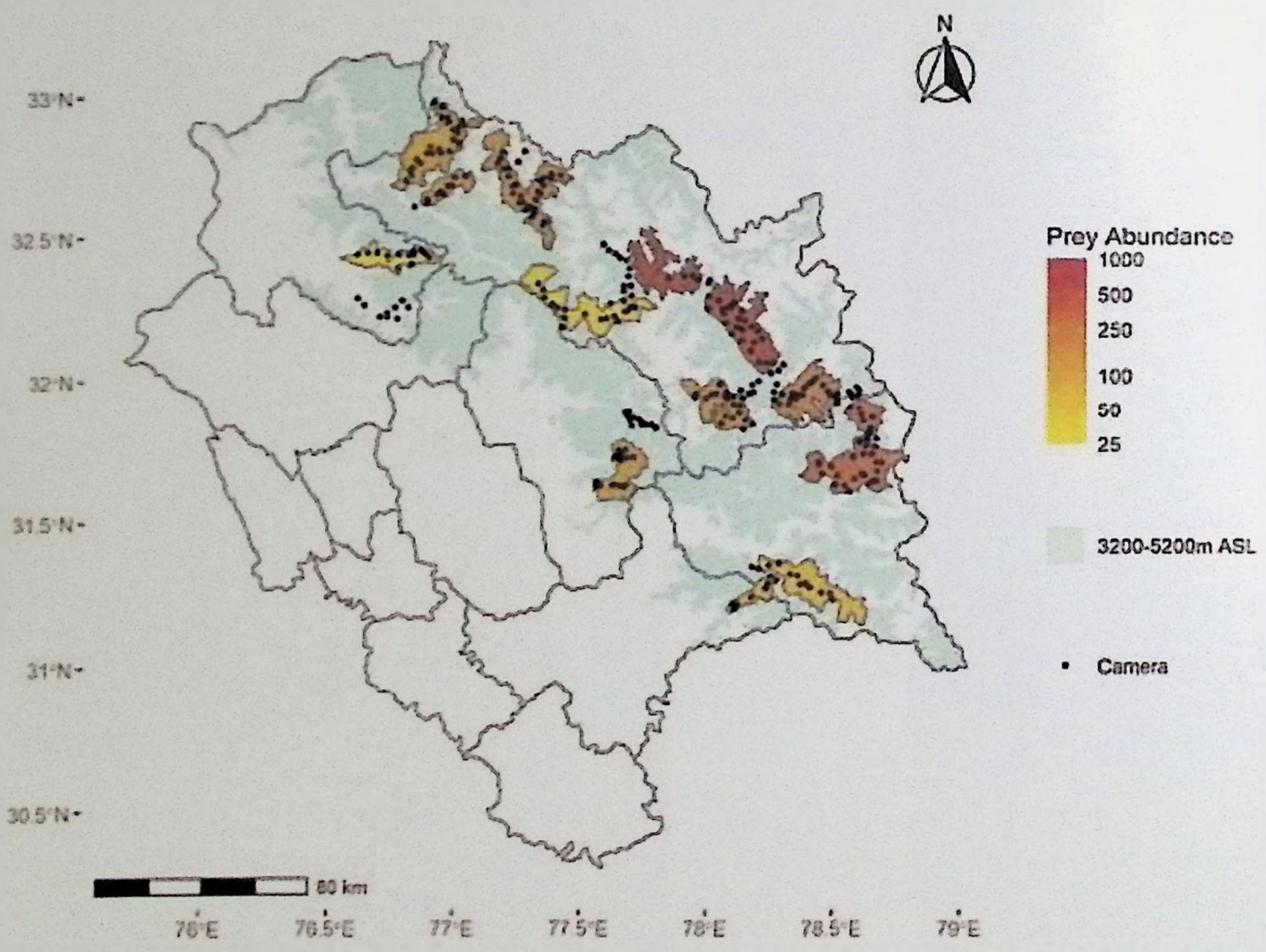


Figure 5: Estimated prey abundance using double observer surveys in the 10 surveyed sites. The light blue region depicts the potential snow leopard habitat elevation range. Black dots represent deployed cameras.

Relationship between snow leopard and prey density

Prey density was shown to have a positive relationship with snow leopard density (slope = 0.25, SE = 0.08, P = 0.01, R2 = 0.51). Sites with a high density of prey population, such as Tabo (Mean = 1.03, 95% CI = 1.01 - 1.15 prey per km²) and Spiti (Mean = 1.09, 95% CI = 1.07 - 1.14 prey per km²) were shown to have high densities of snow leopards (Tabo: 0.37 with 95% CI: 0.18 – 0.72; Spiti: 0.3 with 95%CIs: 0.15 – 0.59 snow leopards per 100 km²). On the other hand, Bharmour and Chandra that reported low densities of prey were shown to have low snow leopard densities.

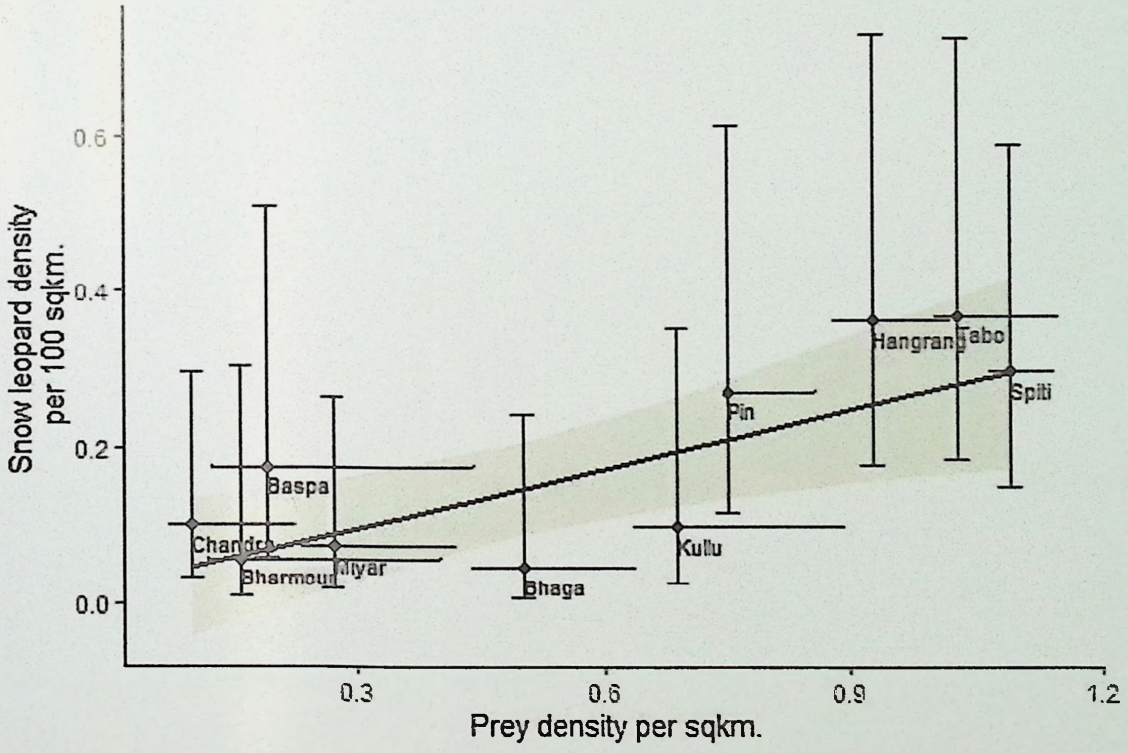


Figure 6: Snow leopard density and prey density is positively correlated across sites. Line represents predicted relationship from a weighted linear regression model (slope= 0.25, SE= 0.08, P= 0.01, R^2= 0.51) and shaded region represents 95% CI on the model prediction.

Site Information

Photo credit: NCF

Photo credit: NCF

Baspa

The Baspa valley covers large parts of the Rakcham-Chitkul Wildlife Sanctuary and its adjacent areas (notably the Rupin pass region towards Jhaka and Jiskun). The valley's lower reaches consist of oak and pine forest along with Indian birch and diverse species of rhododendron. The camera trap area in Baspa region included parts of Baspa valley from Shong village to Nagasti area beyond Chitkul with areas lying within the Rakcham-Chitkul Wildlife Sanctuary. Both sides of Baspa river were surveyed and the area was extended from Sangla Kanda towards Udug naal area beyond Rupin pass and before Jakha-Jiscoon village. The ungulate survey region extended from near Sangla town till the last Indo-Tibetan Border Police (ITBP) check-post in the Dumti region. Both banks of the Baspa river were surveyed. In addition to this, a narrow yet long valley SW of the Sangla town, from Rupin pass down towards the Jakha-Jiskoon villages was also surveyed.

We detected 3 snow leopard individuals on 7 occasions from this site in our camera traps. In addition, we detected black bear, brown bear, Himalayan weasel, mountain weasel, leopard cat, jackal, stone marten, yellow-throated marten, monal, koklass pheasant, snowcock, snow partridge, and musk deer in our camera traps. The ungulate surveys revealed blue sheep abundance to be 93 (95% CI: 62-212).

Bhaga

The Bhaga region falls within the Lahaul region of the Lahual-Spiti district. This region falls under the Trans-Himalayan eco-region and experiences harsh winters and most of the precipitation is mainly in the form of snowfall. The temperature ranges from 300C in summer to -350C in winter. The area is mostly considered a dry alpine region dominated by graminoids, sedges and a few shrubs. Camera trapping for this site was centered around the village of Darcha and surrounding valleys with a coverage within the Kugti Wildlife Sanctuary. Sampling area included the region NW from Darcha towards Shinko la, SE from Darcha towards Yoche, and NE from Darcha towards Zingzing/Bar-Baralacha La. Both banks of the river Bhaga and its tributaries were covered. These valleys and catchments formed the sampling area of the ungulate survey as well.

We detected 1 snow leopard individual on 7 occasions from this site in our camera traps. In addition, we detected mountain weasel, red fox, stone marten, chukar partridge, and snowcock in our camera traps. The ungulate surveys revealed ibex abundance to be 229 (95% CI: 200-290).

Bharmour

Bharmour falls within the Pir Panjal range of the Himalaya with varying altitude from 1350m- c.6000m. and is drained by the Ravi river that originates near the Garechu glacier, at the bottom of the Kugti pass. July-August are the warmest months (mean monthly temperature of 26.08 oC) while January-February are the coldest (with temperature below -10 oC accompanied with heavy snowfall) (Mohanta & Chauhan 2014). The camera trapping for this site was centered around Bharmour town for the Kugti area and Nayagraon for the Holi area. We detected 1 snow leopard individual on 1 occasion from this site in our camera traps. In addition, we detected black bear, brown bear, common leopard, Himalayan weasel, mountain weasel, leopard cat, jackal, stone marten, yellow-throated marten, masked palm civet, monal, koklass pheasant, snowcock, snow partridge, goral and musk deer in our camera traps from Bharmour. The ungulate surveys revealed that Himalayan tahr abundance was 109 (95% CI: 87-177) and ibex abundance estimate was 33 (95% CI: 25-81).

Chandra

The regions between Batal and Tokpo Yongma (including Chandratal) and large parts of the left bank were not surveyed for ungulates given the extreme weather conditions and lack of access due to unseasonal heavy snowfall. The Chandra region falls within the Lahaul-Spiti district and this region is a basin drained by the Chandra river, a sub-basin of the larger Chenab river. The camera trapping for this site was conducted on both banks of the Chandra river from Khoksar till Batal and then northwards into the Chandertal region till Tokpo Yongma (which eventually leads to Baralacha la) covering areas within the Chandertal Wildlife Sanctuary. The ungulate surveys were largely limited to the right bank of the Chandra river from Khoksar till Batal.
We detected 3 snow leopard individuals on 14 occasions from this site in our camera traps. In addition, we detected brown bear, mountain weasel, stone marten, marmot, snowcock, and chukar partridge in our camera traps. The ungulate surveys revealed that ibex abundance estimate was 47 (95% CI: 35-100).

Hangrang

Hangrang valley is the second-largest valley in Kinnaur district in Himachal Pradesh. This valley borders the area of Spiti in the upper Kinnaur region and is very close to Tibetan border of the North and Eastern side of Himachal Pradesh. This whole area experiences a harsh winter and most of the precipitation is mainly in the form of snowfall. The temperature ranges from 250C in summer to -350C in winter. The area is mostly considered a dry Alpine area. The camera trapping and ungulate surveys in this site covered the same areas. In addition to the Hangrang valley, extending from the Khab bridge till Hango village along with its adjacent areas, sampling for this site also included the Upper Sutlej valley and the Ropa valley.

We detected 8 snow leopard individuals on 18 occasions from this site in our camera traps. In addition, we detected brown bear, stone marten, yellow-throated marten, jungle cat, leopard cat, red fox, snowcock, and chukar partridge in our camera traps. The ungulate surveys revealed that ibex abundance estimate was 99 (95% CI: 84-156) and blue sheep abundance estimate was 454 (95% CI: 435-505).

Kullu

This area consists of high mountain ridges, some upwards of 5,800 m, and is divided into three gorges - Tirthan, Sainj and Jiwa Nala - based on the streams that flow through each. Large parts of this region consists of moist temperate oak and conifer forests, along with high altitude birch and fir interspaced with sub-alpine pastures (Baviskar 2003). The camera trapping for this site was split between three valleys, Tirthan and Sainj (within the Great Himalayan National Park) and Parvati valley (within Kheerganga National Park). For the ungulate surveys we covered the Tirthan (Kubri top and Tirth) and Sainj (Rakthi and Chengar) and did not cover Parvati valley.

We detected 2 snow leopard individuals on 18 occasions from this site in our camera traps. In addition, we detected brown bear, black bear, common leopard, Himalayan weasel, mountain weasel, leopard cat, stone marten, yellow-throated marten, vole, red fox, cheer pheasant, koklass pheasant, chukar partridge, goral, and musk deer in our camera traps. The ungulate surveys revealed that blue sheep abundance estimate was 177 (95% CI: 163-229) and tahr abundance estimate was 79 (95% CI: 59-163).

Bhaga

Miyar is a long narrow valley of c.75 km which is located in the Lahual range of the Western Himalayas between the Pir Panjal and Zanskar ranges (Apollo et al. 2018). Thirot is relatively shorter but is covered with a similar extent of glaciers. For both valleys, travelling in from the valley mouths, the landscape transitions from Greater Himalaya temperature pine, birch and rhododendron forests to Alpine and nival zones along an increased elevation gradient. The camera trapping for this site was done across the entire length of Miyar and its neighbouring Thirot valley. The sampling regions for the camera trapping and ungulate surveys were similar.

We detected 2 snow leopard individuals on 5 occasions from this site in our camera traps. In addition, we detected brown bear, mountain weasel, stone marten, red fox, snowcock, snow partridge, chukar partridge, and musk deer in our camera traps. The ungulate surveys revealed that ibex abundance estimate was 164 (95% CI: 142-254).

Pin

This area is situated in the catchment of the Pin River within the Pir Panjal range of the Himalayas. Overall, the terrain is rugged with most regions having an inclination between 30 and 60 degree. The camera trap areas for this site included the Ensa nallah and its surrounding region (around and beyond Mudh village), around Sangnam village and the core region of the Pin valley National Park roughly west of Sagnam village, including the Geychang-Thango area and their connected side valleys. The ungulate survey was conducted in the same area.

We detected 6 snow leopard individuals on 18 occasions from this site in our camera traps. In addition, we stone marten, red fox, and chukar partridge in our camera traps. The ungulate surveys revealed that ibex abundance estimate was 224 (95% CI: 224-256).

Spiti

The Spiti landscape in the Indian trans-Himalayas is a high altitude (3500-6700 m) region covering an area of about 7,600 km². The temperature ranges from -40°C in peak winter to 30°C in summer. Vegetation is broadly classified as 'dry alpine steppe' (Champion and Seth 1968). The camera trapping survey covered the region solely on the left-bank of the Spiti river from around the Lossar village area downstream till Demul covering parts of the Kibber Wildlife Sanctuary. The ungulate survey area covered the same region as well.

We detected 9 snow leopard individuals on 52 occasions from this site in our camera traps. In addition, we detected mountain weasel, stone marten, red fox, snowcock, wolly hare, snowcock, and chukar partridge in our camera traps. The ungulate surveys revealed that blue sheep abundance estimate was 810 (95% CI: 790-850) and ibex abundance estimate was 94 (95% CI: 82-127).

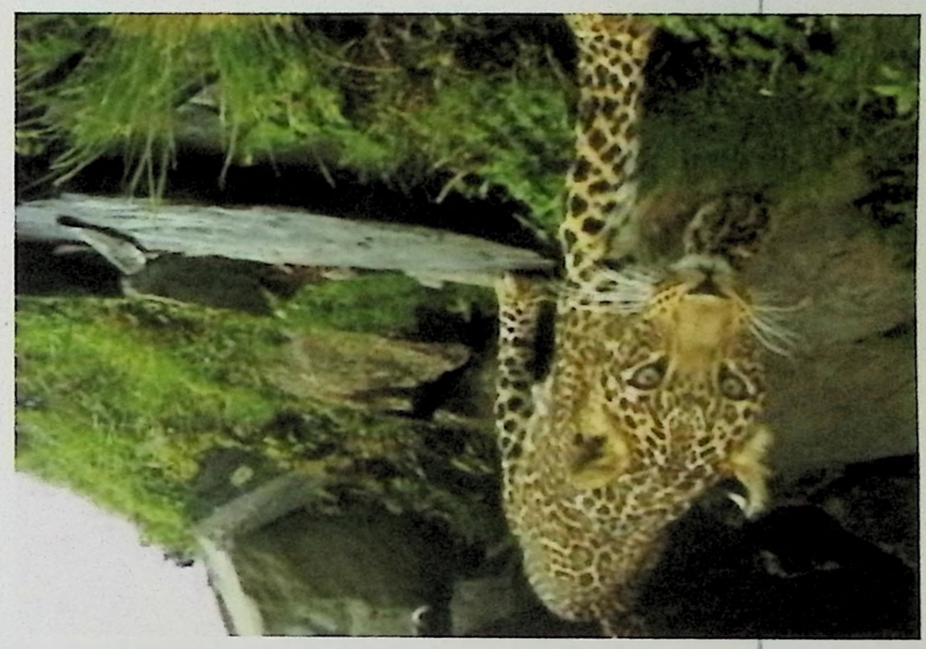
Tabo

This site was sampled along the main Spiti river valley between the villages of Schilling and Sumra. This region also falls within the Indian Trans-Himalayas, but with slightly lower altitudes than the Spiti site. The temperatures can range from summer

Photos by Prasenjeet Yadav

highs of 30°C to winter lows of -30 °C. The vegetation in the region is classified as "dry alpine steppe" (Champion and Seth 1968). The camera trapping and ungulate survey areas predominantly overlapped for this site. This covered both the right bank and left bank areas of Spiti rivers, between the villages of Schilling to Sumra. The surveys were centered from the village of Tabo.

We detected 9 snow leopard individuals on 25 occasions from this site in our camera traps. In addition, we detected mountain weasel, stone marten, red fox, snowcock, wolly hare, snowcock, and chukar partridge in our camera traps. The ungulate surveys revealed that blue sheep abundance estimate was 351 (95% CI: 342-392).



Photos credit: NCF

Non targeted carnivore species detections

Although the primary objective of the camera trap exercise is to generate a long term data for snow leopard population monitoring, these camera traps also captured other animals. We have identified and tagged 28 non target species (Table:) in these camera traps from 10 sites (Table:). We have utilised these data to understand distribution of various non targeted carnivore species in Trans Himalayas. Species with more than 30 detections were used for these analyses.

Species	Capture
Red fox	783
Stone marten	282
Dog	112
Yellow throated marten	49
Brown bear	46
Masked palm civet	39
Black bear	33
Himalayan weasel	31
Mountain weasel	31
Leopard cat	26
Common leopard	14
Wolf	03
Jackal	02
Jungle cat	01

Future Work

This project is the first scientifically robust assessment of snow leopard and its prey population in the State of Himachal Pradesh. This is likely among the first project of its kind to have been completed, at this scale, anywhere across the global snow leopard range. This exercise presents two opportunities for the future:

- *It provides baseline information to the Wildlife Wing to set up a long term monitoring project to track the population of snow leopard and its wild prey species;*
- *It provides a landscape level status, which can be extended to understand the perspectives and motivations of local communities and how it affects conservation action in these regions of the State.*

In terms of systematic long-term monitoring, the State can pursue a process similar to that followed for tiger census in India. The national tiger census is reported once every four years, while field work is ongoing. Himachal Pradesh can choose to further strengthen study design by increasing simultaneous deployment of camera traps and building more capacity among frontline staff to lead such studies in the field. Long term studies can become a very useful way to track the efficacy of on-ground conservation efforts.

The results from this study provide a snapshot of snow leopard and prey estimates across the landscape based on primary evidence. There is a scope to build on this information to understanding the perspectives and motivations of local communities, since these are inevitably linked with the results of on-ground conservation efforts. Local lifestyles, traditional practices and cultural beliefs have a significant role in conservation as well as human wellbeing of communities inhabiting the high Himalayan regions. Capturing such information can allow the Wildlife Wing to develop plans that are aligned to the expectations of local communities residing in these regions.

Capacity Building

An important part of the project was to build local capacity among frontline staff for conducting ecological field surveys. During the course of the project, frontline staff was trained in a camera-trapping prior to expeditions in the landscapes that were surveyed as part of the assessm

The one-day training covered the following topics:

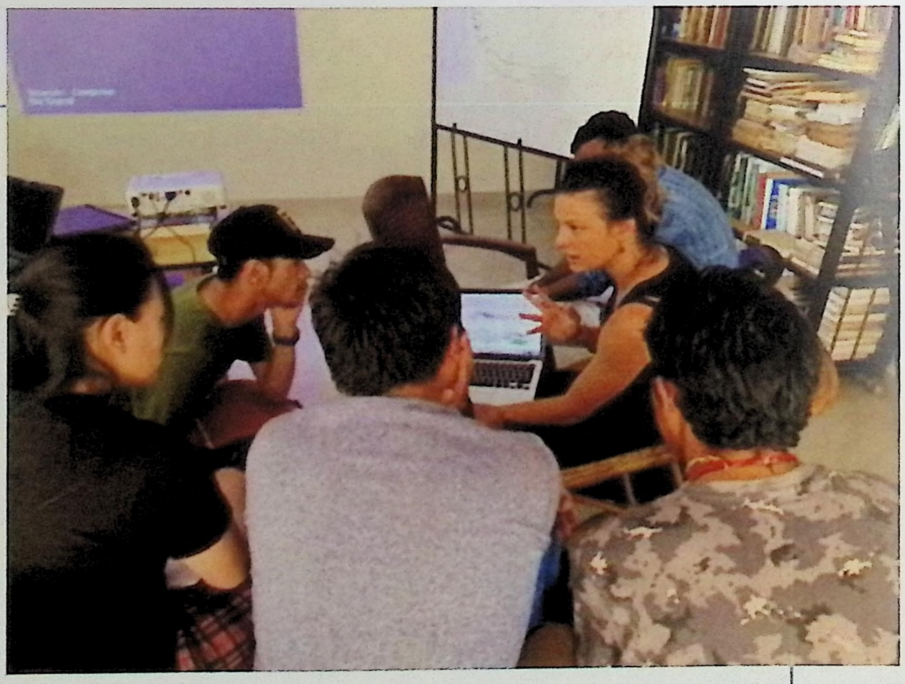
1. Introduction to Population Assessment of the World's Snow Leopards (PAWS) and state-wide estimation of snow leopard and its prey species in Himachal Pradesh
2. An introduction to camera trap studies and types of camera traps
3. Mapping of landscape for areas of high wildlife value, which was led by frontline staff
4. How to plan and conduct a camera trap study with a session on setting up and operating camera traps in the field

Photo credit: NCF

In addition to this, the participants were informed about the various kinds of datasheets used in the project like installation datasheet, monitoring datasheet and removal datasheet. They were also apprised about the workflow of data management, identification and analysis that would follow the field work. Following the training, we led the setting of camera traps in these respective landscapes. Several of the trained frontline staff participated in these exercises which stretched on for up to a fortnight. These cameras had to be monitored once in the 60-day monitoring period and retrieved at the end of 60 days.

In all, 73 frontline staff were trained during the course of the project. This is in addition to similar training programs that have been conducted in Spiti in the previous years. The locations where day-long training programs were carried out include:

Division	Location	No. of attendees	Conducted on
Lahaul	Keylong	19	14 May 2018
Sarahan	Sangla	3	6 May 2019
Bharmour	Bharmour	30	22 May 2019
GHNP	Sai Ropa	21	11 June 2019



We also informed local communities of the camera trapping exercise in order to prevent any sense of intrusion into their areas, as well as to seek their participation and support in the exercise.

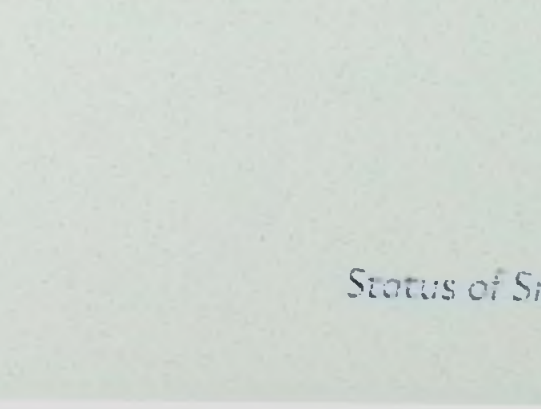
The entire camera trapping exercise was led by a team of 8 local youth of Kibber village in Spiti who have been working on such surveys across the Upper Spiti Landscape since 2010. They were given advanced training at the start of each year in order to ensure that they were fully prepared to lead field work. Such training was carried out at the start of 2018 and 2019. This advanced training was carried out over a month at NCF's head office in Mysore. During this time the team was trained in:

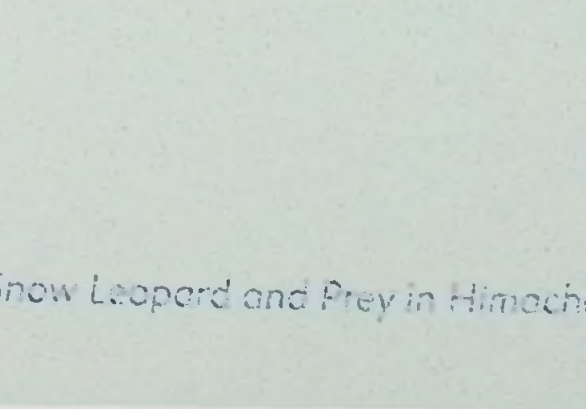
1. Specifics of camera trapping including capture-recapture methods and double-observer surveys (5 days)
2. Handling outdoor medical emergencies (1 day)
3. Conducting interview surveys (1 day)
4. Module on PARTNERS principles for community-based conservation (2 days)
5. Basics of project management and developing work plan for upcoming year (2 days)
6. Working with data in Excel (1 day)
7. Spoken English and basics of writing and reporting (2 days)
8. Workshop on mental health and well-being with a focus on coping up with long durations of field work (1 day)

Shorter training modules were carried out at the start of every field expedition. They were adequately supported by NCF researchers, frontline staff of the HPFD and members of the local community where cameras were set up.

Training for frontline staff of Forest Department in camera trapping in Bharmour (2019)

Community awareness meeting and Forest Department training for camera trapping in Sangla (2019)





Training for frontline staff of Forest Department in camera trapping in Keylong (2018)

Acknowledgments

This project was carried out as a collaborative effort by the Wildlife Wing of the Himachal Pradesh Forest Department and the Nature Conservation Foundation (NCF), Mysuru. Several officers of the Wildlife Wing of Himachal Pradesh Forest Department played an important role across various stages of this project. We list the names of all these officers, field officers and frontline staff in acknowledgement of the role they played in ensuring the success of this project:

Photos by Prasenjeet Yadav

Chief Wildlife Wardens
(in chronological order):
Ms. Archana Sharma (IFS),
Dr. Savita (IFS),
Dr. R.C. Kang (IFS),
Shri. S.K Sharma (IFS),
Dr. G.S. Goraya (IFS).

Chief Conservation of Forest (South)
Shri. Anil Thakur (IFS),
Dr. SK Kapta (IFS),
Shri. PL Chauhan (IFS).

Divisional Forest Officer (HQ)
Shri. NPS Dhaulta.

The Great Himalayan National Park (GHNP):
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DFO (Wildlife) at GHNP,
RFOs of Sainj and Sairopa,
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Forest Guard: Shri. Shivkumar,
Ms. Tinkle Bhat, Shri. Mahesh and Shri. Ashwani Kumar

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RFO Shri. Devender Singh Chauhan
Frontline staff of the Spiti (Wildlife) Division.

We would also like to stress on the critical role played by community members in each of the locations where we conducted field work. This work could not have been done without their active participation and large hearted support.

References

Ale, S. B., & Mishra, C. (2018). The snow leopard's questionable comeback, Science, 359, 1110.

Alexander, J. S., Gopalaswamy, A., Shi, K., & Riordan, P. (2015). Face value: Towards robust estimates of snow leopard densities. PLoS One, 10, e0134815.

Apollo, M., Andreychouk, V., & Bhattarai, S. S. (2018). Short-term impacts of livestock grazing on vegetation and track formation in a high mountain environment: a case study from the Himalayan Miyar Valley (India). Sustainability, 10(4), 951.

Baviskar, A. (2003). Ecodevelopment in the Great Himalayan National Park. Battles over nature: science and the politics of conservation, 267-299.

Bishkek Declaration (2017). http://www.globalsnowleopard.org/blog/2017/08/28/the-bishkek-declaration-2017-caring-for-snow-leopards-and-mountains-our-ecological-future/

Borchers, D.L., and M.G. Efford. 2008. Spatially explicit maximum likelihood methods for capture–recapture studies. Biometrics 64:377–385

Borchers, D. (2012). A non- technical overview of spatially explicit capture-recapture models. Journal of Ornithology, 152, 435–444. https://doi. org/10.1007/s10336-010-0583-z
Boulanger,

Champion, S. H., & Seth, S. K. (1968). A revised survey of the forest types of India. A revised survey of the forest types of India.

Efford, M. G., D. K. Dawson, and D. L. Borchers. 2009. Population density estimated from loca-tions of individuals on a passive detector array. Ecology 90:2676–2682.

Fegatelli, D.A., & Tardelli, L. (2013). Improved inference on capture recapture models with behavioural effects. Statistical Methods and Applications 22:45-66.

Forsyth, D. M., & Hickling, G. J. (1997). An improved technique for indexing abundance of Himalayan thar. New Zealand journal of ecology, 97-101.

Ghoshal, A., et al. (2019). Assessing changes in distribution of the Endangered snow leopard Panthera uncia and its wild prey over 2 decades in the Indian Himalaya through interview-based occupancy surveys. Oryx, 1-13. doi:10.1017/S0030605317001107

Jackson, Rodney, and Gary Ahlborn. "Snow leopards (Panthera uncia) in Nepal: home range and movements." National Geographic Research 5.2 (1989): 161-175.

Jackson, Rodney. Home range, movements and habitat use of snow leopard (Uncia uncia) in Nepal. Diss. University of London, 1996.

Jackson, R. M., Roe, J. M., Wangchuk, R., & Hunter, D. O. (2006). Estimating snow leopard population abundance using photography and capture-recapture techniques. Wildlife Society Bulletin, 34, 772–781.

Janečka, J.E., Jackson, R., Yuquang, Z., Diqiang, L., Munkhtsog, B. (2008). Population monitoring of snow leopards using noninvasive collection of scat samples: a pilot study. Animal Conservation, 11: 401–411.

Jhala, Y. V, Qureshi, Q. & Nayak, A. K. (eds). 2019. Status of tigers, co-predators and prey in India 2018. Summary Report. National Tiger Conservation Authority, Government of India, New Delhi & Wildlife Institute of India, Dehradun. TR No./2019/05.

Johansson, Ö., Samelius, G., Wikberg, E. et al. (2020). Identification errors in camera-trap studies result in systematic population overestimation. Sci Rep 10, 6393.

Karanth, K. U. & Nichols, J. D. (1998). Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79:2852–2862.

Karanth, U., Nichols, J., Kumar, N., Link, W., & Hines, J. (2004). Tigers and their prey: Predicting carnivore densities from prey abundance. Proceedings of the National Academy of Science,101, 4854–4858.

Mondal, S., Karanth, U., Kumar, N., Gopalaswamy, A., Andheria, A., & Ramakrishnan, U. (2009). Evaluation of non-invasive genetic sampling methods for estimating tiger population size. Biological Conservation,142, 2350–2360.

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

McCarthy, T., Mallon, D., Sanderson, E. and Zahler, P. 2016. Biogeography and status overview. In: T.McCarthy and D. Mallon (eds), Snow Leopards, pp. 23-41. Elsevier, New York.

Murali, R., Redpath, S. And Mishra, C. 2017. The value of ecosystem services in the high altitude Spiti Valley, Indian Trans-Himalaya. Ecosystem Services28: 115–123.

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.

Mohanta, R., & Chauhan, N. P. S. (2014). Anthropogenic threats and its conservation on Himalayan brown bear (Ursus arctos) habitat in Kugti wildlife sanctuary, Himachal Pradesh, India. Asian Journal of Conservation Biology, 3(2), 175-180.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/

Sharma, K., Bayrakcismith, R., Tumursukh, L., Johansson, O., Sevger, P.,McCarthy, T., & Mishra, C. (2014). Vigorous dynamics underlie a stable population of the endangered snow leopard Panthera uncia in Tost Mountains, south Gobi, Mongolia. PLoS One, 9, e101319.

Sharma, K., Borchers, D., Mackenzie, D., Durbach, I., Sutherland, C., Nichols, J.D., Lovari, S., Zhi, L., Khan, A.A., Modaqiq, W., McCarthy, T.M., and Mishra, C 2019. Guidelines for estimating snow leopard abundance and distribution using a combination of spatial capture-recapture and occupancy models. Guidelines submitted to the Steering Committee of the Global Snow Leopard and Ecosystem Protection Program with financial support from UNDP, SLT and GEF. Pp. 55

Suryawanshi, K. R., Redpath, S. M., Bhatnagar, Y. V., Ramakrishnan, U., Chaturvedi, V., Smout, S. C., & Mishra, C. (2017). Impact of wild prey availability on livestock predation by snow leopards. Royal Society Open Science, 4, 170026.

Suryawanshi, Kulbhushansingh R., et al. "Sampling bias in snow leopard population estimation studies." Population Ecology 61.3 (2019): 268-276.

Photos by Prasenjeet Yadav

Appendix

Snow leopard Profiles

BAS1

BAS2

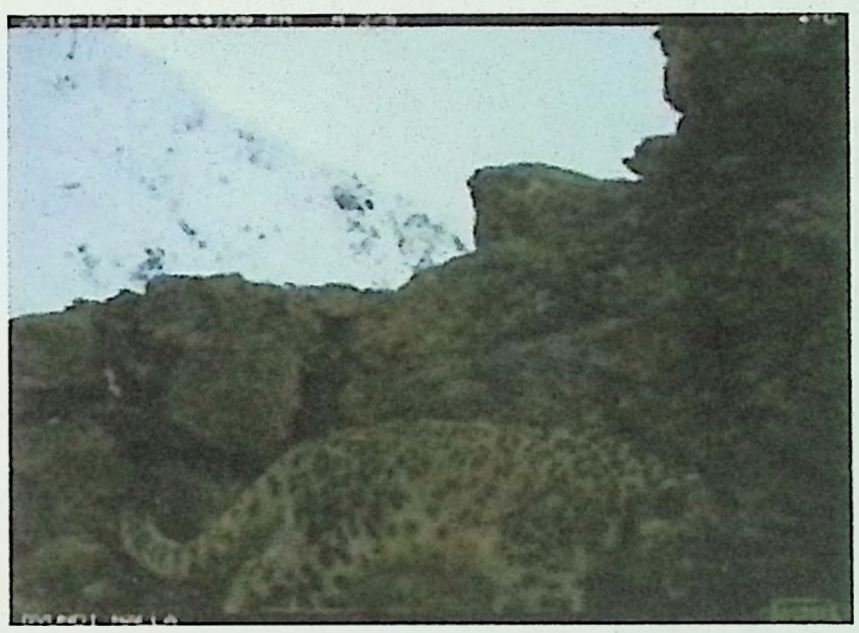
BAS3

BHG1

BHR1

CHA1

CHA2



CHA3

HAN1

HAN2

HAN3

HAN4

HAN5

HAN6

HAN7

HAN8

KUL1

KUL2

MIT1

MIT2

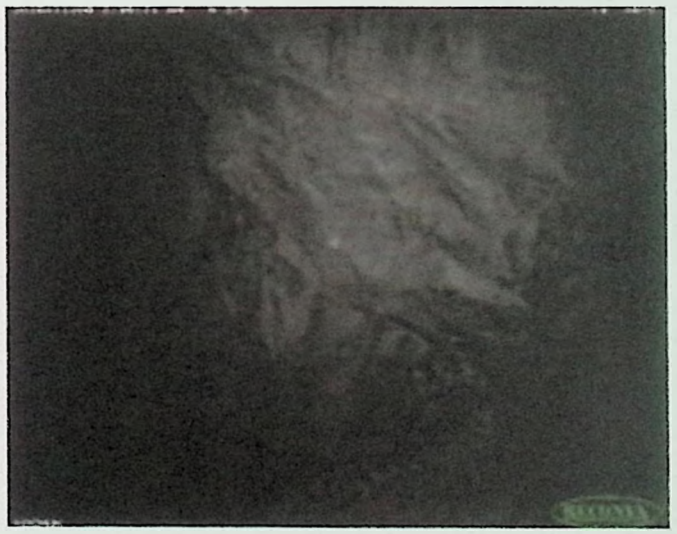
PIN1

PIN2

PIN3

PIN4

PIN5



PIN6

SPI1

SPI2

SPI3

SPI4

SPI5

SPI6

SPI7

SPI8

SPI9

TAB1

TAB2

TAB3

TAB4

TAB5

TAB6

TAB7

TAB8

TAB9

nature
conservation
foundation

SNOW
LEOPARD
TRUST

(Appendix IV)

STATUS OF

SNOW LEOPARD IN UTTARAKHAND

JUNE 2023

STATUS OF SNOW LEOPARD IN UTTARAKHAND

UNDER
THE SNOW LEOPARD POPULATION ASSESSMENT OF INDIA (SPAI) PROGRAM

Uttarakhand Forest Department

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

JUNE, 2023

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Executive Summary

The Snow Leopard (*Panthera uncia*) is an apex predator of the Indian Himalayas and is a culturally, ecologically, and economically important symbol of healthy mountain ecosystems. The distribution of Snow Leopard in India is spread over the northern Himalayan Mountains of the states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand in the western Himalayan region, and Sikkim and Arunachal Pradesh in eastern Himalaya. The ecological integrity of the Snow Leopard habitats is linked closely with the socio-cultural wellness of the local area and the economic well-being of the downstream populations. Recognizing the importance of the conservation of high-altitude environments, Snow Leopard range countries and partners have collaborated through the Global Snow Leopard and Ecosystem Protection Program (GSLEP). These Governments have jointly initiated an effort to conduct a Population Assessment of the World's Snow Leopards (PAWS). As a part of PAWS, the Government of India has launched the 'Snow Leopard Population Assessment in India (SPAI)' program, which seeks to provide accurate population estimates and guide conservation measures. This report summarizes the first state-level survey in Uttarakhand State under the SPAI program to determine the status of Snow Leopards.

The potential Snow Leopard range in Uttarakhand encompasses a large geographic region (12764.35 km^2), that includes the high-altitude areas (3000-5500m) of the state. In a collaborative effort, the Wildlife Institute of India and Uttarakhand Forest Department carried out the Snow Leopard population assessment in two steps following the guidelines of the national population assessment of Snow Leopards in India (MoEFCC, 2019). The first step is to systematically assess the spatial distribution of Snow Leopards in their potential distribution range. Snow Leopard potential distribution ranges were divided into uniform grids (15×15 km), and the presence of Snow Leopard distribution was assessed by sampling in the occupancy method framework. Information on Snow Leopard occurrence was compiled in the form of 448 questionnaires from 42 (15×15 km) sampling grids. The results showed a high probability of Snow Leopard occurrence in the trans-Himalayan areas of the Uttarakhand state compared to greater and mid-Himalayan areas. Based on the probability of site use by Snow Leopard, the habitat was divided into three strata for Step II sampling: high probability of occurrence (> 0.8) in 46.11% (5886 km^2); moderate probability of occurrence (0.8 to 0.5) in 26.9% (3429 km^2); low probability (< 0.5) in 27.02% (3449 km^2).

In the second step, the abundance of Snow Leopards is estimated using camera traps (spatial capture-recapture method) in each stratified region identified in Step I. Camera trap sampling using 3×3 km grids was carried out in the spatial capture-recapture method (SCR framework). Camera trapping was carried out for ~100 days in different habitat blocks. Sampling was carried out in Govind National Park and Sanctuary (50, trap nights= 1,943); Kedarnath Forest Division (70, trap nights= 3,385); trans-Himalayan (105, trap nights= 6,009) and greater Himalayan habitats (43, trap nights= 1,676) of Nanda Devi Biosphere reserve between July 2021 and November 2021. The information from Gangotri National Park and Uttarkashi Division (100, trap nights= 10,100) was also used for population estimation. Further, sampling conducted by WWF in the Munsiyari area of the Pithoragarh division (October 2020 to March 2021, 20 locations, 3640) was also used. Camera trapping efforts yielded 26,773 trap nights and resulted in 372 identifiable Snow Leopard photographs. A total of 41 individuals were identified (6 males, 8 females, 27 unknown). The estimated Snow Leopard population for Uttarakhand State is 124 (SE range 103 to 145) at a density of 0.7 to 1.04 individuals/ 100 km^2 adult Snow Leopard across the potential habitat of Uttarakhand.

The population assessment of Snow Leopards in Uttarakhand filled a crucial knowledge gap and provided landscape-level data to improve management practices. High-altitude protected areas were identified as supporting high densities of Snow Leopards and serving as a stronghold for the species in the state. Continued monitoring and inclusion of prey and conflict information will be crucial for the long-term conservation of Snow Leopard and for ensuring the health of mountain ecosystem services.

1. Background

The Snow Leopard (*Panthera uncia*) is an apex predator of the Indian Himalaya and is a culturally, ecologically, and economically important symbol of healthy mountain ecosystems (Zakharenka et al., 2016). The distribution of Snow Leopards in India is spread over the northern Himalayan Mountains of the states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand in the western Himalayan region and Sikkim and Arunachal Pradesh in eastern Himalaya. The ecological integrity of the Snow Leopard habitats is linked closely with the socio-cultural wellness of the local area and the economic well-being of the downstream populations. The high-mountain ecosystems accumulate precipitation, regulate seasonal runoff, and provide water to the human population beyond regional borders (Zakharenka et al., 2016), benefiting the country's northern region. Additionally, the Snow Leopard range supports important traditional pastoral economies, a rich diversity of medicinal plants and a unique wildlife assemblage of global conservation importance. As an apex predator, the Snow Leopard plays a crucial role in maintaining the ecological balance in the ecosystem, making it an ideal flagship species for wildlife conservation in the Himalaya. The Snow Leopard is listed in Schedule I of the Indian Wildlife (Protection) Act 1972 and the Jammu & Kashmir Wildlife (Protection) Act 1978, as well as in Appendix I of the Convention on International Trade in Endangered Species (CITES) and the Convention on Migratory Species (CMS), providing it with the highest conservation status both globally and in India.

The species ecology, status, and distribution remain poorly understood despite their immense ecological and economic importance. The Snow Leopard is listed as Vulnerable by the International Union for Conservation of Nature (IUCN), with declining populations due to habitat loss, prey depletion and poaching. In India, the species is threatened by multiple factors including overgrazing practices by livestock, conflict with locals, poaching, free-ranging dogs and habitat loss due to tourism and infrastructure development (Kittur et al., 2010; Bhatnagar et al., 2001; Mishra et al., 2010; Maheshwari et al., 2013; Pal et al., 2022). Other than anthropogenic threats intraguild competition between snow leopards, common leopards and woolly wolves also determines the population of snow leopards (Pal et al., 2022). In the absence of limited prey common leopards negatively influence the space use of snow leopards in the winter season, this intraguild interaction affects the fitness and distribution of snow leopards. The study also shows the dietary overlap between woolly wolves and snow leopards. Despite India's extensive history of research and conservation efforts, there is insufficient knowledge regarding

the status of the Snow Leopard. This lack of comprehensive and accurate population estimates poses a significant information gap hindering the effective planning and monitoring of conservation measures.

1.1. Snow Leopard Population Assessment in India (SPAI) program

In recognition of the significance of preserving high-altitude environments, Snow Leopard range countries and their partners have unanimously agreed to collaborate to achieve the goals of the Global Snow Leopard and Ecosystem Protection Program (GSLEP), which includes identifying and securing at least 20 Snow Leopard landscapes across their distribution range. India contributes three significant landscapes, namely Hemis-Spiti, Nanda Devi-Gangotri, and Kanchendzonga-Tawang, for the conservation of the species (Zakharenka et al., 2016). Twelve individual National Snow Leopard and Ecosystems Priorities (NSLEPs) are the foundation of the GSLEP program. These Government bodies have jointly initiated an effort to conduct a Population Assessment of the World's Snow Leopards (PAWS). As a part of PAWS, the Government of India has launched the 'Snow Leopard Population Assessment in India (SPAI)' program, 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. The program is a collaboration between the Indian government, non-governmental organizations and scientific institutions. It aims to provide accurate information about the status of the Snow Leopard population in India and to use this information to guide conservation efforts. The program's overall goal is to gather reliable information on the status of the Snow Leopard population in India, which will be used to guide conservation efforts and policy decisions.

Estimating the population of Snow Leopards precisely is a challenging task because of their highly elusive nature and the terrain where they inhabit, making them difficult to detect and count. Further, their habitat is vast, and limited resources are available for conducting surveys and monitoring. Additionally, their density is expected to vary in different regions, depending on factors such as habitat suitability, prey availability, disturbance, and connectivity (Sharma et al., 2015; Suryawanshi et al., 2019; Pal et al., 2022), making it essential to have an unbiased representation of all habitat types for a large-scale population assessment. To ensure that standardized methodologies are used across the Snow Leopard range, the Wildlife Institute of India and the Nature Conservation Foundation, with support from various national and international resources, have prepared guidelines for conducting a national population

assessment of Snow Leopards in India (MoEFCC, 2019). The exercise is being carried out by all the forest departments of Snow Leopard range states with the technical support of national conservation partners. This report summarizes the first state-level survey in Uttarakhand State under the SPAI program to determine the Snow Leopard status.

1.2. Status of knowledge on Snow Leopard in Uttarakhand

The state of Uttarakhand, with over 92% of its mountainous land area offers an estimated 13000 km^2 of potential habitat for Snow Leopards. Snow Leopard inhabits the higher Himalayan and trans-Himalayan habitat between 3000m to 5500m elevation. The history of Snow Leopard research in the state dates back to 1967 (Dang, 1961) when expeditions to the Nanda Devi region highlighted the presence of Snow Leopards in the state. Later, several anecdotal observations also confirmed the presence of the species from other parts of in Uttarakhand region; Ralam River catchment, eastern Kumaon (Dang, 1967), Kedarnath Wildlife Sanctuary (Green, 1988), and Govind Pashu vihar (Dang, 1968). Since 1980, several short-term surveys and long-term studies have been taken up in the high altitudes of Uttarakhand. Fox et al., 1986 surveyed Snow Leopard and associated species in the Himalaya of Northwestern India including upper Supin, Kopri valleys and Tons River catchment in Govind Pashu Vihar area in Uttarakhand. The study was instrumental in confirming the presence of a diverse array of mammal species including Snow Leopard and its important prey species (Blue sheep and Himalayan Tahr) from Govind Pashu Vihar region. The Nanda Devi decadal expedition program, initiated in 1993, also collected ecological data on Snow Leopards in the Nanda Devi National Park (WII 2015). Maheshwari et al., 2013 conducted a survey that was carried out in four Protected Areas (Govind Pashu Vihar Wildlife Sanctuary, Gangotri National Park, Askot Wildlife Sanctuary and Valley of Flowers National Park) and the buffer zone of Nanda Devi Biosphere Reserve of Uttarakhand State. The study concluded Snow Leopard occurrence in Uttarakhand correlates significantly with Bharal distribution. The study found livestock depredation and infrastructure development as an increasing threat to the existence of Snow Leopard. In 2015, as a part of the scientific monitoring of major wildlife species, the forest department, in technical collaboration with the Wildlife Institute of India, Dehradun, undertook the first-ever survey of the trans-Himalayan region adjoining the Greater Himalayan region of the state of Uttarakhand in June 2015 (Habib et al., 2016). The survey was carried out in 16 valleys (8981.23 km^2) spanning 7 territorial forest and wildlife divisions of 5 zones (Gangotri Landscape, Nanda Devi Biosphere reserve north, Askot Landscape, Pindar Landscape and

Govind Landscape). The survey gathered crucial information on the distribution and status of Snow Leopard and important prey species in the trans-Himalayan landscape of the state. The National Mission for Sustaining Himalayan Ecosystem project conducted an intensive assessment of Snow Leopard ecology in the Gangotri landscape from 2015-2019, which contributed significantly to understanding their distribution, status, and interaction with human use, seasonal changes and co-predators (Pal et al., 2021, 2022,2022b).

Research conducted in the high-altitude areas of Uttarakhand has identified multiple threats to the habitats and populations of the Snow Leopard and other co-existing species. These threats include the degradation of alpine habitats, declining prey species and infrastructure development (Sathyakumar, 1993, 2004; Green, 1985; Maheshwari et al., 2013). Additionally, sub-alpine habitats have also suffered degradation and fragmentation due to anthropogenic activities such as collection of non-timber forest products, free-ranging dogs, poaching, livestock grazing and camping by the herders (Sathyakumar et al., 1993; Awasthi et al. 2003; Sathyakumar et al., 2010; Pal et al., 2021). Although research has been carried out in some regions of the state, there is still a significant dearth of comprehensive and robust data on the current status of Snow Leopards in remote regions.

2. Material and Methods

2.1. Study Area

The potential Snow Leopard range in Uttarakhand encompasses a large geographic region (12764.35 km^2), that includes the high-altitude areas (3000-5500m) of the state. These habitats comprise the non-forested or sparsely forest high altitude alpine and subalpine habitat of trans-Himalayan and greater Himalayan regions. Glaciers cover a large part of the distribution range, and the region is characterized by steep, rugged terrain with several high mountain ranges that exceed 6000m, including Nanda Devi (7,816 m), Chaukhamba Massif (7138m), Bandarpunch (6720 m), Meru (6660m), Gangotri (6613m), Bhagirathi (6607m), Shivling (6543m) and Swargarohini (6,252 m).

Snow Leopard distribution range in the state forms the upper reaches of the following Protected Areas, Forest / Wildlife Divisions: Askot WS, Bageshwar FD, Badrinath FD, Gangotri NP, Govind NP& WLS, Kedarnath WS & WL Division, Nanda Devi NP, Pithoragarh FD, Uttarkashi FD, and Valley of Flowers NP. Livelihoods in this region are tied to an agrarian culture that has seen a steady exodus of youth to the plains, and the economy is a mix of agriculture, animal husbandry practices and sales from NTFP products and tourism/pilgrimage (WII 2021). Livestock grazing by the locals and the migratory herders (Gujjar, Gaddis) is the dominant human use practice in the alpine and subalpine habitats (June to September). Other anthropogenic activities in the subalpine and temperate forests include the extraction of non-timber forest products and collection of fuelwoods, which have been conducted for centuries (Awasthi et al. 2003; Rana et al. 2007). Tourism, mountaineering, and pilgrimage attract numerous visitors to the region, primarily during the summer and autumn seasons. As the northern boundary of the Snow Leopard range shares its borders with China and Nepal, patrolling camps and small settlements of the Indo-Tibetan Border Police and other security agencies are present and control human use in the upper distribution range limit in the state. Livestock grazing in summer, developmental and tourism activities, poaching and advancement of military infrastructure are potential threats to Snow Leopard and co-occurring species inside and outside protected areas (Chandola, 2008; Bhardwaj et al., 2010).

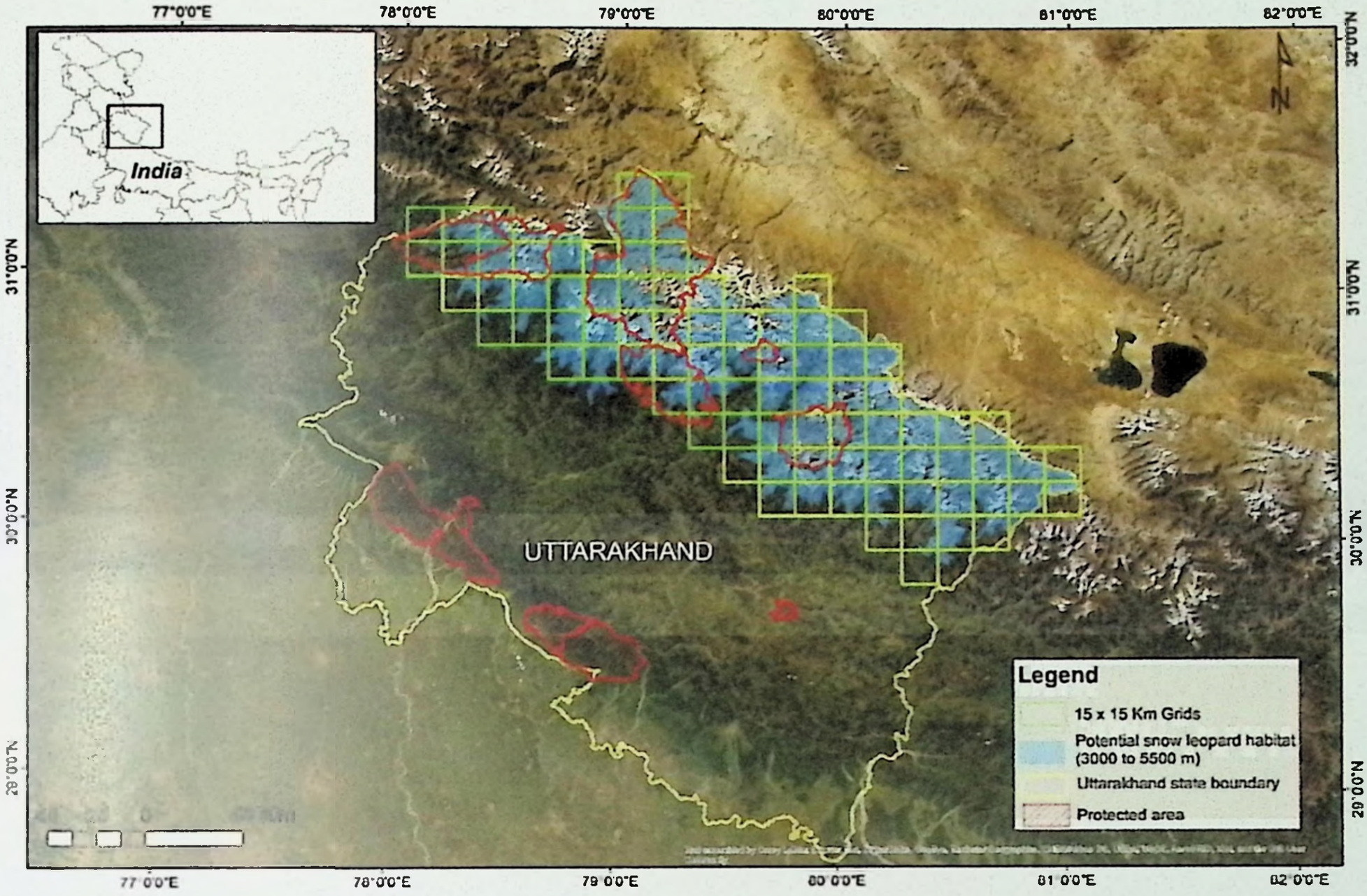


Figure 1: Map of Uttarakhand showing the potential distribution of Snow Leopard (3000m to 5500m elevation), PA boundaries and the sampling grids.

2.2.Methodology

The Snow Leopard population assessment (SPAI) of Uttarakhand was carried out in two steps following the guidelines of the national population assessment of Snow Leopards in India (MoEFCC, 2019). The first step is to systematically assess the spatial distribution of Snow Leopards in their potential distribution range. This step uses an occupancy-based sampling approach (questionnaire/sign survey) to understand the distribution of Snow Leopards and stratify potential Snow Leopard habitats. In the second step, the abundance of Snow Leopards is estimated using camera traps in each stratified region identified in Step I. Before the sampling process, various workshops online and offline were organized with the forest department to focus on planning the implementation of step I and step II assessment in a collaborative effort between the Forest department and the Wildlife Institute of India. These workshops aimed to build an understanding of the sampling framework and planning logistics to carry out surveys.

2.2.1. STEP I: Occupancy-based assessment of Snow Leopard distribution

The primary objective of Step I is to gain a thorough understanding of Snow Leopard distribution in the state. Snow Leopard potential distribution ranges were divided into uniform grids (15x15 km), and the actual presence of Snow Leopard distribution was assessed by sampling in the occupancy method framework (MacKenzie et al., 2006). Information on Snow Leopard occurrence was compiled in the form of 448 questionnaires from 42 (15x15 km) grids (Fig 2). Key informants (tour guides, porters, headers, paramilitary personnel and local people) were questioned about the occurrence of Snow Leopard and their prey species in their area of knowledge. Interviews focus on direct or indirect detections made by the person being interviewed. Respondents who failed to identify study species from the images and were unable to provide reliable information on the location of species detection were excluded from the analyses. In addition, 128 sign surveys (881.95 km) were completed in 41 grids.

Information received for 15x15 grids from each division was compiled into Excel sheets. Sign survey data could not be used for the occupancy analysis due to inconsistencies in GPS locations. The occurrence information gathered from questionnaire surveys was arranged in a detection/non-detection (1/0) framework. Each interviewee's report from a particular site was assigned as a replicate survey within the site. Site covariates (terrain complexity, elevation, vegetation index) that could influence the Snow Leopard's probability of site use were modelled using logistic insertions in the occupancy framework using the unmarked package in R software. Survey covariates that could have influenced the probability of detecting a species

and reporting it to the surveyor were also used to model detection probability. These included respondents' age, profession, duration (in years) of familiarity with their area of knowledge, and time spent in that area annually (Ghoshal et al., 2019). We used the top model to predict the probability of sites being used in unsampled areas.

2.2.2. Step II: Snow Leopard population sampling for regional density estimation

Camera trapping efforts

Step II entails estimating the Snow Leopard population through intensive camera trap sampling in areas within each stratum (identified in step I, Fig. 3), capturing spatial variation in Snow Leopard density. Step I assessment provides the basis for our camera trap site-level sampling approach- ensuring that camera trap surveys occur in each stratum. Areas for step II sampling within different strata (Fig. 4) were delineated. Camera trap sampling using 3x3 km grids was carried out using the spatial capture-recapture method (SCR) framework (Royle & Young, 2008). Forest department officials and researchers from the Wildlife Institute of India deployed cameras based on Snow Leopard signs such as scat, spray or scrape marks and the presence of suitable habitats such as cliffs or animal trails to maximize the capture of Snow Leopards. Major valleys in various high-altitude regions were approached by trekking trails, herder's routes, or walking along rivers and tributaries to their sources (glaciers). The method requires Snow Leopards to be sampled for a long enough duration to be encountered at multiple locations within the sampling area. Additionally, the method also requires the population to be closed, to changes, so sampling must be done over a short enough period to assume closure. A grid size of 3x3 km was chosen and camera trapping was carried out for ~100 days in different habitat blocks. Both side and single-side camera traps were used to optimize the area coverage and identification of individuals.

A joint team of forest officials and researchers from the Wildlife Institute of India carried out sampling in Govind National Park and Sanctuary (50, trap nights= 1,943); Kedarnath Division (70, trap nights= 3,385); Suman-Niti area of NDBR (68, trap nights= 4195), Mana (37, trap nights= 1814), Valley of flowers-Nanda Devi national park & adjoining areas (43, trap nights=1676) between July 2021 and November 2021 (Table 1) The information available from Gangotri National Park and Uttarkashi Division (100, trap nights= 10,100) was also used for population estimation. Further, sampling conducted by WWF in the Munsiyari area of the Pithoragarh division (October 2020 to March 2021, 20 locations, 3640) was also used as a part of Step II sampling for Uttarakhand state.

Table 1: Table showing SPAI step II sampling efforts (July to November 2021) using camera traps in different high-altitude habitats of Uttarakhand.

Area	Trap nights	Total no of cameras
NDBR Buffer Zone (Sumna – Niti)	4195	68
NDBR Buffer Zone (Mana)	1814	37
Valley of Flowers, Nanda Devi national park & NDBR	1676	43
Kedarnath Forest Division	3385	70
Govind National Park and Sanctuary	1943	50
Gangotri National Park	10100	100
Munsiyari (Pithoragarh Division)	3640	20

Spatial capture-recapture

We analyzed the resulting spatial encounter history data using SCR methods (Royle & Young, 2008) implemented in R using the package oSCR (Sutherland et al. 2019). Individual Snow Leopards were identified from camera trap pictures using their unique coat patterns. Individuals who could not be identified because of poor picture quality (e.g., blurry, overexposed) were excluded from the analyses. Sex was determined using cues such as the presence of visible genitals or the presence of accompanying cubs. Cubs were excluded from the analysis. For the analysis, we used individuals for whom we captured on both sides, that is, right and left flank and individuals with one side flank for whom we got maximum captures (Augustine et al. 2018). To accurately identify the Snow Leopard individuals, the photographs from each sampling block were independently reviewed and compared by 2 to 3 experienced researchers. Based on the individual identification, a capture history of Snow Leopard individuals was generated for each camera site. A matrix of individual capture histories, camera trap operation (effort) and camera trap locations was prepared for the SCR analysis. Cubs captured with their mother were not included in the analysis. To account for the fact that Snow Leopards are unlikely to have circular space-use patterns, we use the ecological distance SCR model that allows for non-Euclidean distance estimation (Sutherland et al. 2015). Using this least-cost path approach enables the estimation of one or more resistance parameters ($\alpha 2$) that quantitate how movement is influenced by local landscape structure (Sutherland et al., 2019). Because sex is a partially observed individual attribute, we analyzed the data using the class-structured

likelihood that allows for missing sex information (Royle et al. 2015). We defined the state space (the area within which detectable Snow Leopard activity centres are expected to occur) as a regular grid of points using a 40-km buffer around the camera trap locations (large enough to include activity centres of all individuals exposed to detection on the cameras, Royle et al., 2015) and a resolution of 2 km (fine enough to approximate continuous space but coarse enough for computational tractability). Points that were deemed unsuitable (glaciers, >5300 m), that is, that have a negligible probability of containing Snow Leopard activity centres, were excluded from the state space.

The data were analyzed in a multi-session framework, which allows combining data from several sessions and enables the fitting of models with parameter values that apply across sessions. The camera trapping data from all the areas were arranged in three sessions based on the sampling period: i: Gangotri NP and Uttarkashi Division (November to March 2018-19); ii: NDBR, Govind NP & WS, and Kedarnath WS (July-November 2021); iii: Munsiyari (October to April 2020). For understanding the influence of terrain on Snow Leopard movement, we generated layers of mean slope and ruggedness. We tested the effect of both Euclidean and ecological distance models on Snow Leopard movement and used the best model to fit the rest of the parameters: density (D), detection (p) and space use (σ). We assumed negligible temporal variation in detectability within each session and collapsed all encounters into a single count. We modelled and tested density as a function of three topographical (elevation, ruggedness, slope), one vegetation (Normalized Difference Vegetation Index) and two anthropogenic activity-related (distance to human settlements and protections status) variables. Detection probability was also examined for the effect of sex, and camera trapping effort. Space use was modelled for sex and session. We selected models based on Akaike Information Criterion (AIC) (Burnham & Anderson, 2002). Pearson correlation tests were performed to examine any multicollinearity between covariates. The best model was used to predict realized density (number of individual activity centres per state space pixel, Morin et al. 2017).

3. RESULTS

3.1. Distribution of Snow Leopard based on occupancy in Uttarakhand

For the analysis, we employed 340 interviews for our analyses and removed 108 instances of unreliable information. We developed 20 different competing single-species occupancy models for the Snow Leopard of which the top 5 models are shown in Table 2. Two models with Δ AICc <2 were found. These models shared similar covariates, except for elevation and NDVI. Given the high correlation between these two variables, we elected to use only the top-performing model for inference. Naïve estimates of the proportion of sites used by Snow Leopard and detection probability were 0.71 ±0.07 and 0.7±0.8 respectively. When modelled with survey covariates, site occupancy and detection probability of Snow Leopard were 0.9±0.02 and 0.90±0.07 respectively. The best model showed that the detection probabilities of informants were influenced by the duration spent in the area (Table 2). The occurrence probability of Snow Leopard is influenced by vegetation index and ruggedness (Table 2). The Snow Leopard showed a positive response to a decrease in vegetation index (Normalized Difference Vegetation Index, NDVI), showing a preference towards high-altitude habitats. Snow Leopard showed a quadratic relationship with ruggedness. The pattern showed a high probability of Snow Leopard occurrence in the trans-Himalayan areas of the Uttarakhand state compared to greater and mid-Himalayan areas (Fig 3).

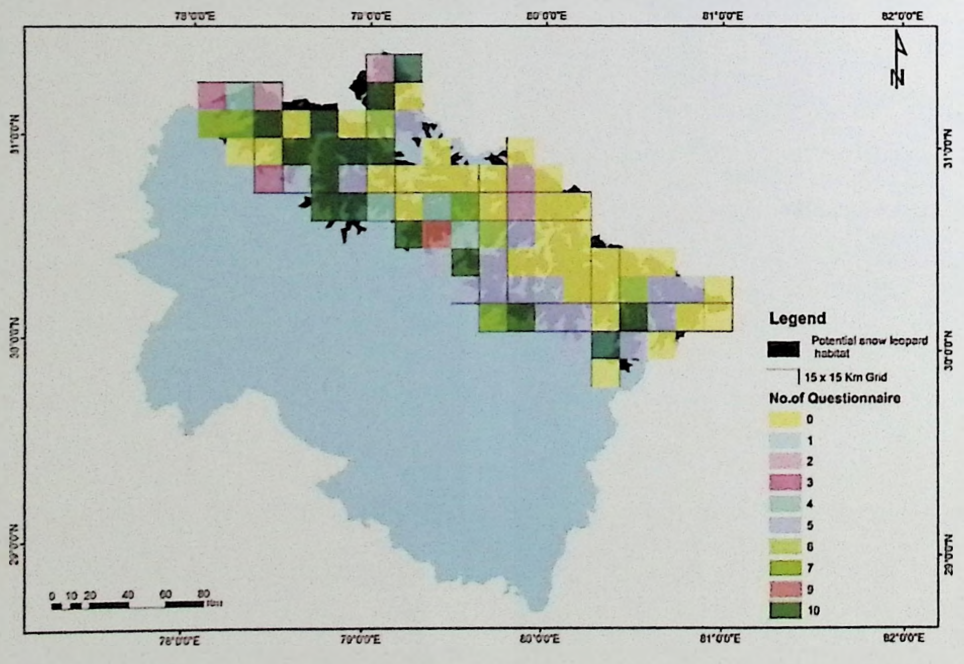


Figure 2: A map of Uttarakhand showing the grid numbers and the questionnaire surveys coverage for SPAI Step 1

Table 2: Table showing top five models of occupancy analysis of Snow Leopard occupancy and detection in Uttarakhand based on questionnaire surveys.

	Model	K	AICc	Delta_AICc	AICcWt	Cum.Wt
1	P~duration ; Psi ~ elevation + ruggedness + I(ruggedness^2)	6	353.85	0	0.27	0.27
2	P~duration ; Psi ~ NDVI + ruggedness + I(ruggedness^2)	6	354	0.14	0.25	0.52
3	P~duration ; Psi ~ elevation + standard deviation of slope	5	356	2.15	0.09	0.61
4	P~duration; Psi ~ elevation + ruggedness	5	356	2.15	0.09	0.7
5	P~duration; Psi~ NDVI + ruggedness	5	357.07	3.22	0.05	0.75

Table 3: Estimates of β-coefficient values with standard error for covariates influencing Snow Leopard occupancy and detection in Uttarakhand based on questionnaire surveys.

	Parameters	Estimate	Standard Error
Occupancy			
	(Intercept)	17.44	6.21
	NDVI	-12.69	5.80
	Ruggedness	-9.65	4.11
	I(Ruggedness^2)	1.41	0.70
Detection			
	(Intercept)	0.79	0.14
	Duration	0.36	0.15

Based on the probability of site use by Snow Leopard, the habitat was divided into three strata for Step II sampling. Potentially high-density areas were defined as those with an occupancy probability greater than 0.8. The areas with a probability of 0.8 to 0.5 and the areas with a probability of less than 0.5 were called potentially moderate-density and low-density habitats, respectively (Fig 3).

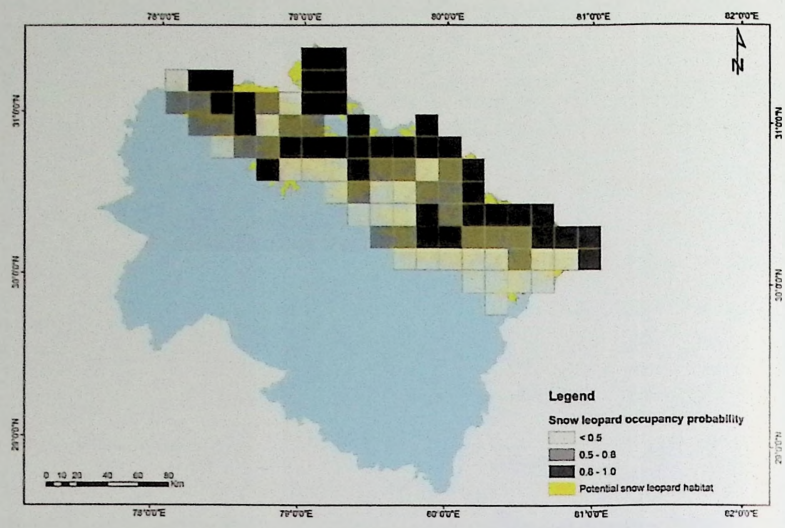


Figure 3: Map showing the results of SPAI step I, Snow Leopard occupancy probability in different high-altitude regions of Uttarakhand.

3.2. Density estimates of Snow Leopard in Uttarakhand

Spatial densities of Snow Leopard

A total of seven sampling blocks were surveyed by camera traps across the high-altitude region of the state (Fig. 1). Camera trapping efforts yielded 26,773 trap nights and resulted in 5632 photographs of wild animals, a total of which 396 were of Snow Leopards. Out of 396, 372 identifiable Snow Leopard photographs were used to create a capture history of 40 individuals (4 males, 10 females, 26 unknown) for the SCR analysis. Other mammals captured on camera traps include 4 large carnivores including the Common leopard (*Panthera pardus*), Himalayan brown bear (*Ursus arctos isabellinus*), Himalayan Wolf (*Canis lupus chanco*) and Asiatic black bear (*Ursus thibetanus*) and 8 ungulates including Himalayan blue sheep or bharal (*Pseudois nayaur*), Himalayan musk deer (*Moschus spp*), Himalayan tahr (*Hemitragus jemlahicus*), Himalayan Serow (*Capricornis thar*), Himalayan goral (*Naemorhedus goral*), Indian Wild pig (*Sus scrofa*), Barking deer (*Muntiacus muntjac*) and Sambar (*Rusa unicolor*) (Table 4). The average period of operation per camera was 68.95±1.77 (SE) days.

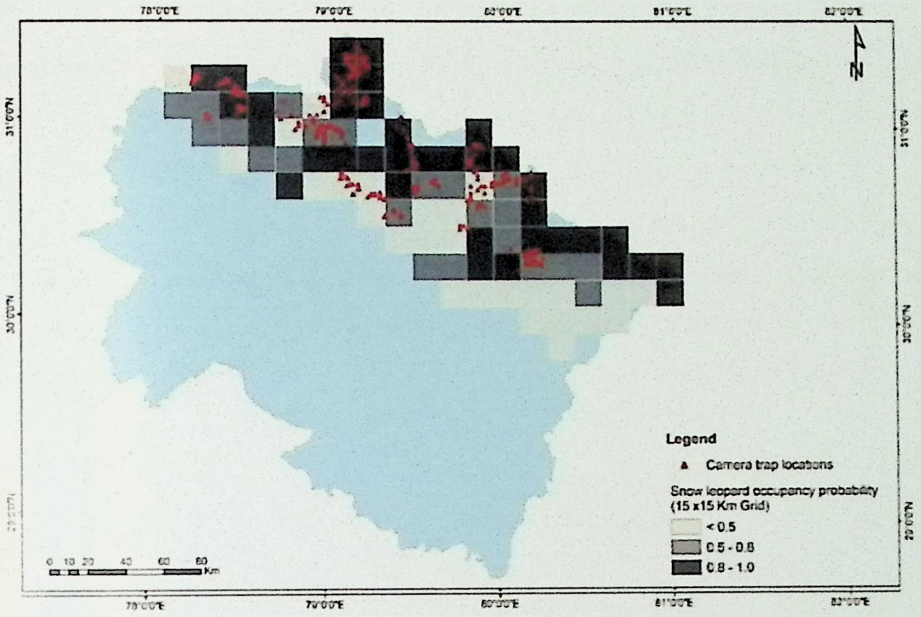


Figure 4: Map showing the results of SPAI step I, Snow Leopard occupancy probability in different high-altitude regions of Uttarakhand, India.

Table 4: Capture (No. of capture/ 100 trap nights ± Standard Error, No. of captures) rate of Snow Leopard and other co-predators and prey species captured during SPAI step II sampling in different high-altitude regions of Uttarakhand.

Area	Snow Leopard (*Panthera uncia*)	Common Leopard (*Panthera pardus*)	Himalayan Brown bear (*Ursus arctos isabellinus*)	Himalayan Wolf (*Canis lupus chanco*)	Asiatic black bear (*Ursus thibetanus*)	Himalayan tahr (*Hemitragus jemlahicus*)	Bharal (*Pseudois nayaur*)	Himalayan musk deer (*Moschus leucogaster*)	Sambar (*Rusa unicolor*)	Himalayan Serow (*Capricornis thar*)	Barking deer (*Muntiacus muntjac*)	Himalayan goral (*Naemorhedus goral*)	Indian wild pig (*Sus scrofa*)
Sumna-Niti	0.66 (±0.18) N=31	-	-	-	-	-	3.22 (±0.83) N=153	0.04 (±0.04) N=2	-	-	-	-	-
Mana	*0.22* (±0.15) *N=6*	-	-	-	0.03 (±0.03) N=1	2.14 (±0.88) N=47	0.40 (± 0.23) N=11	-	-	-	-	-	-
Valley of Flowers, Nandadevi national park & adjoining areas	-	0.08 (±0.06) N=2	-	-	0.23 (±0.14) N=3	1.06 (±0.73) N=29	0.50 (±0.41) N=15	0.72 (±0.43) N=23	-	0.03 (±0.03) N=1	-	0.38 (±0.25) N=5	0.12 (±0.09) N=2
Kedarnath Forest Division	0.02 (±0.02) N= 1	-	0.02 (±0.02) N=1	-	0.11 (±0.07) N=4	1.56 (±0.68) N64	-	0.42 (±0.26) N=14	0.74 (±0.35) N=27	-	0.02 (±0.02) N=1	-	0.11 (±0.11) N=6
Govind National Park and Sanctuary	*0.02* (±0.02) *N=1*	0.26 (±0.20) N=4	0.53 (±0.33) N=17	-	-	-	1.30 (±0.83) N=37	0.18 (±0.11) N=5	0.06 (±0.06) N=1	-	-	-	0.0 (±0.06) N=1

Table 5: Summary of sampling effort for three camera trap sessions conducted in Uttarakhand: sampling period, season, number of camera stations, number of trap nights, number of independent Snow Leopard photographs (multiple captures of the same individual within 24 h at a camera site were excluded), number of unique adult individuals detected per survey, average captures (average of the number of times captured individuals were detected) and average spatial captures (average of the number of unique cameras captured individuals were detected at).

Session	Sampling period	No. of camera traps	No. of trap nights	No. of independent photographs	No. unique individuals	Average captures	Average spatial captures
Gangotri NP & Uttarkashi Division	151 days (Nov 2017-March 18)	100	10,100	333	22	8.39	8.39
NDBR, Govind NP & WS and Kedarnath WS	137 (July 2021 – Nov 2021)	262	12,929	15	12	1.25	3.57
Pithoragrah Division	183 Oct 2020-March 2021	20	3,660	24	6	4	10.38

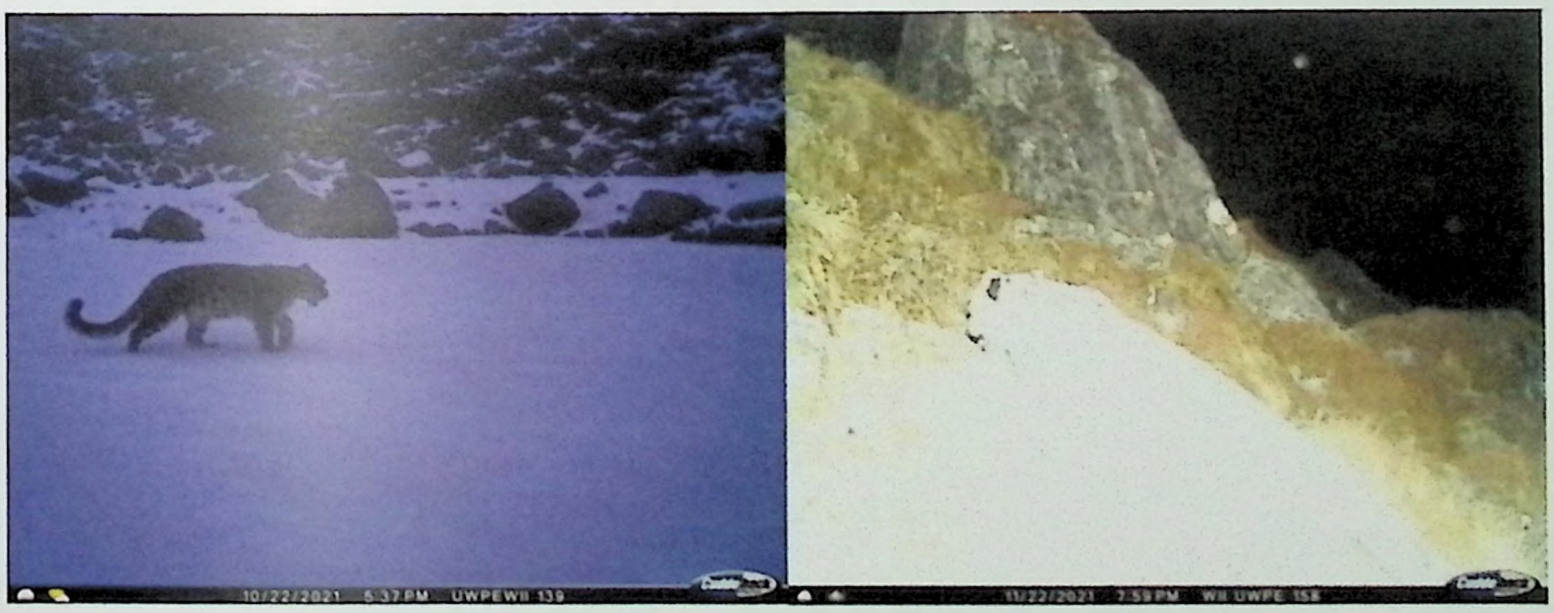


Figure 5: First photographic capture of Snow Leopard from (a) Govind National Park and (b) Kedarnath Division.

For modelling the Snow Leopard density, we first tested models for movement parameters. The best-supported model for movement parameters was the model with the slope as ecological distance. The conductance coefficient was estimated to be -0.875 (SE = 0.05). Ecological distance

model with slope was then used to fit the density, detection and spatial use of Snow Leopard. The correlation was ($r \geq 0.7$) between ruggedness and slope, elevation, distance from the village, NDVI with elevation and NDVI with distance from the village, and hence these predictor variables were not used together in models. We tested 20 ecologically meaningful models of which the top five models are shown in Table 6. The final model showed density to be positively related to protection status (0.502; S.E: 0.32), and elevation (1.26; S.E: 0.37). The results showed Snow Leopard population estimates for Uttarakhand state to be 124 (SE 21). Maximum likelihood estimates of the real scale parameters with associated standard error are mentioned in Table 7. The encounter rate varied with camera trapping effort (β: 0.012 SE 0.003). Space use was found to vary across sex. The best model was used to predict the spatial densities for the potential Snow Leopard habitat of Uttarakhand. High-altitude areas with rugged habitats and better protection status (protected area) support high densities in Uttarakhand.

Table 6: Top five candidate models for evaluating the role of covariates on Density (D), detection probability (p), spatial scale (σ) and ecological distance (asu). (Number of parameters (K), Akaike Information Criteria (AIC), Difference between AIC of each model and the model with the lowest AIC (ΔAIC), AICc weights (wi), cumulative AIC weights (Σwi).

	Model	logL	K	AIC	dAIC	weight	Cumwt
1	Density (~ protection status + elevation) detection (~effort); sigma (~sex); movement (~slope - 1)	526	9	1069	0	0.51607	0.52
2	D(~slope + elevation + protection status); p(~effort); sig(~sex); asu(~slope - 1)	526	10	1071	2	0.18995	0.71
3	D(~ruggedness + I(ruggedness^2) + elevation + protection status); detection (~effort); sigma(~sex); movement (~slope - 1)	525	11	1072	2.9	0.12135	0.83
4	D(~slope + I(slope^2) + elevation +protection status) p(~effort) sig(~sex) movement (~slope - 1)	525	11	1073	3.3	0.1016	0.93
5	D (~ruggedness + distance from human settlements) detection (~effort) sigma (~sex) movement (~slope - 1)	529	9	1075	5.9	0.02657	0.96

Table 7: Maximum likelihood estimates (MLE) and standard error (SE) of estimated parameters for AIC-top model (D (~ status + elevation) p (~effort)) σ (~sex) asu (~slope − 1).

	Parameters	Estimate	SE
Detection	Intercept	-0.561	0.36
	effort	0.012	0.003
Sigma	Intercept	-1.178	0.128
	Male	0.547	0.076
Density	Intercept	-3.902	0.507
	Protection status	0.502	0.321
	Elevation	1.26	0.37
Movement Cost	Slope	-0.875	0.005

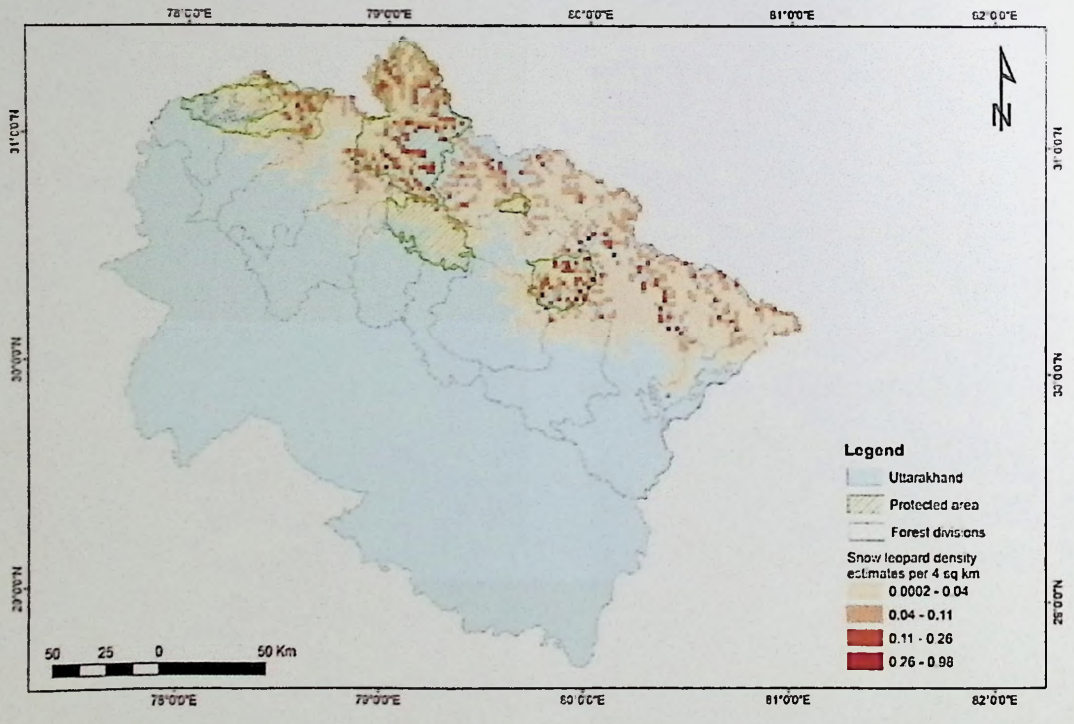


Figure 6: Density surface map of Snow Leopard in different divisions and protected areas of Uttarakhand State.

Table 8: Snow Leopard population estimates for different high-altitude divisions of Uttarakhand State.

Division	SL	SE Range	Potential habitat (Km^2)
Gangotri National Park	36	(31-43)	1700
Pithoragarh Forest Division	29	(24 -34)	3388
Nanda Devi Biosphere Reserve + Valley of Flowers NP	23	(19-27)	2076
Nanda Devi National Park	10	(8-11)	436
Uttarkashi Forest Division	8	(7-9)	1196
Govind Wildlife Sanctuary & National Park	7	(6-8)	800
Kedarnath Wildlife Sanctuary	3	(2-3)	604
Others (Badrinath Forest Division, Tehri Forest Division, Nanda Devi Forest Division, Askot Musk Deer WLS, Upper Yamuna Barkot Forest Division, Kedarnath Wildlife Division, Rudraprayag Forest Division, Tons Forest Division)	8	(6-10)	2576

4. Discussion

The Snow Leopard population assessment in Uttarakhand is the first comprehensive study to provide reliable scientific data on the status of the Snow Leopard population in the state. The survey covered 12764.35 km^2 of high-altitude habitat in the Kumaon and Garhwal regions of the state. Step I of the study revealed a gradient of Snow Leopard occupancy in Uttarakhand, with a high probability of occurrence in 46.11% (5886 km^2), moderate probability of occurrence in 26.9% (3429 km^2), and low probability in 27.02% (3449 km^2). The study also identified trans-Himalayan and Greater Himalayan valleys such as Nelang, Gangotri, Sumna, and Niti as good habitats, while subalpine habitats such as Srikant and Kedarnath were identified as moderate-density habitats. Low-elevation temperate habitats were found to have a low probability of Snow Leopard density.

Based on the results of Step II, the state-wide Snow Leopard population was estimated to be 124 (SE range 103 to 145) at a density of 0.7 to 1.04 individuals/ 100 km^2 adult Snow Leopard across the Snow Leopard habitat of Uttarakhand. The SE range indicated that the population could range between 103 to 145 adult individuals. The findings of both step I and step II showed a consistent pattern, where high altitude habitats above 3500 meters supported more Snow Leopards in the state. High-altitude protected areas (e.g., Gangotri National Park and Nanda Devi National Park) were identified as supporting high densities of Snow Leopards and serving as a stronghold for the species in the state. Despite human activities such as livestock grazing, tourism, and paramilitary presence in these protected areas, the high densities of Snow Leopards highlight the importance of protection in sustaining Snow Leopards.

Earlier studies have confirmed that Uttarakhand provides high-quality habitat for Snow Leopard (Bhatnagar et al., 2016), owing to its intricate, pristine high Himalayan ranges and diverse prey species. Additionally, a considerable portion of the Snow Leopard range in Uttarakhand is also protected (5440 Km^2, ~ 49 %) as protected areas which includes Askot Musk Deer WLS, Gangotri NP, Govind NP, Govind Pashu Vihar WLS, Kedarnath WLS, Nanda Devi NP and Valley of Flowers NP. The previous estimation based on habitat quality and limited population estimates from snow ranges across India (Bhatnagar et al., 2016) estimated the expected population in Uttarakhand as

86 Snow Leopards. However, there was a lack of density representation from Uttarakhand in the extrapolated estimates. The estimates were mainly extrapolated based on studies from trans-Himalayan landscapes from other states, with a proper representation of greater Himalayan landscapes lacking. The current study overcomes these limitations by providing robust estimates of the state-wide Snow Leopard population based on systematic sampling across various habitats and human use. These results are encouraging and underscore the importance of good management practices, support from local communities support and the protection of core habitats (in the form of PAs) in sustaining Snow Leopard populations in the state.

The conservation of large carnivores, such as Snow Leopards, cannot solely rely on protected areas (PAs) and requires the integration of outside PAs in human-dominated landscapes (Johansson et al., 2016). However, the feasibility of this approach depends on how conducive the habitat conditions are outside PAs. The density of Snow Leopards outside PAs was found to be relatively low in Uttarakhand. These areas are crucial for facilitating connectivity across different landscape units. Avoidance of human-related risks and low prey availability can strongly constrain functional connectivity for carnivores (Ghoddousi et al., 2021). Grazing and medicinal plant collections are common human practices in alpine regions, including protected areas (Sathyakumar et al., 1993; Awasthi et al., 2003; Sathyakumar et al., 2010; Kittur et al., 2010). Infrastructure development for the military and tourism is additional pressure on the Snow Leopard habitat across its range (Maheshwari et al., 2013). Other major issues Snow Leopards face include conflict with herders and declining prey populations (Bhatnagar et al., 2001; Mishra et al., 2010; Maheshwari et al., 2020). A recent study on Snow Leopards in the Gangotri landscape emphasized the need to mitigate issues such as low prey availability and hunting pressure in these corridors to make them conducive for Snow Leopards (Pal et al., 2022). Local communities hold the key to resolving such issues and conservation practitioners need to work closely with them. The information available on the interaction between Snow Leopards and nomadic pastoralists in the region is currently limited and there is a pressing need for further research in this area. It is crucial to implement action at the landscape level through the collaboration of community clusters working in tandem with the government, NGOs and the private sector (e.g., tourism agencies) (Kunkel et al., 2016).

The population assessment of Snow Leopards in Uttarakhand is a significant milestone in monitoring and conserving the species in the region. The survey filled a crucial knowledge gap

and provided landscape-level data to improve management practices. Continued monitoring efforts are essential for understanding the status of Snow Leopards and evaluating the effectiveness of management actions. To obtain a more comprehensive understanding of the Snow Leopard population and conservation issues, it is recommended to supplement this data by including information on prey, and conflict status. Further, long-term studies are a helpful way to track the efficacy of on-ground conservation efforts. Such information is critical for the long-term conservation of Snow Leopards across their range and for ensuring the health of mountain ecosystems and the services they provide.

5. The way forward

Regular monitoring is essential for the long-term conservation of the Snow Leopard in the state. To achieve this, it is recommended that a state population assessment of Snow Leopards be conducted on a regular basis similar to the tiger census carried out in the country. Regular assessments will provide critical information for identifying issues, and threats and developing mitigating strategies.

Based on our experience and the logistical challenges faced during the survey, certain improvements are recommended for future surveys:

- More camera traps: The team faced a major constraint due to the limited number of cameras (~ 400). To obtain images of both flanks of the Snow Leopard, it would be preferable to deploy all the cameras as double-sided. The team also attempted to sample prey density in the various sampling blocks, but due to the low number of camera traps and insufficient captures, the prey estimation attempts were unsuccessful. More camera traps will also help in increasing the simultaneous deployment of camera traps across the state.
- Analyzing prey species information and estimating their densities: The survival of large carnivores hinges on the availability of abundant terrestrial mammalian prey (Carbone et al., 1999). In order to gain a better understanding of Snow Leopard densities in the region, it is crucial to have information on the spatial densities of their prey species. With novel methods available such as CTDS, and REM it's possible to have an estimate of spatial densities of prey species across large landscapes (Mason et al., 2022). It is recommended that in the next survey, a dedicated effort should be made to estimate the prey species in the Snow Leopard habitat.
- Sample more areas from Kumaon Himalaya: The study successfully covered a range of Snow Leopard densities, but it was found that the bulk of information gathered on the species was from the Eastern and Central regions of the state. To further expand information on Snow Leopards, it is recommended that sampling efforts should be increased, particularly in the unexplored and remote potential Snow Leopard habitats of the Kumaon region, including areas such as Darma, Rupkund area.

- Supporting the census surveys information from key long-term sites: Long-term studies and information on vital rates are keys to understanding the mechanisms of population growth, decline or stability, and are important for effective conservation actions. Information on basic population parameters such as mortality rates and survival is also scanty and is limited to only one study from Tost Mountains, Mongolia (Sharma et al., 2014). Establishing long-term monitoring of Snow Leopards will enable a better understanding of population parameters, how they respond to threats and the effectiveness of management actions. There is also a need to enhance the understanding of the spatial structure of the population and to understand the connectivity of the population and the movement of animals at the landscape level.

References:

Augustine, B. C., Royle, J. A., Kelly, M. J., Satter, C. B., Alonso, R. S., Boydston, E. E., & Crooks, K. R. (2018). Spatial capture-recapture with partial identity: An application to camera traps.Ann. Appl. Stat. 12, 67–95.

Awasthi, A., Uniyal, S. K., Rawat, G. S., & Rajvanshi, A. (2003). Forest resource availability and its use by the migratory villages of Uttarkashi, Garhwal Himalaya (India). Forest Ecology and Management, 174(1-3), 13-24.

Bhardwaj, M., Uniyal, V.P. & Sanyal, A.K. (2010). Estimating relative abundance and habitat use of Himalayan blue sheep Pseudois nayaur in Gangotri National Park, Western Himalaya, India. Galemys: Bolet´ın Informativo de la Sociedad Espa˜nola para la Conservaci´on y Estudio de los Mam´ıferos 22, 545–560.

Bhatnagar, Y. V., Mathur, V. B., & McCarthy, T. (2001, August). A regional perspective for Snow Leopard conservation in the Indian Trans-Himalaya. In National Workshop on Regional Planning for Wildlife Protected Areas (pp. 6-8).

Bhatnagar, Y. V., Mathur, V. B., Sathyakumar, S., Ghoshal, A., Sharma, R. K., Bijoor, A., ... & Lal, P. (2016). South Asia: India. In Snow Leopards (pp. 457-469). Academic Press.

Burnham, K.P. & Anderson, D.R. (2002). Model selection and multimodel inference: a practical information-theoretic approach. 2nd edn. New York, NY: Springer.

Carbone, C., Mace, G. M., Roberts, S. C., & Macdonald, D. W. (1999). Energetic constraints on the diet of terrestrial carnivores. Nature, 402(6759), 286-288.

Chandola, S. (2008). Vegetation inventory of cold desert habitat of Nilang Area of Jadh Ganga Catchment (Uttarkashi) in Garhwal Himalaya. (Degree of Doctor of Philosophy in Botany). H.N.B Garhwal University, Srinagar Garhwal.

Dang, H. 1961. A natural sanctuary in the Himalaya: Nanda Devi and Rishi Ganga Basin. J. of Bombay nat. Hist. Soc 58: 707-718

Dang, H. (1967). The Snow Leopard and its prey. Cheetal, 10(1), 72-84.

Dang, H. (1968). Govind Pashu Vihar. Cheetal, Journal of the Wildlife Preservation Society of India, Dehradun 11:65-83.

Fox, J. L., Sinha, S. P., Chundawat, R. S., & Das, P. K. (1986). A Survey of Snow Leopard and Associated Species in the Himalaya of Northwestern India. Project Completion Report.

Ghoddousi, A., Buchholtz, E.K., Dietsch, A.M., Williamson, M.A., Sharma, S., Balkenhol, N., Kuemmerle, T. & Dutta, T. (2021). Anthropogenic resistance: accounting for human behaviour in wildlife connectivity planning. One Earth 4, 39–4

Ghoshal, A., Bhatnagar, Y. V., Pandav, B., Sharma, K., Mishra, C., Raghunath, R., & Suryawanshi, K. R. (2019). Assessing changes in distribution of the endangered Snow Leopard Panthera uncia and its wild prey over 2 decades in the Indian Himalaya through interview-based occupancy surveys. Oryx, 53(4), 620-632.

Green, M. J. (1988). Protected areas and Snow Leopards: their distribution and status. In Proceedings of the Fifth International Snow Leopard Symposium. International Snow Leopard Trust and Wildlife Institute of India, Seattle, Washington (pp. 3-19).

Habib, B., Mohan, D., Bhattacharya A., Shrotriya, S., Mondal, I., and Rawat, G.S. (2016): Status of Wildlife in Trans-Himalayan regions of Uttarakhand Forest Department and Wildlife Institute of India. Pp.44.

Johansson, Ö., Rauset, G. R., Samelius, G., McCarthy, T., Andrén, H., Tumursukh, L., & Mishra, C. (2016). Land sharing is essential for Snow Leopard conservation. Biological Conservation, 203, 1-7.

Kittur, S., Sathyakumar, S., & Rawat, G. S. (2010). Assessment of spatial and habitat use overlap between Himalayan tahr and livestock in Kedarnath Wildlife Sanctuary, India. European Journal of Wildlife Research, 56, 195-204.

Kunkel, K., Hussain, S., Khatiwada, A., Nyhus, P., McCarthy, T., & Mallon, D. (2016). A review of lessons, successes, and pitfalls of livestock insurance schemes. Snow Leopard, Biodiversity of the World: Conservation from Genes to Landscapes. Elsevier, New York, 173-178.

Mackenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, I.I. & Hines, J.E. (2006) Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence.Academic Press, San Diego, USA

Maheshwari, A., & Sathyakumar, S. (2020). Patterns of livestock depredation and large carnivore conservation implications in the Indian Trans-Himalaya. Journal of Arid Environments, 182, 104241.

Maheshwari, A., Sharma, D., Sathyakumar, S. (2013). Snow Leopard (Panthera Uncia) surveys in Western Himalayas, India. Journal of Ecology and Natural Environment. 5(10):303-309.

Mason, S. S., Hill, R. A., Whittingham, M. J., Cokill, J., Smith, G. C., & Stephens, P. A. (2022). Camera trap distance sampling for terrestrial mammal population monitoring: lessons learnt from a UK case study. Remote Sensing in Ecology and Conservation, 8(5), 717-730.

Mishra, C. (2001). High altitude survival: conflicts between pastoralism and wildlife in the Trans-Himalaya. Wageningen University and Research.

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.

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.

Morin, D.J., Fuller, A.K., Royle, J.A. & Sutherland, C. (2017). Model-based estimators of density and connectivity to inform conservation of spatially structured populations.Ecosphere 8, e01623.

Pal, R., Bhattacharya, T., Qureshi, Q., Buckland, S. T., & Sathyakumar, S. (2021). Using distance sampling with camera traps to estimate the density of group-living and solitary mountain ungulates. Oryx, 55(5), 668-676.

Pal, R., Panwar, A., Goyal, S. P., & Sathyakumar, S. (2022b). Changes in ecological conditions may influence intraguild competition: inferring interaction patterns of Snow Leopard with co-predators. PeerJ, 10, e14277.

Pal, R., Sutherland, C., Qureshi, Q., & Sathyakumar, S. (2022). Landscape connectivity and population density of Snow Leopards across a multi-use landscape in Western Himalaya. Animal Conservation, 25(3), 414-426.

Rana, N., Sati, S. P., Sundriyal, Y. P., Doval, M. M., & Juyal, N. (2007). Socio-economic and environmental implications of the hydroelectric projects in Uttarakhand Himalaya, India. Journal of Mountain Science, 4, 344-353.

Royle, J. A., & Young, K. V. (2008). A hierarchical model for spatial capture-recapture data. Ecology, 89(8), 2281-2289.

Royle, J. A., Sutherland, C., Fuller, A. K., & Sun, C. C. (2015). Likelihood analysis of spatial capture-recapture models for stratified or class structured populations. Ecosphere, 6(2), 1-11.

Sathyakumar, S. (1993). Status of mammals in Nanda Devi National Park. Scientific and Ecological Expedition to Nanda Devi. A Report. Dehradun, Wildlife Institute of India, 5-15.

Sathyakumar, S., & Bashir, T. (2010). Wildlife of the Himalaya: Conservation issues and the way forward. Mountains, Ecosystem and Man, 322-343.

Sharma, K., Bayrakcismith, R., Tumursukh, L., Johansson, O., Sevger, P., McCarthy, T., & Mishra, C. (2014). Vigorous dynamics underlie a stable population of the endangered Snow Leopard Panthera uncia in Tost Mountains, South Gobi, Mongolia. PloS one, 9(7), e101319.

Sharma, R. K., Bhatnagar, Y. V., & Mishra, C. (2015). Does livestock benefit or harm Snow Leopards? Biological Conservation, 190, 8-13.

Suryawanshi, K. R., Khanyari, M., Sharma, K., Lkhagvajav, P., & Mishra, C. (2019). Sampling bias in Snow Leopard population estimation studies. Population Ecology, 61(3), 268-276.

Sutherland, C., Fuller, A. K., & Royle, J. A. (2015). Modelling non-Euclidean movement and landscape connectivity in highly structured ecological networks. Methods in Ecology and Evolution, 6(2), 169-177.

Sutherland, C., Royle, J. A., & Linden, D. W. (2019). oSCR: a spatial capture-recapture R package for inference about spatial ecological processes. Ecography, 42(9), 1459-1469.

WII(2015). Nanda Devi Expedition 2015. Technical Report submitted by Wildlife Institute of India to Uttarakhand State Forest Department, 80 p.

Wildlife Institute of India (WII). (2021). Comprehensive Human-Wildlife Conflict (HWC) Management Strategy in Select Districts/Landscapes of Uttarakhand. Project Final Report. Wildlife Institute of India, Dehradun, India. 105 pp.

Zakharenka, A., Sharma, K., Kochorov, C., Rutherford, B., Varma, K., Seth, A., ... & Yunusov, N. (2016). The global Snow Leopard and ecosystem protection program. In Snow Leopards (pp. 559-573). Academic Press.

ANNEXURE I

DATASHEETS FOR FIELD SAMPLING

SIGN SURVEY SHEET

Date_/_/__ Track No___ Observer(s)_____Start time_____ End time_____Total km Walked _____ Grid Id _____
Start GPS (elevation)_____ End GPS(elevation)_____ Location (nearest village, block,dist,state)_____
Weather today(sky, windy, rain/snow)_____ Weather previous day (sky, windy, rain/snow)_____

S.No	Species	Time	Distance walked	GPS (elevation)	Sign type	Sign age	Aspect	Slope	Rangeland use	Vegetation type	Substrate type	Dominant topography	Canopy (%)	Total 100% (plot of 10 m) Barren includes snow, litter cover and barren ground					Remarks (Area name / other remarks
														Shrub (%)	Herb (%)	Grass (%)	Rock (%)	Barren (%)	

Rangeland use: seasonal grazing (SG) / year round grazing (YRG)/ lopping(L)/ human habitation (HH)/ protected area(PA)
Habitat vegetation: Barren/ Alpine grassland/ shrub land/Mixed broadleaved forest forest/ mixed conifer forest/ other
Landform ruggedness: Cliff/ very broken/ moderately broken/ rolling/ flat
Dominant topography: Cliff/ Ridgeline/ Hill slope/valley floor/ Basin or bowl/ Stream-bed or drainage/boulder field/ talus or scree slope/ rockfall or landslide/ bluff/ terrace/ glacier
Type of settlement: Village/ grazing camp/ town/ corral

CAMERA TRAP SHEET

S.No.	Date	Lat	Long	c'ix	Cam1	Cam2	Aspect	Slope	Rangeland use	Vegetation type	Landform Ruggedness	Distance to nearest human settlement (m)/ grazing camp	Dominant topography	Canopy (%)	Total 100% (plot of 10 m) Barren includes snow, litter cover and barren ground					Remarks
															Shrub (%)	Herb (%)	Grass (%)	Rock (%)	Barren (%)	

Rangeland use: seasonal grazing (SG) / year round grazing (YRG)/ lopping(L)/ human habitation (HH)/ protected area(PA)
Habitat vegetation: Barren/ Alpine grassland/ shrub land/Mixed broadleaved forest forest/ mixed conifer forest/ other
Landform ruggedness: Cliff/ very broken/ moderately broken/ rolling/ flat
Dominant topography: Cliff/ Ridgeline/ hill slope/valley floor/ Basin or bowl/ Stream bed or drainage/boulder field/ talus or scree slope/ rockfall or landslide/ bluff/ terrace/ glacier
Type of settlement: Village/ grazing camp/ town/ corral

Scat collection sheet

Sample ID	Researcher	Date	Species	Sign	Sign age	Lat	Long	Ele	Vegetation	Dominant topography	Area	Remarks

DATA SHEET – 2
विवरण तालिका – २

SNOW LEOPARD POPULATION ASSESSMENT IN INDIA (SPAI)

QUESTIONNARIE (प्रश्नावली)

Interview No. (साक्षात्कार संख्या) _____

GPS Location (लोकेशन) _____

01. RESPONDENT'S ATTRIBUTES (प्रतिक्रियादी के गुण)

Name (नाम) _____

Age (आयु) _____

Gender (लिंग) _____

Occupation (पेशा / रोजगार) _____

Village Town (गाँव) _____

District (जिला) _____

Community (समुदाय) _____

Q1. Details about YOUR area of knowledge / activity
आपके ज्ञान गतिविधि के विषय

- Area (valley) name, show on map)
  क्षेत्र (घाटी / पोरी नाम, मानचित्र पर दिखाएं)
- Activities (e.g. patrolling, grazing, fuel wood/fodder collections etc)
  गतिविधियाँ (जैसे गश्त, चराई, ईंधन लकड़ी / चारा संग्रह आदि)
- Time of activity (e.g. seasons)
  गतिविधि का समय (जैसे मौसम)

DATA SHEET – 2
विवरण तालिका – २

- Duration of time spend per year (days / months)
  प्रति वर्ष इन गतिविधियों पर बिताया समय अवधि क्या है
- Total duration of familiarity with the area (in years)
  क्षेत्र के साथ परिचित होने की कुल अवधि (वर्षों में)

02. RESPONDENT'S KNOWLEDGE ON SNOW LEOPARD (प्रतिक्रियादी की हिम तेंदुए के विषय में जानकारी)

Q2. Have you heard of snow leopard? Yes (indirect) Yes/ No
क्या आपने हिम तेंदुए के बारे में सुना है हाँ / नहीं

Q3. Have you seen Snow leopard Yes / No, evidence Yes / No (Scat / sample / pug-mark / kill)
क्या आपने हिम तेंदुआ देखा है हाँ / नहीं, संकेत हाँ / नहीं (मलोट / प्रतिदर्श / पगमार्क / शिकार)

Q4. Which of these do you identify as snow leopard? (Showing photos of snow leopard along with some other similar sized felids, Image Plate below) Correct identification / Wrong identification
आप इनमें से किसको हिम तेंदुए के रूप में पहचानते हैं? (हिम तेंदुआ और समान आकार के अन्य बिल्ली प्रजाति के साथ हिम तेंदुए की तस्वीरें दिखाएं, नीचे छवि प्लेट देखें) सही पहचान / गलत पहचान

Q5. Which of these do you identify as objects of snow leopard? (Showing photos of snow leopard pug-mark, scat and sample (from Data Sheet - 1) Correct identification / Wrong identification
आप इनमें से किसको हिम तेंदुए के संकेत के रूप में पहचानते हैं? (हिम तेंदुए के [illegible] तस्वीरें दिखाते हुए, विवरण तालिका - १) सही पहचान / गलत पहचान

03. OCCURRENCE OF SNOW LEOPARD (हिम तेंदुआ कहाँ पाया जाता है)

Q6. Within YOUR areas of knowledge / activity, where have you seen or received evidence of snow leopard in the last year?
आपके ज्ञान / गतिविधि के क्षेत्र के भीतर, आपने पिछले वर्ष के दौरान हिम तेंदुआ का [illegible] कहाँ देखा है?

- Name of the area (e.g. Hushe/Arindo pasture, show on map) Details about the area (e.g. [illegible] towards south-west of the pasture, or name village name)

DATA SHEET – 2
विवरण तालिका – २

क्षेत्र का नाम (उदाहरण: हुशे/हुए चरागाह, मानचित्र पर दिखाएं), क्षेत्र के बारे में विवरण (जैसे चरागाह के दक्षिण-पश्चिम की ओर दूरस्थ, निकटतम गाँव / शहर)

- Year, Month, Season
  वर्ष, महीना / मौसम

Q7. Where was the earliest evidence of snow leopard seen? (Take help of map as much as you can remember)
हिम तेंदुए का सबसे पहला संकेत कहाँ देखा गया था? (जितनी भी जानकारी याद कर सकें, मानचित्र की मदद लें)

Q8. What evidence were? Direct sighting, scat, sample, pug-mark, kill
क्या संकेत देखा? प्रत्यक्ष दर्शन, मल, प्रतिदर्श, पगचिह्न, शिकार

Q9. When did you see?
आपने इसे कब देखा?

- Name of the area (e.g. Hushe/Arindo pasture, show on map)
  क्षेत्र का नाम (उदाहरण: हुशे/हुए चरागाह, मानचित्र पर दिखाएं)
- Details about the area (e.g. Slope now and it towards south-west of the pasture, nearest village/town etc)
  क्षेत्र के बारे में विवरण (जैसे कि चरागाह के दक्षिण-पश्चिम की ओर ढलान, निकटतम गाँव / शहर)
- Year, Month/Season
  वर्ष, महीना / मौसम

04. RESPONDENT'S KNOWLEDGE ON PREY BASE (प्रतिक्रियादी की हिम तेंदुए के शिकार से सम्बंधित जानकारी)

Q10. Are you familiar with
1. Bharal? Yes / No
   भरल से परिचित हैं / नहीं
2. Argali? Yes No

DATA SHEET – 2
विवरण तालिका – २

अरगली से हैं / नहीं

3. Kashmir Musk deer? Yes No
   कश्मीर कस्तूरा हिरण से हैं / नहीं
4. Tahr? Yes No
   दहर हैं / नहीं
5. Goral? Yes No
   गोराल से हैं / नहीं
6. Serow? Yes No
   सेरो हैं / नहीं
7. Markhor? Yes No
   मारखोर से हैं / नहीं
8. Ibex? Yes No
   चकोर से हैं / नहीं
9. Others (Please specify) _____
   अन्य कोई और (बताएं) _____

Q11. How do you know about them?
आप इनके बारे में कैसे जानते हैं?

Q12. Identify those species about which you have answered 'Yes' in the above question
ऊपर आपने जिन प्रमुख शिकार जानवरों को देखा है उनकी पहचान बताइये

Correctly Identified सही पहचान

Could not Identify पहचान नहीं

05. OCCURRENCE OF PREY BASE (हिम तेंदुए के शिकार कहाँ कहाँ पाए जाते हैं)

Q13. What snow leopard prey species have you seen in your area of knowledge/activity?
आपने गतिविधि वाले क्षेत्र में आपने कौनसी हिम तेंदुए के शिकार वाली प्रजातियां देखी हैं?

(a) _____ (b) _____ (c) _____

(d) _____ (e) _____

Q14. Within YOUR areas of knowledge, where have you seen the above mentioned species during the last year ?

अपने परिचितों वाले क्षेत्र में आपने पिछले एक वर्ष में इन जानवरों को कहाँ देखा है ?

- Name of the area (e.g. Harkishen pasture, show on map)
  क्षेत्र का नाम (उदाहरण, हरकिशन चरागाह, मानचित्र पर दिखाएँ)
- Details about the area (e.g. village towards south-west of the pasture, nearest village/town)
  क्षेत्र के बारे में विवरण (जैसे कि चरागाह के दक्षिण-पश्चिम की ओर गाँव, निकटतम गाँव / शहर)
- Year, Month/Season
  वर्ष, महीना / मौसम

Q15. Were prey species of snow leopard / evidence ever seen in the past ? Yes / No
क्या इन प्रजातियों या इनके शरीर पिछले वर्ष से पहले भी कहीं दिखाई देती थी ? हाँ / ना

Q15. Name them: इनके नाम बताइए

(a) _____ (b) _____ (c) _____

(d) _____ (e) _____

Q17. What evidence was? Direct sighting / kill / footprint / droppings
क्या था वह ? प्रत्यक्ष देखा / शिकार / पगचिह्न / मल

Q18. Where did you see? (in the past)
कहाँ देखा ? (पिछले वर्ष से पहले)

- Name of the area (e.g. Harkishen pasture, show on map)
  क्षेत्र का नाम (उदाहरण, हरकिशन चरागाह, मानचित्र पर दिखाएँ)
- Details about the area (e.g. village towards south-west of the pasture, nearest village/town)
  क्षेत्र के बारे में विवरण (जैसे कि चरागाह के दक्षिण-पश्चिम की ओर गाँव, निकटतम गाँव / शहर)

- Year, Month/Season
  वर्ष, महीना / मौसम

06. RESPONDENT'S KNOWLEDGE ON CO-PREDATORS (प्रतिवादी की सह-शिकारी से सम्बंधित जानकारी)

Q19. Are you familiar with:
1. Himalayan black bear? Yes/ No
   हिमालयन काला भालू / भूरा भालू ? हाँ / ना
2. Asiatic black bear? Yes/ No
   एशियाटिक काला भालू / काला भालू ? हाँ / ना
3. Common leopard? Yes/ No
   तेंदुआ / गुलदार ? हाँ / ना
4. Tiger? Yes/ No
   बाघ / बाघ ? हाँ / ना
5. Red Fox? Yes/ No
   लाल लोमड़ी ? हाँ / ना
6. Others (Please specify) _____
   अन्य कोई और (बताएं) _____

Q20. How do you know about them?
आप इनके बारे में कैसे जानते हैं ?

Q21. Identify those predators about which you have answered 'Yes' in the above question
ऊपर आपने जिन जानवरों को देखा है उनकी पहचान कराइए

Commonly encountered सही सामान

Could not identify पता नहीं

07. OCCURRENCE OF CO-PREDATOR BASE (सिन तेंदुए के सह-शिकारी कहाँ-कहाँ पाए जाते हैं)

Q22. What other predator species have you seen in your area of knowledge activity?
अपने परिचितों वाले क्षेत्र में आपने और किन तेंदुए के सह-शिकारी जानवरों को देखा है ?

(a) _____ (b) _____ (c) _____

(d) _____ (e) _____

Q23. Within YOUR areas of knowledge, where have you seen the above mentioned species during the last year ?
अपने परिचितों वाले क्षेत्र में आपने पिछले एक वर्ष में इन जानवरों को कहाँ देखा है ?

- Name of the area (e.g. Harkishen pasture, show on map)
  क्षेत्र का नाम (उदाहरण, हरकिशन चरागाह, मानचित्र पर दिखाएँ)
- Details about the area (e.g. village towards south-west of the pasture, nearest village/town)
  क्षेत्र के बारे में विवरण (जैसे कि चरागाह के दक्षिण-पश्चिम की ओर गाँव, निकटतम गाँव / शहर)
- Year, Month/Season
  वर्ष, महीना / मौसम

Q24. Were these species / evidence ever seen in the past ? Yes / No
क्या यह प्रजातियाँ या इनके संकेत पिछले वर्ष से पहले भी कहीं दिखाई देते थे ? हाँ / ना

Q25. Name them: इनके नाम बताइए

(a) _____ (b) _____ (c) _____

(d) _____ (e) _____

Q26. What evidence was? Direct sighting / kill / footprint / droppings
क्या संकेत दिखाई दिया ? प्रत्यक्ष दर्शन / शिकार / पगचिह्न / मल

Q27. Where did you see? (in the past)

कहाँ दिखाई देते थे (पिछले वर्ष से पहले)

- Name of the area (e.g. Harkishen pasture, show on map)
  क्षेत्र का नाम (उदाहरण, हरकिशन चरागाह, मानचित्र पर दिखाएँ)
- Details about the area (e.g. village towards south-west of the pasture, nearest village/town)
  क्षेत्र के बारे में विवरण (जैसे कि चरागाह के दक्षिण-पश्चिम की ओर गाँव, निकटतम गाँव / शहर)
- Year, Month/Season
  वर्ष, महीना / मौसम

08. PERCEPTIONS ON SNOW LEOPARD & STATUS (सिन तेंदुए और उसकी स्थिति के विषय में लोगों की विचार धारणा)

Q28. How frequently do/did you see snow leopard? (Choose one from both the time periods)
पिछले तेंदुए को आप कितनी बार देखते हैं / थे ? (दोनों समयावधि में से एक-एक चुनें)

Current (वर्तमान)	Historic (ऐतिहासिक)
Never: have not seen a snow leopard since 2019 कभी नहीं: 2019 के बाद से एक बार भी तेंदुए को नहीं देखा है	Never: have not seen a snow leopard before 2019 कभी नहीं: 2019 के पहले एक भी बार तेंदुए को नहीं देखा है
Rarely: have seen once or twice since 2019 शायद ही कभी: 2019 से अभी तक कभी एक या दो बार देखा है	Rarely: have seen once or twice before 2019 शायद ही कभी: 2019 के पहले एक या दो बार देखा है
Occasionally: have seen every month कभी कभी: हर महीने दिखता है	Occasionally: have seen every month कभी कभी: हर महीने दिखता था
Often: have seen on my work अक्सर: हर हफ्ते दिखता है	Often: seen every week अक्सर: हर हफ्ते दिखता था
Always: have seen every day हमेशा: रोज ही दिखता है	Always: seen every day हमेशा: रोज ही दिखता था

Q29. What do you think about the current status of snow leopard in comparison to historic times?
(Choose one)
पुराने समय से तुलना में आज सिन तेंदुए की संख्या (2019 के बाद) के बारे में आप क्या सोचते हैं ?

- Sharp decline (तेज गिरावट)
- Slight decline (मामूली गिरावट)
- Stable (स्थिर)
- Slight increase (मामूली वृद्धि)
- Sharp increase (तेज वृद्धि)

Q32. Overall do you think snow leopard status/ abundance has increased or decreased in your area in the last 10 years?
क्या आपको लगता है कि पिछले 10 वर्षों में आपके क्षेत्र में हिम तेंदुए की स्थिति/बहुतायत में वृद्धि हुई है या कमी आई है?

Q33. What do you think about the current status of prey species in comparison to historic times? (Choose one)
ऐतिहासिक समय की तुलना में आज शिकार की प्रजातियों की वर्तमान स्थिति के बारे में क्या सोचते हैं? (एक चुनिए)

- Sharp decline (तेज गिरावट)
- Slight decline (मामूली गिरावट)
- Stable (स्थिर)
- Slight increase (मामूली वृद्धि)
- Sharp increase (तेज वृद्धि)

Q34. How long ago / do did you see the prey species all snow leopard diet (e.g. blue sheep, ibex) last? (Choose one)
आप हिम तेंदुए की शिकार प्रजातियों (जैसे नीली भेड़, आइबेक्स) को पिछली बार कितने समय पहले देखे थे? (एक चुनिए)

Current (वर्तमान)	Historic (ऐतिहासिक)
Never: have not seen a prey species since 2019 कभी नहीं: 2019 के बाद से शिकार प्रजातियों को नहीं देखा है	Never: have not seen a prey species before 2019 कभी नहीं: 2019 के पहले तक भी शिकार प्रजातियों को नहीं देखा है
Rarely: have seen once or twice since 2019 शायद ही कभी: 2019 के बाद एक बार या दो बार देखा है	Rarely: have seen once or twice before 2019 शायद ही कभी: 2019 के पहले एक या दो बार देखा है
Occasionally: have seen every months कभी कभी: हर महीने दिखाई दे	Occasionally: were rarely seen कभी कभी: हर महीने दिखाई दे
Often: have seen every week अक्सर: हर हफ्ते दिखाई दे	Often: were rarely seen अक्सर: हर हफ्ते दिखाई दे
Always: have seen every day हमेशा: रोज ही दिखाई दे	Always: were rarely seen हमेशा: रोज ही दिखाई दे

RISK LIST (खतरे की सूची)

Sl. No क्रमांक	Livelihood आजीविका / पेशा	Concern चिंता

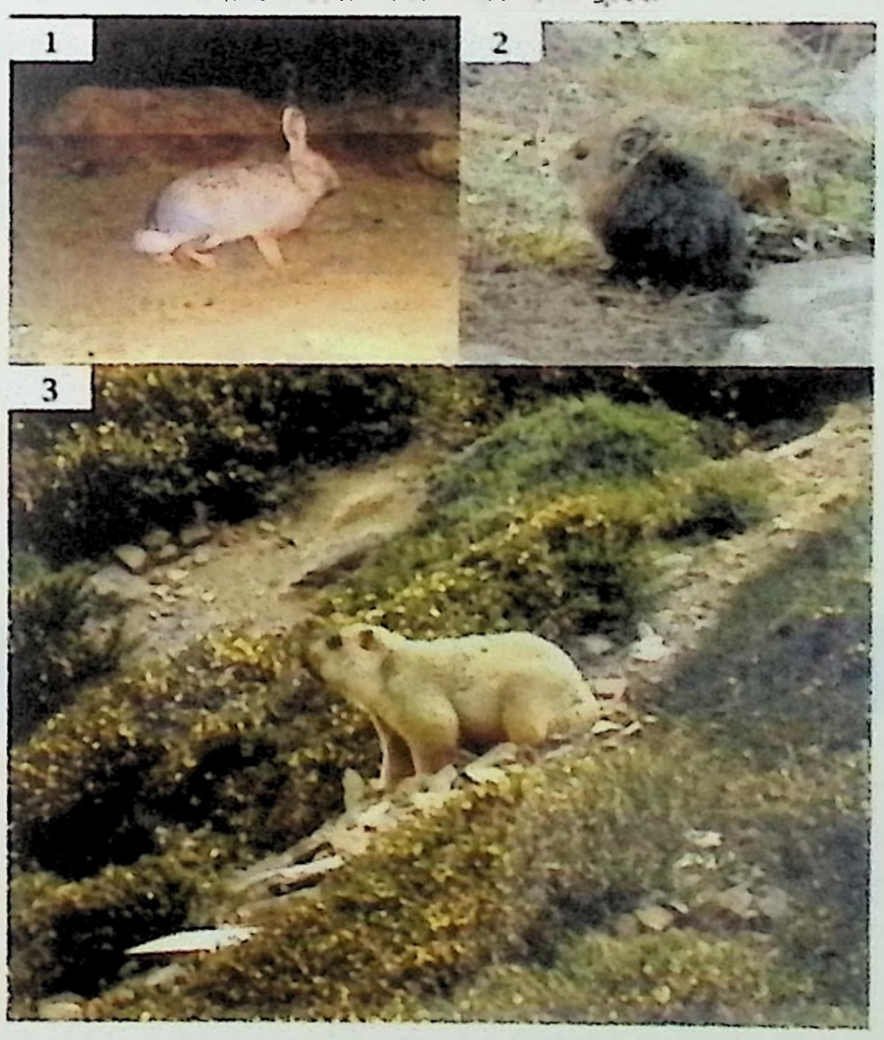
Photos of common animals found in Snow Leopard habitats for identification by respondents (See question no. 10 & 19)

उत्तरदाताओं द्वारा पहचान के लिए हिम तेंदुए के आवास में पाए जाने वाले सामान्य जानवरों की तस्वीरें (प्रश्न संख्या 10 और 19 देखें)

Images of Snow Leopard & Co-predators (For Question No. 4, 19 & 21)
हिम तेंदुए और सह-शिकारियों की छवियाँ (प्रश्न संख्या 4, 19 और 21 के लिए)

Images of Ungulates in Snow Leopard habitat (For Question No. 10 & 12)
हिम तेंदुए निवास स्थान में खुर वाले जन्तुओं की छवियाँ (प्रश्न संख्या 10 और 12 के लिए)

Images of other animals in Snow Leopard habitat
हिम तेंदुए निवास में अन्य जानवरों की छवियाँ



ANNEXURE - II

FOREST TYPES

Temperate-subalpine forest

Alpine forest

Trans Himalaya

ANNEXURE III: IMAGES OF RESEARCHERS, FOREST FIELD STAFF & FIELD ASSISTANTS CONDUCTING FIELD WORK

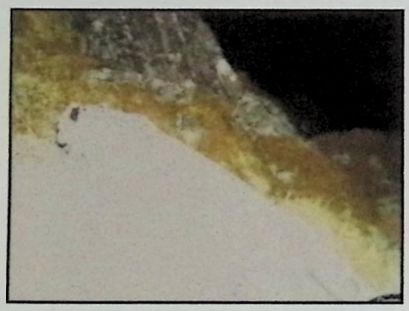
ANNEXURE - IV

IMAGES OF SNOW LEOPARD INDIVIDUALS

GOVIND NATIONAL PARK

GV_SL1 (RIGHT FLANK)

KEDARNATH WILDLIFE SANCTUARY



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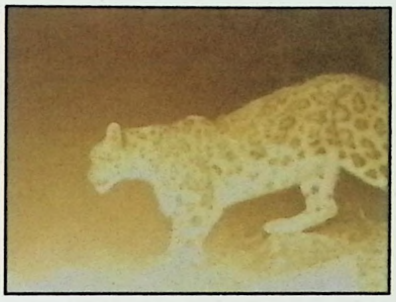
NANDA DEVI BIOSHPERE RESERVE

Mana SL_R1 (RIGHT FLANK) Mana SL_R2 (RIGHT FLANK) NI_SL_R1 (LEFT FLANK)

NI_SL_R2 (LEFT FLANK)



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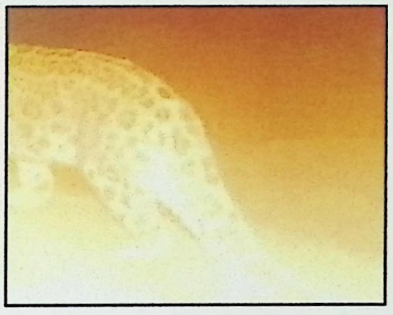

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GANGOTRI NATIONAL PARK

R1L1 (LEFT FLANK)

R1L1 (RIGHT FLANK)

R2L2 (LEFT FLANK)

R2L2 (RIGHT FLANK)

R3L3 (LEFT FLANK)

R3L3 (RIGHT FLANK)

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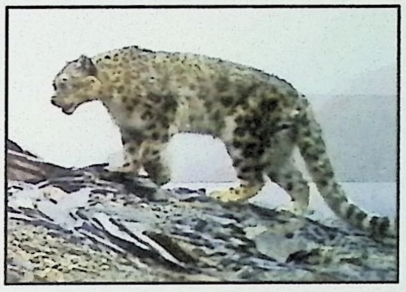

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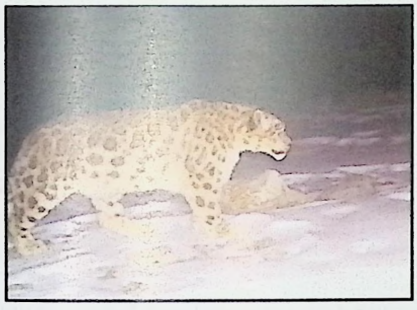

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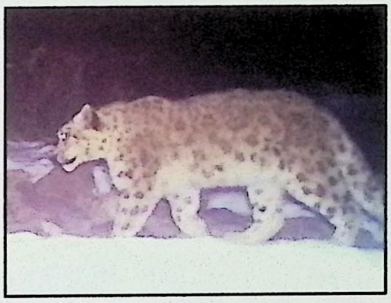

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R22L22 (RIGHT FLANK)

ANNEXURE V

IMAGES OF LARGE CARNIVORES & UNGULATES CAPTURED IN CAMERA TRAPS IN TRANS-HIMALAYAN AND GREATER HIMALAYAN REGION OF UTTARAKHAND, INDIA

Snow Leopard

Common leopard

Himalayan Brown Bear

Asiatic Black bear

Himalayan Tahr

Blue sheep

Himalayan Wolf

Musk deer

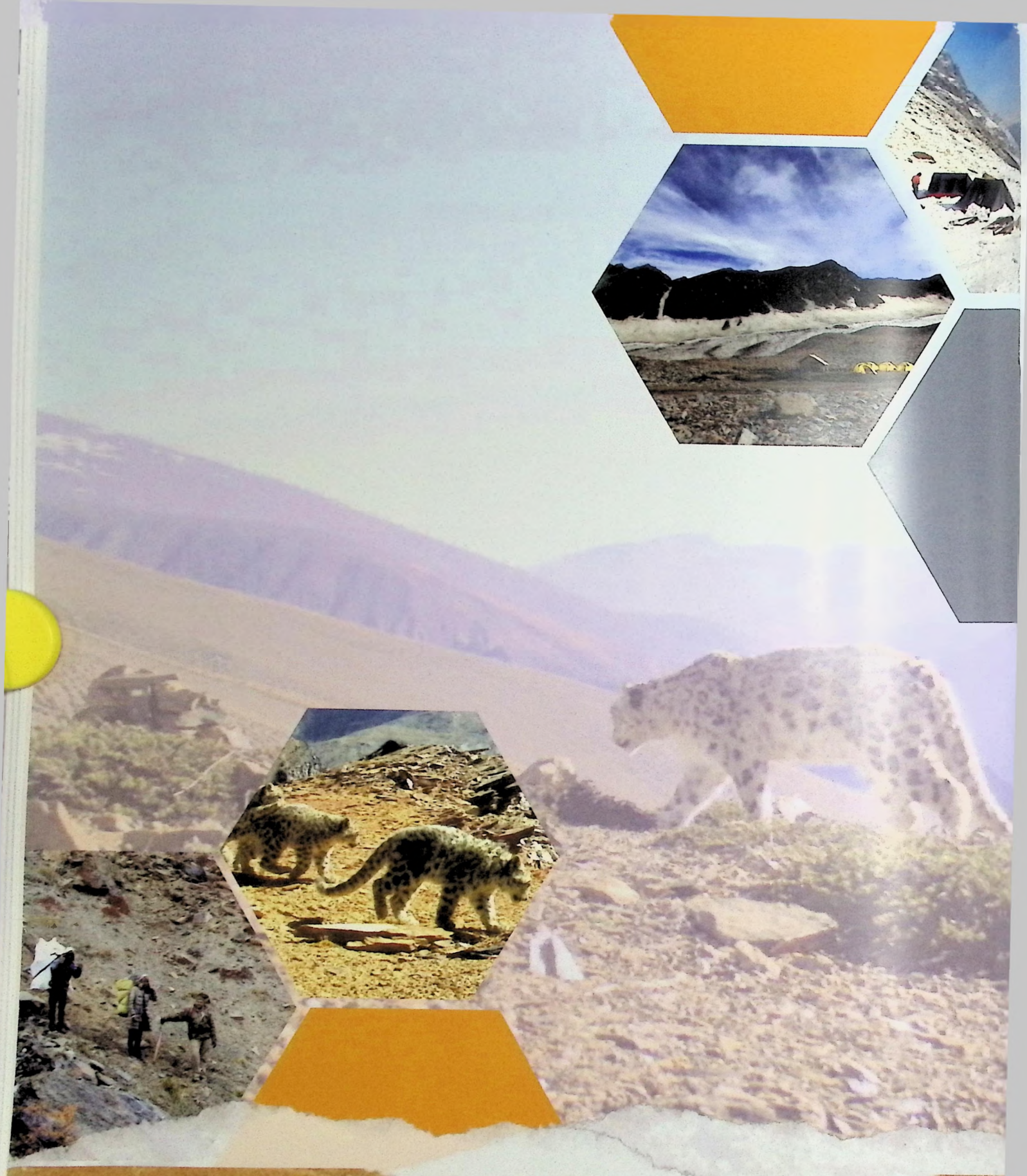
Sambar

Himalayan Serow

Barking deer

Himalayan Goral

Indian Wild Pig



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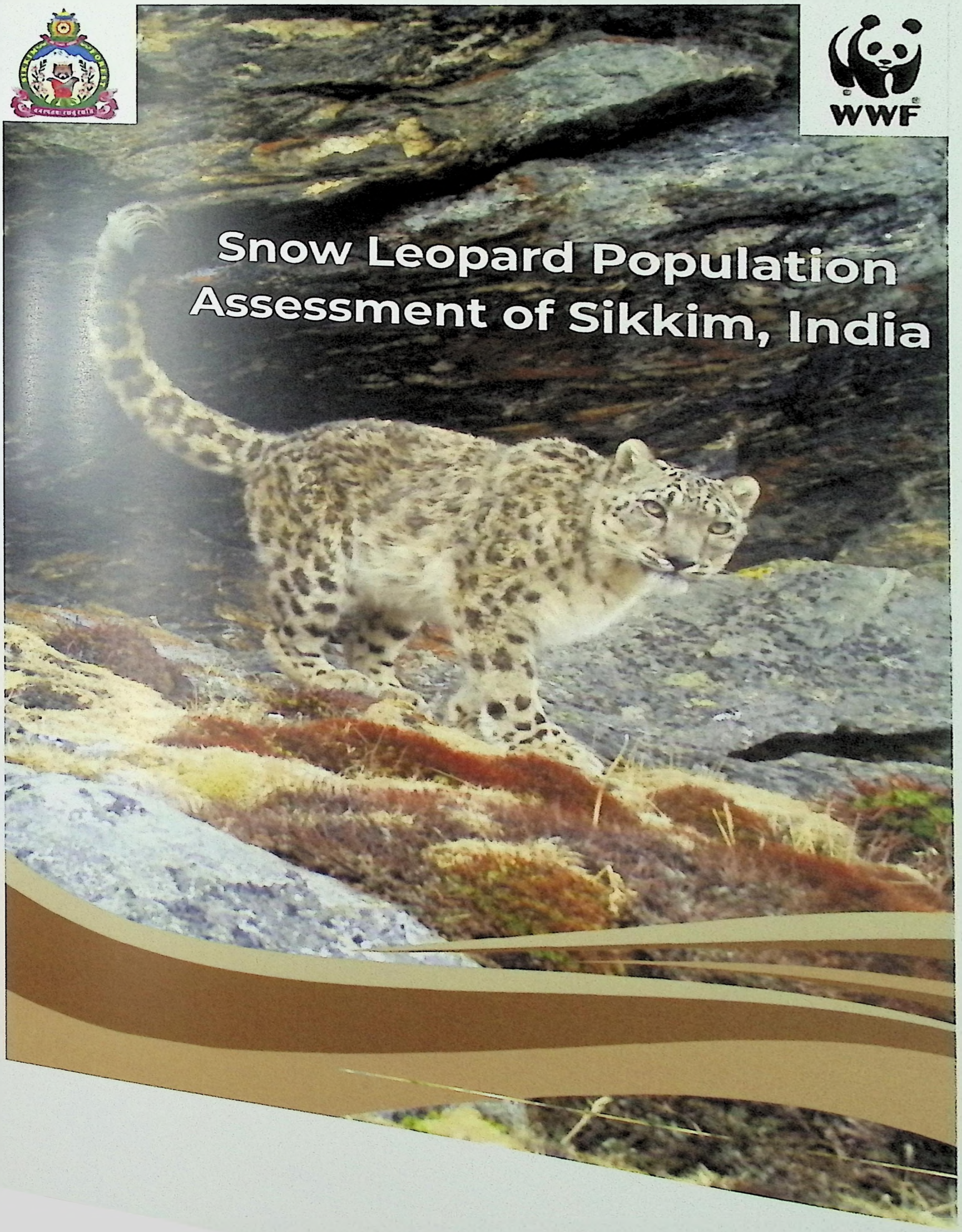
(Appendix V)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Snow Leopard Population
Assessment of Sikkim, India

Snow Leopard Population Assessment of Sikkim, India

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Gangtok & Pakyong districts- Dev Chettri, Raju Jairu, FG Jivan Rai and FG Passang Bhutia.

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- Other Contributors 1

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Introduction

Accurate evaluations of snow leopard abundance and density play a crucial role in establishing foundational data, appraising the effectiveness of conservation endeavors, and devising appropriate management strategies. While many studies on snow leopards primarily concentrate on gauging their distribution and abundance, reliable estimates of their population density are accessible for less than three percent of their global habitat (Sharma and Singh, 2020). Acknowledging the significance of dependable snow leopard population assessments, the governments of the 12 countries encompassing their habitat have launched the Population Assessment of the World's Snow Leopards (PAWS) initiative, overseen by an expert panel at GSLEP (Sharma et al., 2020). Among these nations, India has committed to safeguarding and conserving snow leopards globally. It has initiated its independent Snow Leopard Population Assessment of India (SPAI) to facilitate a comprehensive evaluation of the country's snow leopard populace (MoEFCC, 2019).

Across their geographic range, snow leopards confront an amalgamation of historical and emerging threats. These threats encompass expansive development undertakings like mining and extensive infrastructure development, illicit trade targeting their body parts, retaliatory killings stemming from livestock predation, escalating livestock numbers in specific regions of their habitat, and the overarching impact of climate change.

In the backdrop of these growing threats to snow leopards and their habitat, accurate population density data provides a baseline understanding of the species' health and distribution, enabling conservationists to monitor population trends, assess the effectiveness of conservation measures, and make informed decisions about management strategies. With reliable density estimates, policymakers and researchers can prioritise and allocate resources effectively, implement targeted interventions to mitigate threats and ensure the long-term survival of this elusive and endangered species in its natural habitat.

The Forest and Environment Department, Government of Sikkim and Ministry of Environment Forest and Climate Change (MOEFCC) designated WWF-India as its technical partner for the snow leopard population assessment in the state. The primary objective of this report was to estimate the population and density of snow leopards across the state of Sikkim.

This report presents the results of a statewide camera trap-based field study to assess the population-density of snow leopards.

Methods

Designing the State-level Population assessment survey

Since there was little to no prior information on the abundance and distribution of snow leopards in the state, we used a two-step process to design the snow leopard population assessment study. Using a digital elevation model, we delineated the entire region above 3000 metres in the state as the potential snow leopard habitat. Subsequently, we conducted simulations to create possible study designs (Figure 1) that would provide acceptable precision (less than 20%) for the population and density estimates of snow leopards (Efford, 2020). The spatial capture-recapture models require sufficient detections of individual snow leopards and subsequent recaptures to estimate parameters such as population size and density reliably. The simulations aimed to approximate an optimal camera trap placement strategy that would maximise the number of unique snow leopard individuals captured and recaptures of these individuals in different camera traps.

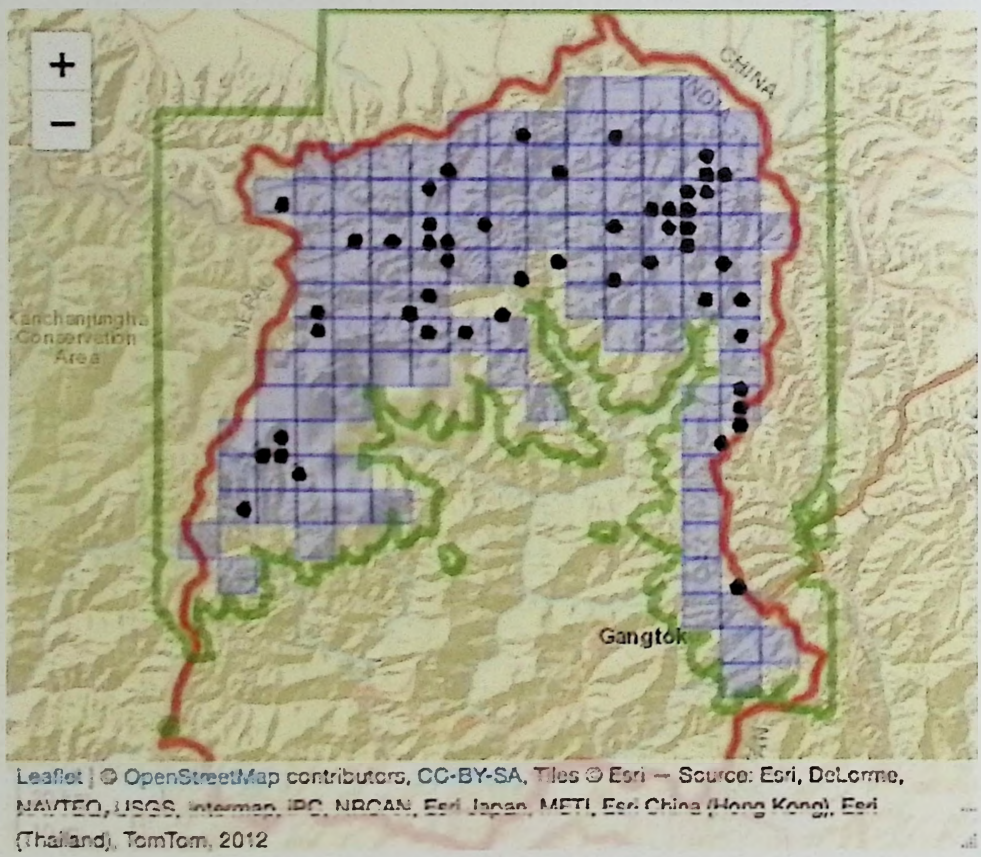

Figure 1. One of the suggested camera trap survey designs derived from simulations to optimise sufficient detections and recaptures of snow leopards to estimate snow leopard abundance and density reliably

Field Workshops and Training

We trained approximately 25 community members that included youth and Himal Rakshaks in the field techniques required for snow leopard population assessment surveys. That primarily included training in the use of GPS devices, mobile application-based data collection and use of camera traps. The specific aspect of field-craft included finding and identifying snow leopard signs, understanding of snow leopard ecology and basic safety protocols for working in the high altitudes. Around ten such training workshops were conducted in different locations in the state over a period of two years.

Field Survey

Camera trapping was conducted from April to September and covered 99 locations across the state of Sikkim (Figure 2). Overall, the camera traps operated for 9360 trap nights. Trap placement was informed by fine-scale eco-geographical features where snow leopard captures were likely to be maximised.

Figure 2. Camera trap installation in Pangolakha Wildlife Sanctuary.

Camera trap locations were selected based on the signs of snow leopards, such as pugmarks, scats, scrapes and scent marks, to maximise the chance of capturing snow leopards at each location. The grids (survey units) were selected for camera trap sampling to maximise the captures of unique individuals and subsequent recaptures.

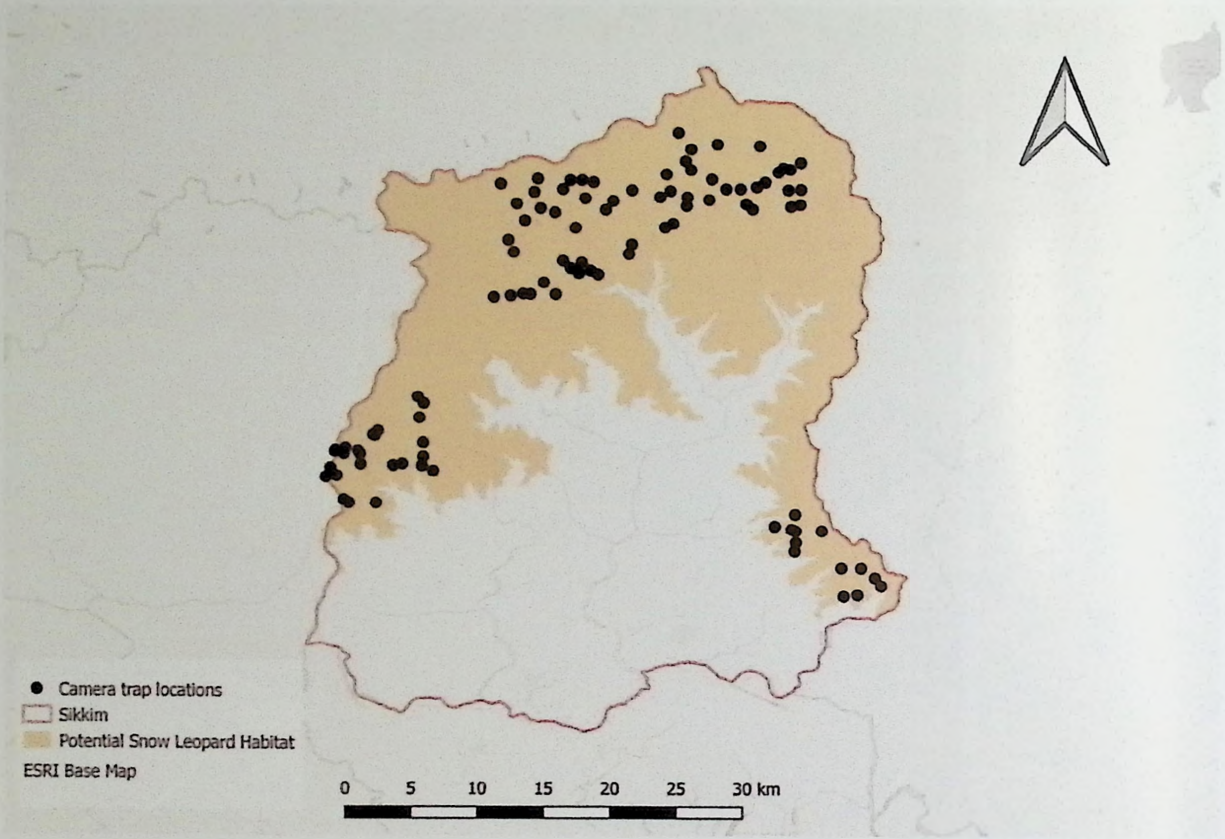

Figure 3. Map of the potential snow leopard habitat and the location of camera traps in the state of Sikkim, India.

Individual Identification of Snow Leopards

We used digiKam image management software (https://www.digikam.org/) to tag the snow leopard images and Camelot software (https://camelotproject.org/) to build a database of images. Two researchers used rosette patterns across multiple body parts of snow leopard images to individually identify and distinguish snow leopard individuals. A third independent researcher did subsequent verification of the identified snow leopard images, and discrepancies were identified and resolved. We then set up the data for the Spatially Explicit Capture-Recapture (SECR) analysis (Borchers, 2012; Efford and Fewster, 2013). The SECR analysis requires two files, one containing the information about the coordinates of detectors (camera traps) and a capture-history file that contains information on each snow leopard detection, its time and the camera trap in which the detection occurred.

Data analysis

We used Spatially Explicit Capture-Recapture Models to estimate the abundance and density of snow leopards in Sikkim (Borchers, 2012; Efford and Fewster, 2013). The SECR models explicitly incorporate the spatial data of a species captured at different locations with the assumption that animals located closer to camera traps have a high chance of being detected, while animals sufficiently far away from the traps are unlikely to be captured (Borchers, 2012). SECR models are also reasonably robust to violation of some common assumptions though caution is always recommended when dealing with crucial assumptions. We used the built-in "make.mask" function in the package secr to create a mask around the camera trap locations. The specific parameters included a spacing of 1000 metres, restricting the mask to within the region identified as snow leopard habitat. This resulted in a state space of approximately 5179 km^2. We used the package secr (Efford, 2020) in program R (R Core Team, 2020) to run the SECR models. The model specifications were as follows.

Table 2. The models used for the spatially explicit capture-recapture analysis, their parameters and description.

S.No.	Model specification	Model details
1	list(g0 = ~1, sigma = ~1)	constant (null) model
2	list(g0 = ~b, sigma= ~1)	learned animal response to detectors
3	list(g0 = ~h2, sigma= ~1)	2-class mixture
4	list(g0= ~k, sigma= ~1)	site learned response

Results and discussion

Fourteen individual snow leopards were detected in over 64 snow leopard capture events in 20 camera traps across the state.

Using the Null model, the population estimate of snow leopards in Sikkim is 21 snow leopards (SE = 3.54) in 5179 km^2 of snow leopard habitat in the state.

The density of snow leopards in the state was 0.40 (±0.11) snow leopards/100 km^2 (95% CI = 0.23 to 0.69 snow leopards/100 km^2.

Sikkim's maiden snow leopard population density estimate marks a milestone in scientific research and conservation endeavors. This landmark assessment fills a critical gap in our understanding of snow leopard populations and provides a vital foundation for tailored conservation strategies within this unique Himalayan region.

Figure 4. Snow leopard from Mangan district.

References

Borchers, D., 2012. A non-technical overview of spatially explicit capture–recapture models. J. Ornithol. 152, 435–444. https://doi.org/10.1007/s10336-010-0583-z

Efford, M., 2020. secr: Spatially explicit capture-recapture models.

Efford, M.G., Fewster, R.M., 2013. Estimating population size by spatially explicit capture-recapture. Oikos 122, 918–928. https://doi.org/10.1111/j.1600-0706.2012.20440.x

MoEFCC, 2019. Snow leopard population assessment in India: Population Assessment of World's Snow Leopards(PAWS) for India. 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.

R Core Team, 2020. R: A Language and Environment for Statistical Computing.

Sharma, K., Borchers, D., Mackenzie, D., Durbach, I., Sutherland, C., Nichols, J., Lovari, S., Zhi, L., Ale, S., Khan, A.A., Modaqiq, W., McCarthy, T., Alexander, J.S., Mishra, C., 2020. PAWS Guidelines. Global Snow Leopard and Ecosystem Protection Program.

Sharma, R.K., Singh, R., 2020. Over 100 Years of Snow Leopard Research: A Spatially Explicit Review of the State of Knowledge in the Snow Leopard Range. WWF International, Gland, Switzerland.

(Appendix VI)

WWF

DEPARTMENT OF ENVIRONMENT, FOREST & CLIMATE CHANGE
ARUNACHAL PRADESH

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STATE-WIDE ASSESSMENT OF THE POPULATION AND DENSITY OF SNOW LEOPARDS IN ARUNACHAL PRADESH, INDIA

सत्यमेव जयते

CHIEF MINISTER
ARUNACHAL PRADESH

M E S S A G E

The State of Arunachal Pradesh is endowed with some of India's most significant range land and high-altitude ecosystems that sustain range of biodiversity including snow leopard (*Panthera uncia*). The high altitude ecosystem plays a pivotal role not only for biodiversity conservation but also support thousands of local communities for livelihood requirements. The *brokpa* community (nomadic Yak herders) particularly in parts of western Arunachal Pradesh have been using these areas since generations, and they are intricately linked to their lifestyle and culture.

In 2008, the Government of India launched a flagship project called the Project Snow Leopard to conserve and safeguards the unique natural heritage of high-altitude wildlife populations and their habitats by promoting conservation through participatory policies and actions. This is a significant recognition that the unique cultures, traditions and livelihoods of the mountain communities are closely linked, and they have a stewardship role to play in conserving them.

The Department of Environment, Forest and Climate Change (DoEFCC), Arunachal Pradesh, initiated a pioneering project to assess the population of snow leopards in 2021. This exercise was challenging given that the snow leopard habitat in Arunachal Pradesh, unlike most other places, is not easily accessible, and the terrains are rugged. This is the first ever study that attempts a robust assessment of the population of snow leopards in the state and it does at a scale that covers the entire potential habitat of the snow leopards. DoEFCC co-opted WWF-India as the technical knowledge partner to design the study, train staff and execute the fieldwork.

Under this assessment, the DoEFCC has covered the entire state with more than 115 camera traps installed between June and December 2021, and subsequently, a couple of divisions have repeated this exercise in 2022 and 2023. The final report on this assessment "*State wide snow leopard assessment of the population and density of snow leopards in Arunachal Pradesh, India*" has estimated the population of 36 snow leopards, with the density of 0.26 snow leopards/ 100 square kilometres (SE=0.11)! It is also an exciting news to see around 80% interviewees have confirmed presence of snow leopard during a perception survey carried in eleven districts of the State.

I complement the team involved in preparing the first-ever report on snow leopard population assessment and its density for the State of Arunachal Pradesh. I am sure the report will provide clear pathways to the forest department and other stakeholders of the State for conservation of the species and their habitats through an inclusive conservation model.

(Pema Khandu)

Mama Natung

सत्यमेव जयते

स्वच्छ भारत

**Minister for Environment,
Forests & Climate Change,
Water Resources,
Sports and Youth Affairs
Govt. of Arunachal Pradesh**

MESSAGE

I am happy to note that the Department of Environment, Forest and Climate Change has conducted a State wide snow leopard population assessment and its density in the state of Arunachal Pradesh for the first time. Arunachal Pradesh's potential snow leopard habitat is estimated at approximately 15,181 sq km, however, there is no rigorous field studies have been conducted on the abundance and distribution of snow leopards in the state as of now.

Perfectly at home amongst the windswept slopes of the high peaks, snow leopard is an iconic species of the high mountain regions. Snow leopards also serve as a key indicator of the health of their habitat. Unfortunately, Snow leopards face several threats to their survival, such as retaliatory killing due to livestock predation, hunting of its wild prey species and the overarching effects of climate change. Protecting snow leopards and their habitats ensures the health and biodiversity of the fragile mountain ecosystems of Arunachal Pradesh and the well-being of people dependent on the mountains and those living downstream across the densely populated plains of Assam. I, therefore, understand that this assessment will surely provide necessary information and data to draw a long-term conservation plan for snow leopard and other high-altitude wildlife species.

The Department of Environment Forests and Climate Change and the Ministry of Environment Forests and Climate Change, Government of India designated WWF-India as its technical partner for the snow leopard population assessment in the state with the primary objective to carry out population and density estimation of snow leopards in Arunachal Pradesh. I must congratulate the Department of Environment Forests and Climate Change and WWF India for accomplishing these objectives and coming out with an estimated population of 36 snow leopards in the state of Arunachal Pradesh.

This report presents the result of a State-wide interview-based survey conducted with various stakeholders to assess the presence of snow leopards and critical threats to the species and wild ungulates, followed by a camera trap-based field study to assess their population. I believe that the information gathered through this assessment process will help Government of Arunachal Pradesh in preparing a long-term conservation plan for Snow Leopard and its high-altitude fragile habitats of Arunachal Pradesh.

(Mama Natung)

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MESSAGE

This report represents the first-ever scientifically robust estimation of snow leopard population and density in Arunachal Pradesh, laying the groundwork for long-term monitoring and conservation planning. It indicates a significant step forward in our understanding and conservation efforts of this elusive and majestic species that now has an estimated population of 36 individuals in Arunachal Pradesh, marking a crucial milestone in our conservation journey in the state.

While we celebrate this success, the report also sheds light on the primary threats faced by snow leopards in the region, with accidental killing/snaring and retaliatory killing identified as major concerns.

Importantly, the insights gathered from local herding communities underscore the vital role they play in snow leopard conservation efforts. Their perspectives provide a valuable opportunity for collaboration and partnership towards sustainable conservation practices.

Going ahead, these findings are a springboard for future conservation actions. Our commitment to protecting the snow leopard and its habitat must be unwavering, and collaboration with local communities and stakeholders remains paramount.

I extend my heartfelt gratitude to the Department of Environment, Forests and Climate Change, Arunachal Pradesh, for their dedication to executing this vital project and their commitment to protecting this majestic cat.

Together, let us continue to work tirelessly towards a future where the 'monarch of the mountains' roams free and is thriving in its natural habitat.

Mr Ravi Singh
SG and CEO,
WWF-India

Ngilyang Tam, IFS
PCCF (WL & BD) & CWLW

FOREWORD

The Department of Environment, Forest and Climate Change (DoEFCC), Arunachal Pradesh, initiated a pioneering project to assess the population of snow leopards of the State. The detailed snow leopard population assessment survey was carried out during 2021-2022 and there are a few repeat surveys in a couple of forest divisions. This is the first-ever study to assess snow leopard population and its habitat status in the State through a systematic and scientific survey techniques. The study used a state-of-the-art simulation to develop a robust design for the assessment, followed by a gruelling period of fieldwork where the frontline staff of the state forest department participated with great enthusiasm. The protocol aligns with the principles outlined in the PAWS and SPAI (MoEFCC 2019).

DoEFCC co-opted WWF-India as the technical knowledge partner to design the study, train frontline staff and execute the fieldwork and the survey has been carried out into two phases – a) state-level snow leopard presence, perceptions and threat assessment and b) state-level snow leopard population assessment survey.

In phase I: a total of 282 interviews were conducted in 160 locations (from hamlets, villages, and grazing camps to townships) covering 293 grids (10 km × 10 km), forming the area of the interviewees' knowledge and under phase II, we used a two-step process to design the snow leopard population assessment as there was little to no prior information on the abundance and distribution of snow leopards in the state.

Prior to the field assessment, a series of 2-day training workshops were organised at Tawang, Dirang, Itanagar, Aalo, Yinkiong, Pasighat, Tezu and Deban (Namdapha TR) between March and July 2021. A total of 11 forest divisions were covered during these workshops, and around 80 participants, which included DFOs, RFOs, Deputy Rangers, Forest Department frontline staff and local volunteers, were trained. The workshops were designed to inform the participants about the known distribution, habitat preference and behaviour of snow leopards and the various aspects of camera trap site selection and installation.

I acknowledge the efforts that have gone into this assessment and hard work of forest officials and frontline staff given the snow leopard habitat in Arunachal Pradesh, unlike most other places, is not easily accessible, and the terrains are tough and rugged. This is the first study that attempts a robust assessment of snow leopard population in the state, and it will add new dimensions to the conservation of the species and high-altitude ecosystem of Arunachal Pradesh.

(Ngilyang Tam, IFS)

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EXECUTIVE SUMMARY

Solitary, almost silent and majestically beautiful, the snow leopard is one of the most enigmatic big cats. It is also one of the most elusive and endangered. Highly adapted to life on the cold, rocky slopes of High Asia, the snow leopard is a master of stealth and camouflage. Very rarely seen by humans, it has come to be known as the 'ghost of the mountains.' It has also become an icon for these breathtaking and critically important landscapes, which house a diverse array of unique high-altitude species and provide critical ecosystem services for hundreds of millions of people.

The snow leopard (*Panthera uncia*) is the apex predator of the Trans-Himalayas. It also has a high significance in the local folklore, culture and traditions of the Himalayan communities that share space with this species. The Government of India launched a flagship project called the Project Snow Leopard in 2008 to conserve and safeguard the unique natural heritage of high-altitude wildlife populations and their habitats by promoting conservation through participatory policies and actions. This is a significant recognition that the unique cultures, traditions and livelihoods of the mountain communities are closely linked with these landscapes, and they have a stewardship role to play in conserving them.

Cat species hold a special significance across most tribes of Arunachal Pradesh as totemic symbols of spiritual significance, and often most of these tribes have the highest sanctions (in-kind) if they violate the taboo on hunting carnivores. The high-altitude areas of Arunachal Pradesh have largely remained unexplored from a wildlife research and conservation perspective. Even though the state has more than 15,000 km2 of potential snow leopard habitat, no rigorous assessment of the status of the snow leopards exists so far.

The Department of Environment, Forests and Climate Change (DoEFCC), Arunachal Pradesh, initiated a pioneering project to assess the population of snow leopards in the year 2021. This exercise was challenging given that the snow leopard habitat in Arunachal Pradesh, unlike most other places, is not easily accessible, and the terrain is particularly challenging. This is the first study that attempts a robust assessment of the population of snow leopards in the state and does it at a scale that covers the entire potential habitat of the snow leopards. The study used state-of-the-art simulations to develop a robust design for the state-level assessment, followed by a grueling period of fieldwork when the frontline staff of the state forest department participated with great enthusiasm.

forest department participated with great enthusiasm. The protocol aligns with the principles outlined in the PAWS and SPAI (MoEFCC 2019).

DoEFCC co-opted WWF-India as the technical knowledge partner to design the study, train the staff and execute the fieldwork. Following is the summary of the results of this project:

1. Camera trapping was conducted from the 24th of June to the 09th of December 2021, covering 115 locations across Arunachal Pradesh.
2. Before camera trapping, 282 interviews were conducted with herders and ex-hunters in 160 locations (from hamlets, villages, and grazing camps to townships) covering 293 grids (10 km × 10 km) to assess state-level snow leopard presence, perceptions, and threats to the species and its habitat.
3. Over 80% of the interviewees positively confirmed the presence of snow leopards from all the surveyed districts.
4. Eight individual snow leopards were detected in over 40 snow leopard capture events in 16 different camera traps in the Tawang and Bomdila Divisions.
5. The population estimate of snow leopards in the state of Arunachal Pradesh is 36 snow leopards (SE = 15). The density of snow leopards in the state was 0.26 (SE = 0.11) snow leopards/100 km²
6. The most significant threat to snow leopards is accidental killing/snaring in all the surveyed districts except West Kameng and Tawang, where retaliatory killing is the primary threat, followed by accidental killing/snaring.
7. The development of large-scale infrastructure and free-ranging dogs seriously threatens the wildlife in high-elevation areas of the West Kameng and Tawang districts.
8. This report provides the first-ever scientifically robust estimates of the snow leopard population and density in Arunachal Pradesh. The report provides a baseline of the state of snow leopards in Arunachal Pradesh to establish a long-term monitoring plan for the species.
9. By providing a comprehensive overview of the potential threats to the snow leopards in the state, the report also provides a foundation for establishing a conservation program.
10. In addition, insights and perspectives of the local herding communities in the report highlight an important opportunity to engage and partner with local communities for conservation, for which Arunachal Pradesh is already a pioneer and a leading example to emulate.

INTRODUCTION

Perfectly at home amongst the windswept slopes of the high peaks, snow leopards are an iconic species of the high mountain regions of Central Asia. Snow leopards also serve as a key indicator of the health of their habitat, i.e. their presence indicates a healthy mountain ecosystem. Unfortunately, snow leopards face several threats to their survival, such as habitat fragmentation due to poorly planned infrastructural developments, retaliatory killing due to livestock predation, hunting of its wild prey species and the overarching effects of climate change. Protecting snow leopards and their habitats ensures the health and biodiversity of the fragile mountain ecosystems and the well-being of people dependent on the mountains and those living downstream across the densely populated plains. Snow leopards also have immense cultural significance in the regions where they are found, and their conservation is important for preserving the local cultures and traditions.

Globally, the snow leopard is distributed across 12 countries in Central and South Asia, including Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyz Republic, Mongolia, Nepal, Pakistan, Russian Federation, Tajikistan, and Uzbekistan. Inhabiting an estimated 1.8 million km2 of an area, snow leopards share landscapes with local communities that depend on various traditional forms of agro pastoralism (Snow Leopard Working Secretariat 2013).

In India, the snow leopard is found in the Union Territories of Ladakh and Jammu and Kashmir, the states of Uttarakhand and Himachal Pradesh in the Western Himalayas and the states of Arunachal Pradesh and Sikkim in the Eastern Himalayas. Arunachal Pradesh's potential snow leopard habitat is estimated at approximately 15,181 km², and an expert opinion-based estimate of the snow leopard population in the state stood at 42 snow leopards (Bhatnagar et al. 2016). No rigorous field studies have been conducted on the abundance and distribution of snow leopards in the state.

Reliable estimates of the abundance and density of snow leopards are essential for establishing baselines, evaluating the effectiveness of conservation actions and formulating appropriate management actions. Although most snow leopard studies focus on distribution and abundance surveys, globally, reliable snow leopard population density estimates are available for less than three percent of their distribution range (R. K. Sharma and Singh 2020). Recognising the importance of reliable estimates of the snow leopard population, governments of the 12 snow leopard range countries initiated the population assessment of the world's snow leopards (PAWS) under the technical oversight of an expert panel at GSLEP.

The Government of India is a signatory to the global commitments for the protection and conservation of snow leopards. It has initiated the Snow Leopard Population Assessment of India (SPAI) to guide the rigorous assessment of the snow leopard population in the country.

Snow leopards face several historic and new threats across their distribution range. Threats include large-scale development projects such as mining and extensive infrastructure, poaching for body parts, retaliatory killing due to livestock predation, growing livestock numbers in certain parts of its range and an overarching effect of climate change.

The Department of Environment, Forests and Climate Change of Arunachal Pradesh and the Ministry of Environment Forests and climate change (MOEFCC) designated WWF-India as its technical partner for the snow leopard population assessment in the state. The primary objectives of this report were to

1. Estimate the population and density of snow leopards across the state of Arunachal Pradesh
2. Examine the critical threats to snow leopards and their habitat in the state

This report presents the results of a state-wide interview-based survey with the herders and ex-hunters to assess the presence of snow leopards and critical threats to snow leopards and wild ungulates, followed by a camera trap-based field study to assess their population.

METHODS

State-level snow leopard presence, perceptions, and threat assessment survey

We included the entire region above 3000 metres in the state as the potential snow leopard habitat. We divided the entire area into 10km x 10 km grids. The grids were plotted in Google Earth (Google Inc., USA), and all known landscape features, including the major roads and settlements, were identified and marked. Village selection for interview surveys was informed by two criteria (1) proximity to high altitude areas and (2) known history of pastoral use of high altitude areas. A total of 160 such locations were spread across 11 districts of Arunachal Pradesh and included medium to large-sized villages, hamlets and townships (Table 1).

A total of 282 interviews were conducted in 160 locations (from hamlets, villages, and grazing camps to townships) covering 293 grids (10 km × 10 km), forming the area of the interviewees' knowledge. We explained the grids' boundaries to the respondents using Google Earth and oriented them to the grids using prominent features such as rivers, mountains and roads.

Questionnaires were designed considering that our primary target respondents were herders and ex-hunters whose lives and livelihoods were linked to the snow leopard habitat.

The questionnaire was divided into five primary sections (Annexure 1):

1. Basic details of the interviewee and the village.
2. Wildlife presence/absence (16 species for two timelines- 1998 and 2017).
3. Threats to the high-altitude habitat of the snow leopard.
4. Perception towards wildlife, particularly snow leopards.
5. Snow leopard hunting or trade.

We focused on people who access the high-elevation sub-alpine and alpine areas (> 3500 m) periodically for transhumance, hunting, and medicinal and aromatic plant collection, as they are most likely to come across the snow leopard habitat and evidences of its presence. For the present purpose, Brokpas (nomadic, Yak and sheep herders in Tawang and West Kameng districts) and ex-hunters in each location were considered the ideal respondents. In case of the unavailability of herders/ hunters in a particular location, village administrative heads, and senior members were approached for the interviews.

Table 1. Interview-based assessment of snow leopard distribution, threats to snow leopards and their habitat in the state of Arunachal Pradesh

District	Tribe interviewed	Grids covered	Interviews taken	Grids with reported snow leopard presence	Proportion of grids occupied by snow leopards
Tawang	Monpa	32	78	29	91
West Kameng	Monpa, Miji	14	47	13	93
East Kameng	Nyishi and Sullung	15	14	15	100
Kurung Kumey	Nyishi	24	24	22	92
Upper Subansiri	Tagin and Galo	36	19	35	97
Shi Yomi	Memba, Adi and Bokar	41	31	28	68
Upper Siang	Adi, Memba and Khamba	36	20	31	86
Dibang	Idu Mishmi	82	23	61	74
Lohit	Digaro Mishmi	6	4	6	100
Changlang	Lisu	9	1	9	100
Anjaw	Miju Mishmi	51	18	46	90
Total	13	336	279	295	88

Designing the state-level snow leopard population assessment survey

Since there was little to no prior information on the abundance and distribution of snow leopards in the state, we used a two-step process to design the snow leopard population assessment study. Using a digital elevation model, we delineated the entire region above 3000 metres in the state as the potential snow leopard habitat. Subsequently, we conducted simulations to create possible study designs (Figure 1) that would provide acceptable precision (less than 20%) for the population and density estimates of snow leopards (M. Efford 2020). The spatial capture-recapture models require sufficient detections of individual snow leopards and subsequent recaptures to reliably estimate parameters such as population size and density. The simulations aimed to approximate an optimal camera trap placement strategy that would maximise the number of unique snow leopard individual capturesand recaptures in different camera traps.

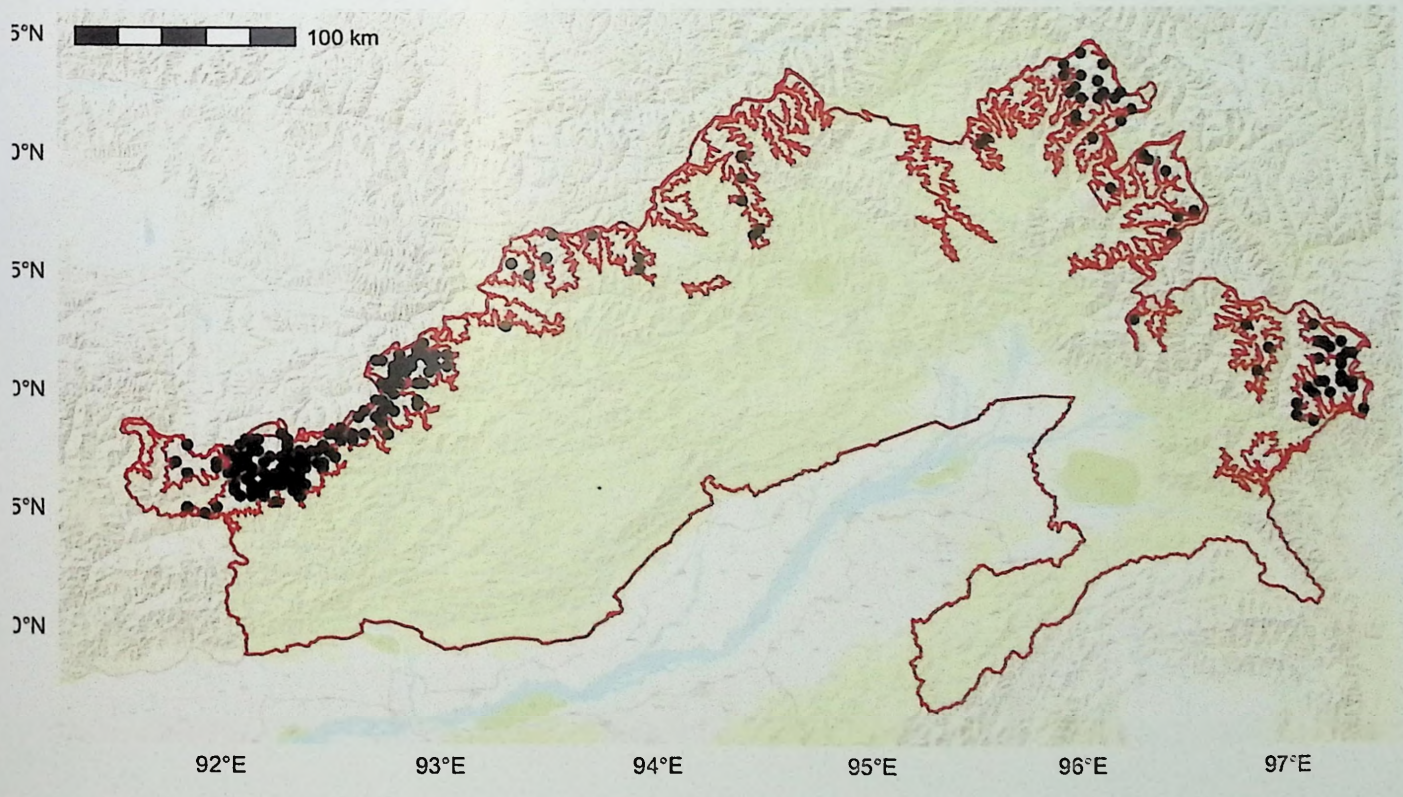


Figure 1. One of the suggested camera trap survey designs using simulations to optimise sufficient detections and recaptures of snow leopards to reliably estimate snow leopard abundance and density

Field Workshops and Training

A series of 2-day training workshops were organised at Tawang, Dirang, Itanagar, Aalo, Yinkiong, Pasighat, Tezu and Deban between March and July 2021. A total of 11 forest divisions were covered during these workshops, and around 80 participants, which included DFOs, RFOs, Deputy Rangers, Forest Department frontline staff and local volunteers, were trained. The workshops were designed to inform the participants about the known distribution, habitat preference and behaviour of snow leopards and the various aspects of camera trap site selection and installation. There were practical sessions focused on training using camera traps and handheld GPS units. The SPAI survey protocols of the snow leopard and wild ungulate population assessment were also covered during the sessions. Lastly, a survey plan for each division, including the possible areas to be covered, the routes to be taken, and other field logistics, was prepared in consultation with the local experts.

A field guide was developed and provided to all the divisions. This included information on the camera-trap survey design, snow leopard signs, practical tips for site selection, camera trap installation/placement (with pictures), protocols for carrying out animal-sign and threat assessment survey along with a pictorial guide of all the signs of the relevant species, desired settings for the different camera trap models used, pictorial guide to the relevant GPS functions, camera trap survey datasheet, and animal-sign and threat assessment datasheet.

Field Survey

Camera trapping was conducted from the 24th of June to the 09th of December 2021, covering 115 locations across Arunachal Pradesh (Figure 2). Overall, the camera traps operated for 8775 trap nights. Trap placement was informed by fine-scale eco-geographical features where snow leopard captures were likely to be maximised. Camera trap locations were selected based on the signs of snow leopards, such as pugmarks, scats, scrapes and scent marks, to maximise the chances of capturing snow leopards at each location. The grids (survey units) were selected for camera trap sampling to maximise the captures of unique individuals and subsequent recaptures.

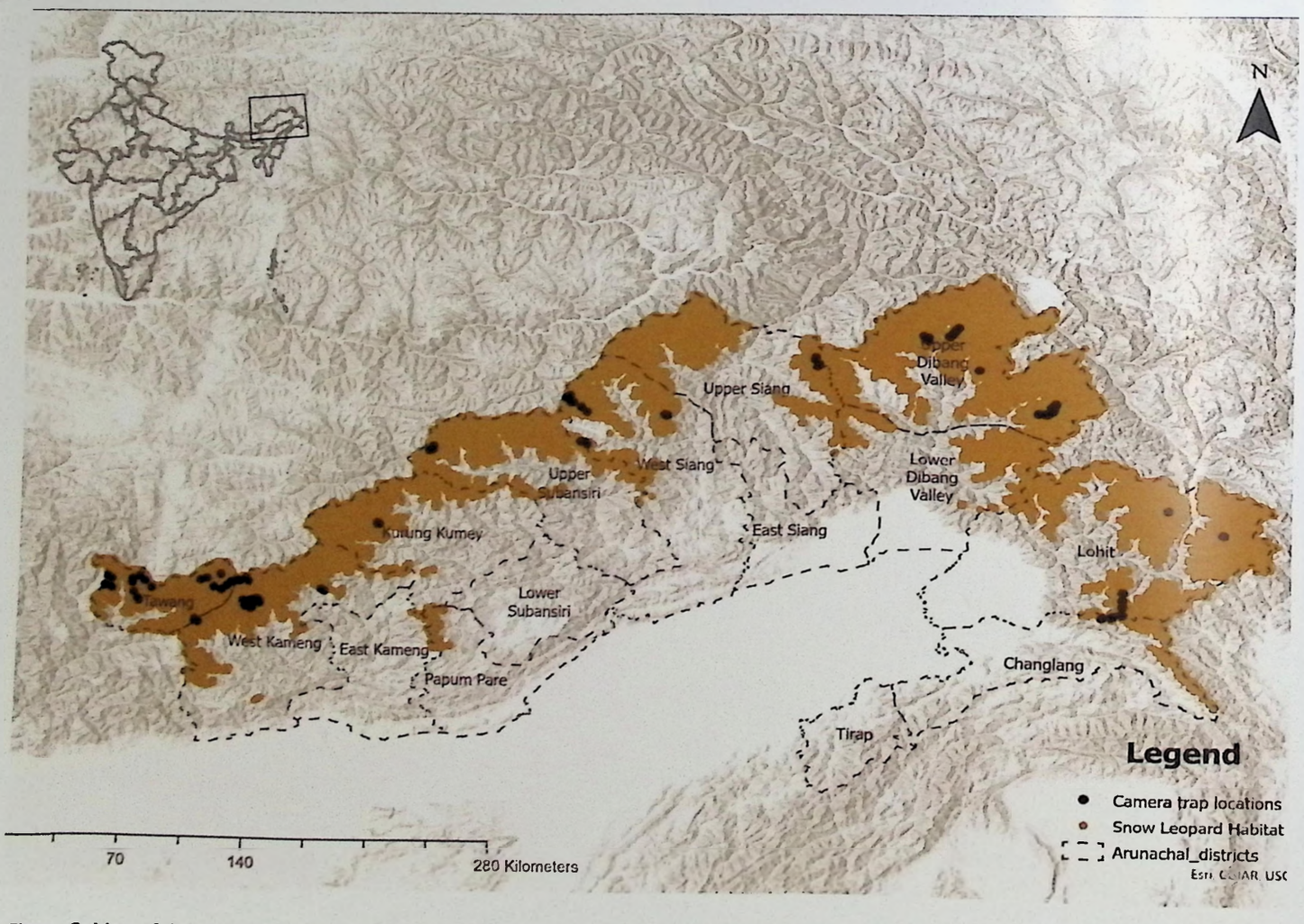


Figure 2. Map of the potential snow leopard habitat and the locations of camera traps within that. The map in the inset shows the state of Arunachal Pradesh in India.

Individual Identification of Snow Leopards

We used digiKam image management software (https://www.digikam.org/) to tag the snow leopard images and Camelot software (https://camelotproject.org/) to build a database of images. Two researchers used rosette patterns across multiple body parts of snow leopard images to individually identify and distinguish snow leopard individuals. A third independent researcher did subsequent verification of the identified snow leopard images and resolved discrepancies. . We then set up the data for the Spatially Explicit Capture-Recapture (SECR) analysis (Borchers 2012; M. G. Efford 2011). The SECR analysis requires two files, one containing the information about the coordinates of detectors (camera traps) and the other containing a capture-history file with information on each snow leopard detection, its time, and the camera trap in which the detection occurred.

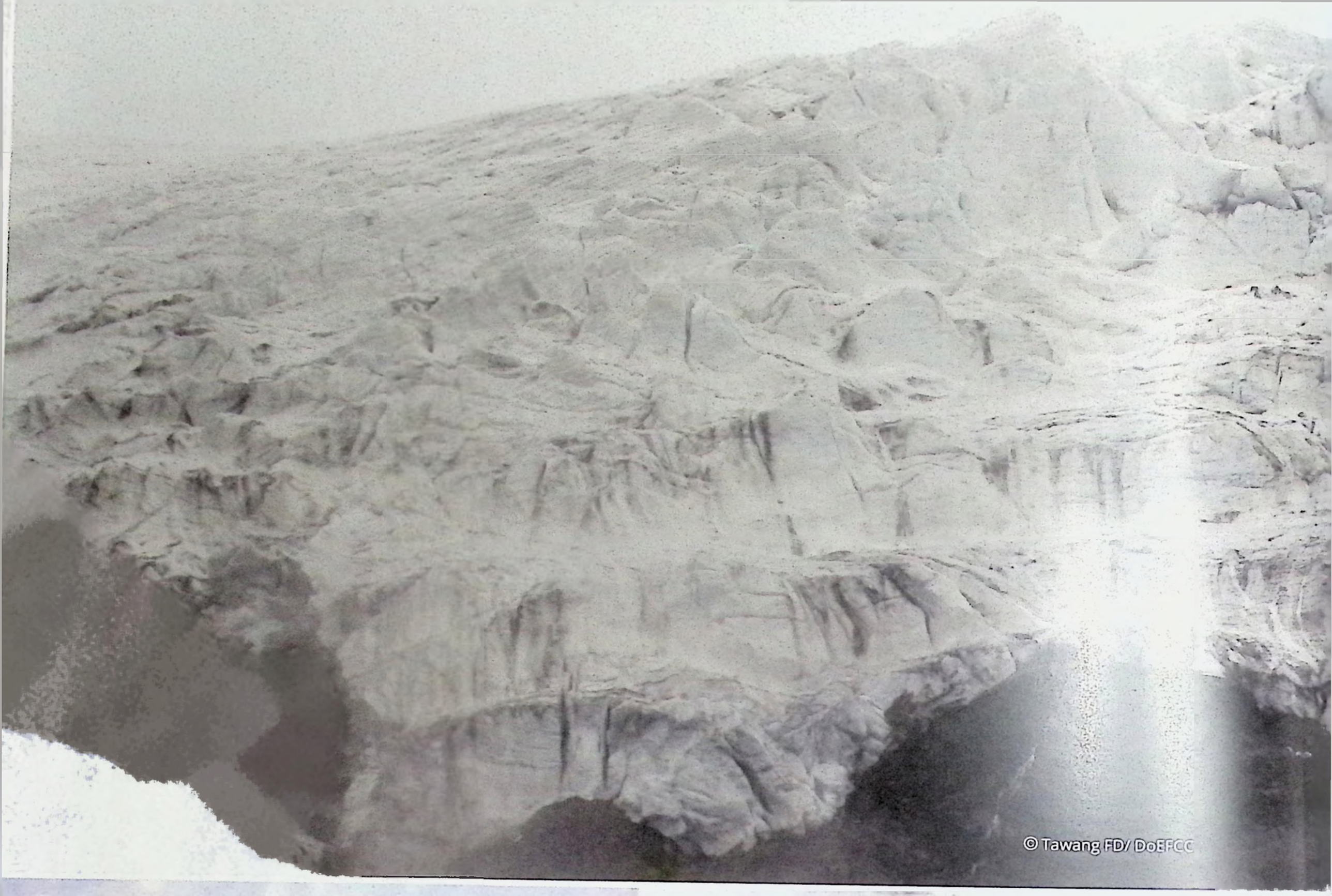
Data analysis

We summarised the data gathered from 213 interviewees grid-wise, corresponding to the respondent's area of knowledge. The presence of snow leopards, primary threats to snow leopards and their habitat and respondents' perceptions about the region's wildlife were summarised in Excel.

We used Spatially Explicit Capture-Recapture Models to estimate the abundance and density of snow leopards in Arunachal Pradesh (Borchers 2012; M. G. Efford 2011). The SECR models explicitly incorporate the spatial data of a species captured at different locations with the assumption that animals located closer to camera traps have a high chance of being detected, while animals sufficiently far away from the traps are unlikely to be captured (Borchers 2012). SECR models are also reasonably robust to violation of some common assumptions though caution is always recommended when dealing with crucial assumptions. We used the built-in "make.mask" function in the package SECR to create a mask around the camera trap locations. The specific parameters included a buffer of 25,000 metres and spacing of 1000 metres, restricting the mask to the region identified as the snow leopard habitat. This resulted in a state space of approximately 22,616 km^2. We used the package SECR (M. Efford 2020) in program R (R Core Team 2020) to run the SECR models. The model specifications were as follows.

Table 2. The models used for the spatially explicit capture-recapture analysis, their parameters, and description.

S.No.	Model specification	Model details
1	list(g0 = ~1, sigma = ~1)	constant (null) model
2	list(g0 = ~b, sigma= ~1)	learned animal response to detectors
3	list(g0 = ~h^2, sigma= ~1)	2-class mixture
4	list(g0= ~k, sigma= ~1)	site learned response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RESULTS AND DISCUSSION

Snow leopard presence, perceptions and threats based on interview surveys

The prime focal species, the snow leopard, expectedly came out to be one of the rarest mammals reported. Two hundred thirteen respondents for 1998 and 199 for 2017 claimed to know about the presence of snow leopards in the high elevation areas. However, only 54 respondents claimed to have direct sightings or have come across signs of snow leopards. Chinese Goral was the rarest mammal, reported only by five people in the Tawang district. Red Goral was rare in the west and common in central and eastern Arunachal Pradesh. Similarly, Sun Bear was more common in the east; its presence in western Arunachal Pradesh needs further confirmation.

Human use of the high-altitude areas in different districts varies, and this is evident in the threat perception of respondents according to their respective districts. The build-up of large-scale defence, related infrastructure, and free-ranging dogs was perceived as the most significant threats in Tawang and West Kameng districts. On the other hand, accidental snaring and hunting were the primary threat to snow leopards in all other districts.

None of the respondents perceived snow leopards as a significant threat to their livestock. There have been very few instances of snow leopards preying upon the livestock. The primary threat to livestock across the state is the Asiatic wild dog. Although, free-ranging dogs are an even more significant threat to the livestock in the high-altitude regions of Tawang and West Kameng districts. In summary,

1. Over 80% of the interviewees positively confirmed the presence of snow leopards from all the surveyed districts.

2. Primary motivation for the locals in all the surveyed districts (except West Kameng and Tawang) to visit the snow leopard habitat is to hunt musk deer, followed by the Cordyceps collection. Most people visiting the snow leopard habitat in West Kameng and Tawang are herders, followed by Cordyceps collectors.

3. The biggest threat to snow leopards is accidental killing/snaring in all the surveyed districts except West Kameng and Tawang, where retaliatory killing is the primary threat followed by accidental killing/snaring.

4. The development of large-scale infrastructure and the rise in the population of feral dogs pose a serious threat to the wildlife in high-elevation areas of West Kameng and Tawang districts.

5. All the surveyed tribes (except Lisu) traditionally have a taboo on hunting big cats for various beliefs. Due to the spread of Christianity in most districts, the protection of the big cats due to traditional beliefs is reducing.

6. Generally, the number of skilled hunters in most villages in every district is drastically reducing with every generation. The young generations with better access to education prefer to move to bigger towns and cities for government or private jobs. More jobs are available in remote villages (road labourers, guides or porters for defence agencies, private contractors, etc.), providing a steady income supply to the locals. Some of these factors are responsible for reducing the instances of hunting.

Eight individual snow leopards were detected in over 40 snow leopard capture events in 16 camera traps in the Tawang and Bomdila Divisions.

Using the Null model, the population estimate of snow leopards in Arunachal Pradesh is 36 snow leopards (SE = 15) in 14,156 km2 of snow leopard habitat in the state.

The density of snow leopards in the state was 0.26 (±0.11) snow leopards/100 km2, with the lowest density being 0.11 snow leopards/100 km2 and the highest being 0.57 snow leopards/100 km2 (Figure 3).

This report provides the first-ever scientifically robust estimates of the snow leopard population and density for Arunachal Pradesh. While we have highlighted the potential limitations of the survey and analysis, the report provides baselines of the snow leopards in Arunachal Pradesh to establish a long-term monitoring plan for them. The project also provided tremendous exposure to field methods for monitoring snow leopards to the State Department of Forest and Wildlife staff and citizen scientists. By providing a comprehensive overview of the potential threats to the snow leopards in the state, the report also provides a foundation for establishing a conservation program. In addition, the insights and perspectives of the local herding communities in the report also provide an excellent opportunity to engage and partner with local communities for conservation, for which Arunachal Pradesh is already a pioneer and a leading example to emulate.

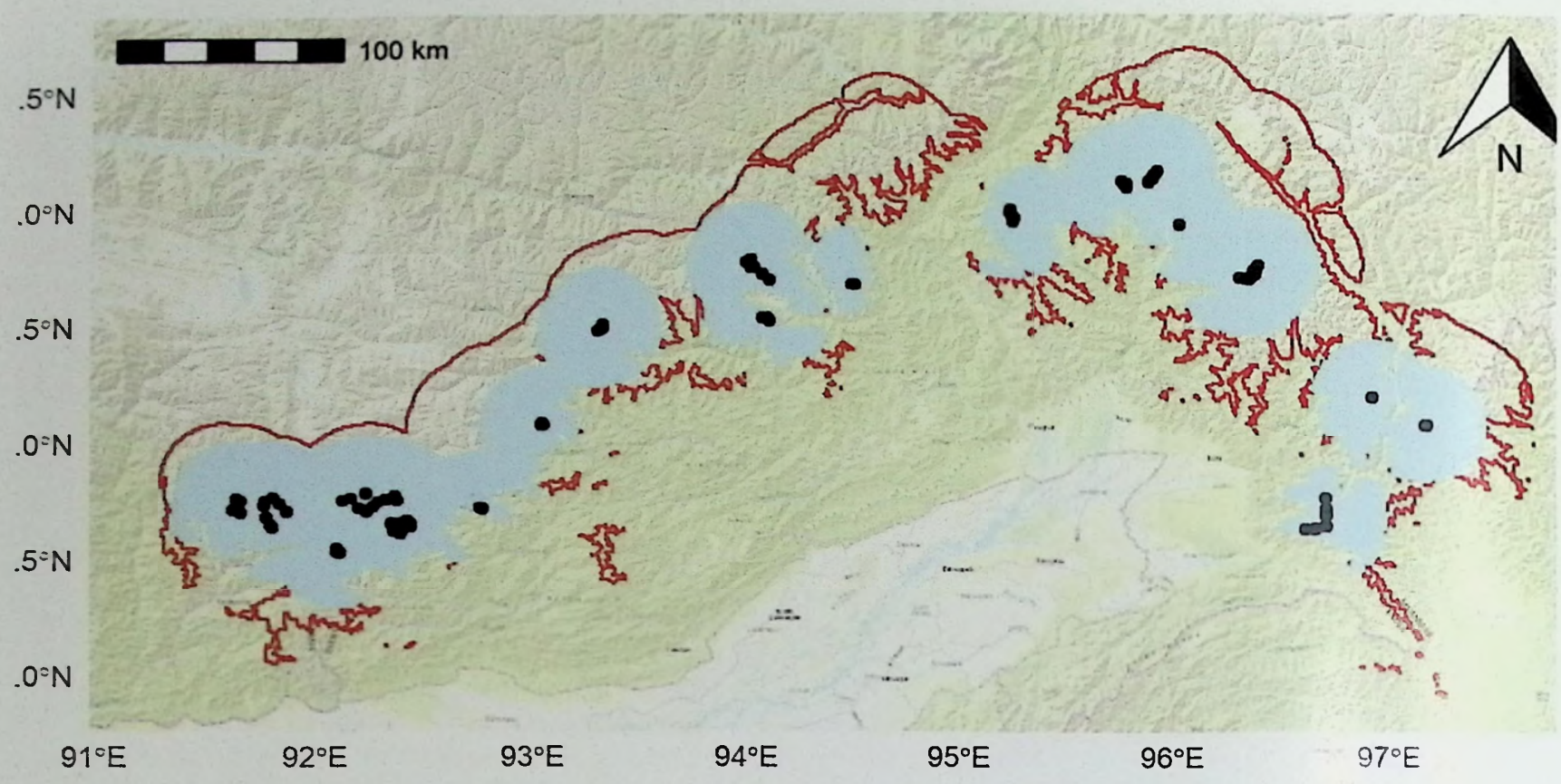

Figure 3. Showing camera trap locations (black circles), the effective survey region (light blue shaded region) and the potential snow leopard habitat (enclosed by the red polygon).

Limitations

Snow leopards were not detected in any other division (other than Tawang and Bomdila Divisions), indicating the need to calibrate the field sampling to confirm whether it's a genuine absence of snow leopards in these divisions or an inadequacy in sampling effort and approach. The successive trap-revealed movement also indicated a lack of sufficient snow leopard recaptures at different distances, one of the critical parameters for the observation model (the spatial detection function) of SECR to estimate density using inverse prediction/maximum likelihood.

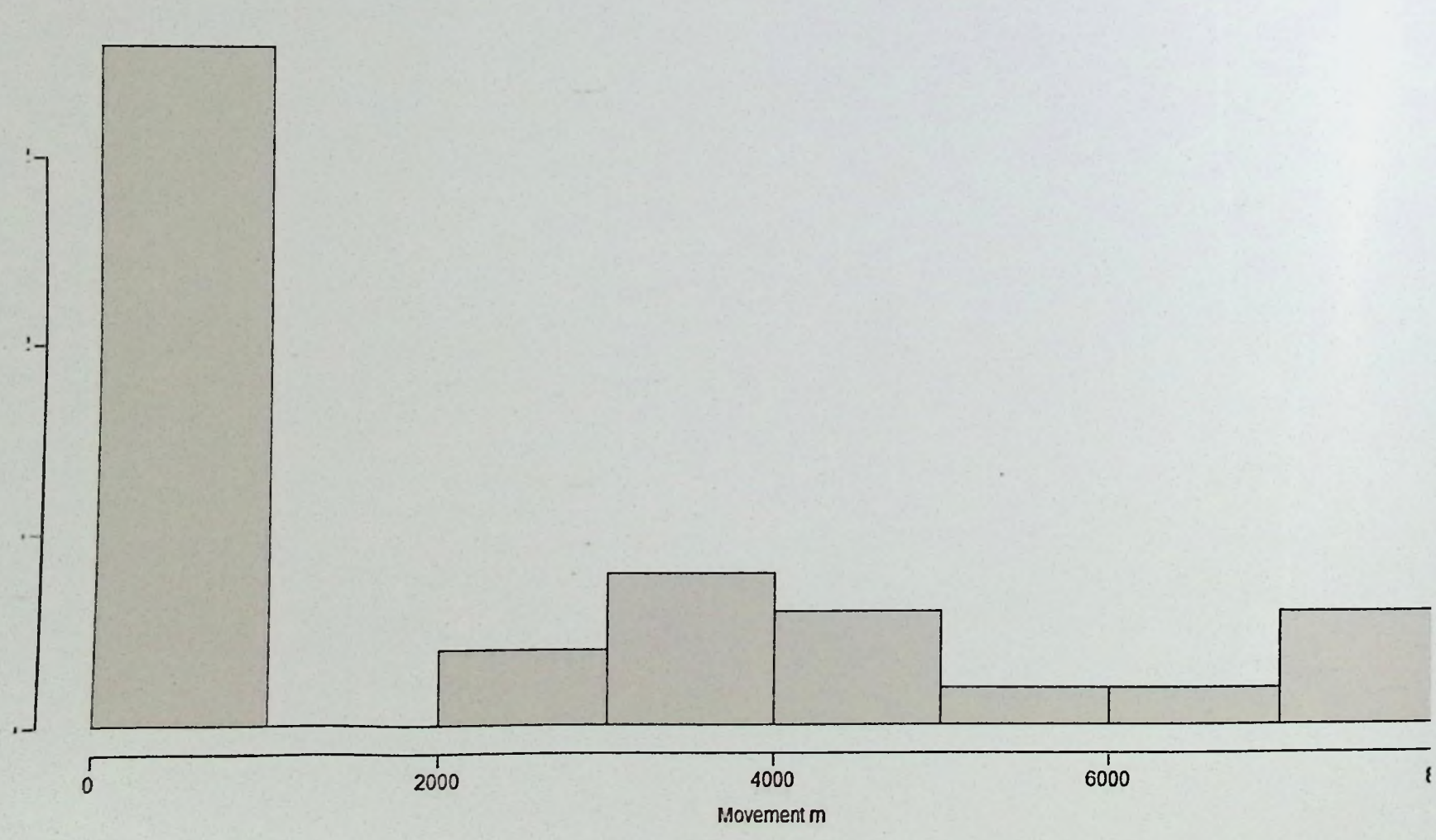

Figure 4. Showing the successive trap-revealed movement of snow leopards

APPENDIX

Snow leopard population monitoring by Tawang Forest Division

August 2022 – July 2023

The state-wide population assessment surveys for snow leopards were conducted by the Department of Environment, Forest and Climate Change, Arunachal Pradesh in collaboration with WWF-India in the year 2021. This was part of the Snow leopard Population Assessment of India (SPAI). This first of a kind exercise gave interesting insights about the presence and distribution of the high-altitude fauna and established the baselines for the population of snow leopards in the state.

As a follow-up exercise, Tawang Forest Division conducted camera-trap surveys to monitor the snow leopard population in Tawang district between August 2022 and July 2023. Snow leopards were recorded in 10 different locations. A formal analysis of the data is underway.

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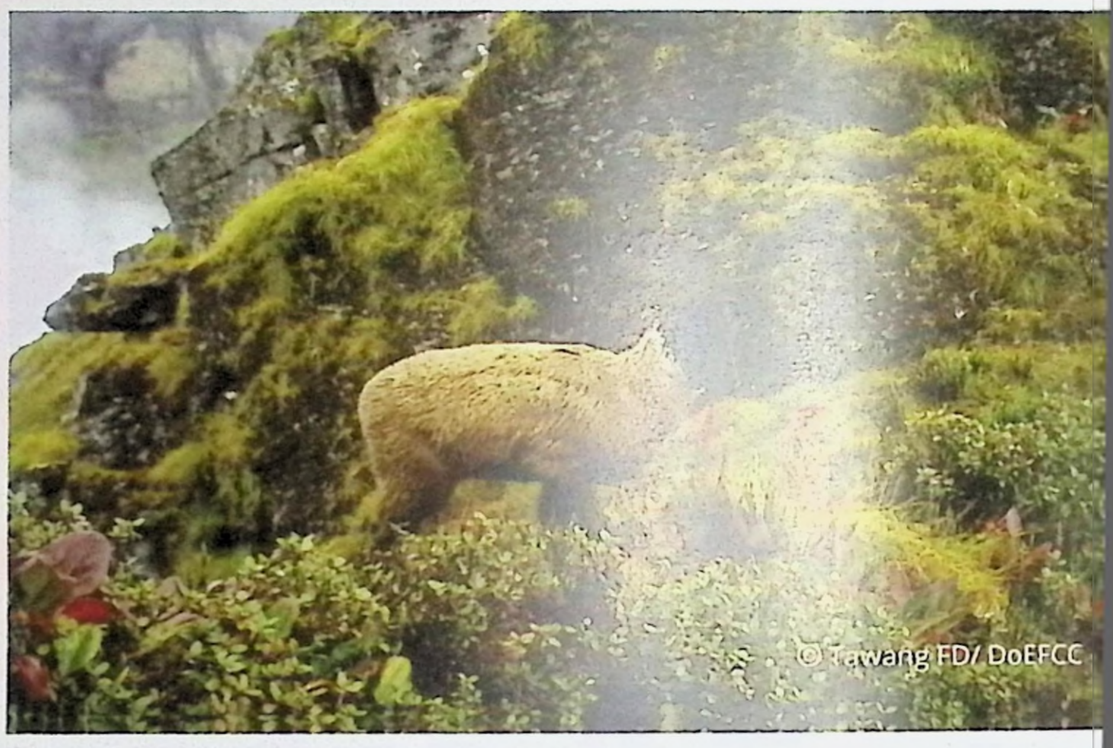
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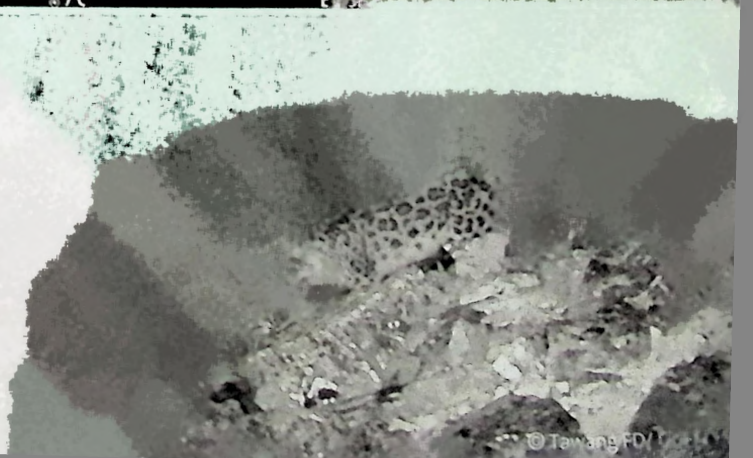
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© Tawang FD/ DoEFCC
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© Tawang FD/ DoEFCC
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ACRONYMS

WWF- Worldwide Fund for Nature

GSLEP- Global Snow Leopard and Ecosystem Protection Program

PAWS- Population Assessment of World's Snow Leopards

SPAI- Snow Leopard Population Assessment of India

MOEFCC- Ministry of Environment, Forests and Climate Change

DoEFCC- Department of Environment, Forests and Climate Change, Arunachal Pradesh

BIBLIOGRAPHY

Bhatnagar, Yash et al. 2016. 'Snow Leopard Status and Conservation: Regional Reviews and Updates: South Asia: India'. In Snow Leopards, Biodiversity of the world: conservation from genes to landscapes, eds. Thomas McCarthy and David Mallon. Elsevier, 457–69.

Borchers, David. 2012. 'A Non-Technical Overview of Spatially Explicit Capture–Recapture Models'. Journal of Ornithology 152(S2): 435–44.

Efford, Murray. 2020. 'Secr: Spatially Explicit Capture-Recapture Models'. https://CRAN.R-project.org/package=secr.

Efford, Murray G. 2011. 'Estimation of Population Density by Spatially Explicit Capture–Recapture Analysis of Data from Area Searches'. Ecology 92(12): 2202–7.

Janaki, M., Rohan Pandit, and Rishi K. Sharma. 2020. 'The Role of Traditional Belief Systems in Conserving Biological Diversity in the Eastern Himalaya Eco-Region of India'. Human Dimensions of Wildlife: 1–18.

MoEFCC. 2019. Snow Leopard Population Assessment in India: Population Assessment of World's Snow Leopards(PAWS) for India. 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. https://docslib.org/doc/2086737/snow-leopard-population-assessment-in-india (October 26, 2022).

R Core Team. 2020. 'R: A Language and Environment for Statistical Computing'. https://www.R-project.org/.

Sharma, Koustubh et al. 2020. Population Assessment of the World's Snow Leopards.

Sharma, Rishi Kumar, and Rashmi Singh. 2020. Over 100 Years of Snow Leopard Research: A Spatially Explicit Review of the State of Knowledge in the Snow Leopard Range. Gland, Switzerland: WWF International.

Snow Leopard Working Secretariat. 2013. Global Snow Leopard and Ecosystem Protection Program. Bishkek, Kyrgyz Republic.

ACKNOWLEDGMENT

Division & PA wise acknowledgement (2021)

Snow Leopard Assessment team, Along Forest Division, 2021:

Participants	Designation
Jumdo Geiyi	DCF, DFO
Tanga Murtem	RFO, Mechukha Forest Range
Bomli Bagra	Dy. FR
Tateng Gaduk	DDBR staff
Taken Taring	DDBR staff
Lham Tsering	(Research Associate), WWF India
Yana Logyo	(Research Associate), RGU
Lhakpa Naksang	Guide
Nyime Mardo	Guide
Pasang philley	Cook
Tao Rai	Cook
Tagam Rai	LC
Pasang Mardo	LC
Bahadur Mardo	LC

Snow Leopard Assessment team, Anjaw Forest Division, 2021:

Participants	Designation
V.K Reddy	DFO
Kidak Lollen	RFO
Michen Pul	community volunteer
Prytomso Pul	community volunteer
Rolinso Pul	community volunteer
Ajitso Pul	community volunteer
Seema Devi	community volunteer
Sanjeev Kumar	community volunteer
Rajkishor Sahani	community volunteer
Nang Swapnali Chowlu	community volunteer
Angulum Towang	community volunteer
Saleemai Pul	community volunteer
Kago Rita	community volunteer
Limo Lollen	community volunteer
Taku Sai	RGU

Snow leopard assessment team, Anini Forest Division 2021

Participants	Designation
Suraj Singh	DFO
Kenjum Rina	DFO
Taluk Rime	DFO
Sagar Sonar	Volunteer
Rakesh Adhikari	Volunteer
Midu Molo	Volunteer
Endro Tayu	Volunteer
Ema Milli	Volunteer
Dayba Mipi	Volunteer
Dilip Molo	Volunteer
Kila Umpe	Volunteer
Horish Doley	Volunteer
Tali Miwu	Volunteer
Anjithey Mikhu	STPF
Andu Mihu	STPF
Divya Deshwal	WII
Mohd. Akram	WII

Snow Leopard Assessment Team, Bomdila Forest Division, 2021:

Participants	Designation
Chukhu Loma, IFS	DFO Bomdila
R. S. Gonpapa	RFO, Dirang
Koj Hassang	UDC, Office Assistant
Hage Tajang	Fgd, Dirang Range
Nito Liyak	Fgd, Bomdila Range
Lobsang Sherap Phaichilupa	Researcher
Lobsang Namgyal	Videographer
Urgen Dorjee	Local guide
Zhokpu	Local guide
Kunzang	Local guide
Tashi	Brokpa
Yonten	Brokpa
Conba	Brokpa
Dor-Yeshi	Brokpa

Snow Leopard Assessment Team, Daporijo Forest Division, 2021:

Participants	Designation
Boken Pao	DFO
Menbi Riddi	community volunteer
Tusu Riddi	community volunteer
Marten Riddi	community volunteer
Tason chader	community volunteer
Vijay chetry	community volunteer
Tabia Garam	community volunteer
Kanu sorang	community volunteer
Rukbom Riddi	community volunteer

Snow Leopard Assessment Team, Kamlang Tiger Reserve & Wildlife Sanctuary, 2021:

Participants	Designation
Chestha singh	FD & DFO Kamlang TR
Harshraj D Wathore	FD & DFO Kamlang TR
Kelsang Dechen	RFO
Pramod Singh Meyan	Dy. Ranger
Anand Singh Rawat	Dy. Ranger
Maniram Chetry	Data Operator
Aditya Das	Field Biologist
Pintu Chanda	Forest Guard
Rupani Namchoom	Forest Guard
Koliyan Namchoom	Forest Guard
Sunil Rangmang	STPF
Krishna Deori	STPF
Buddhiman Rai	STPF
Lokesh Mam	STPF
Bomliso Halai	STPF
Jengu Halai	STPF
Tinamso Halai	STPF
Mayoso Halai	STPF
Adatlum Hakung	STPF
Tatolum Pul	STPF
Hawaso Halai	STPF
Damanso Yun	Local Volunteer
Sinkha Halai	Local Volunteer
Jeney Halai	Local Volunteer
Aswin Halai	Local Volunteer

Participants	Designation
Aswin Halai	Local Volunteer
Dihemso Halai	Local Volunteer
Sorin Halai	Local Volunteer
Batamso Halai	Local Volunteer
Bakhiso Yun	Local Porter
Roman Halai	Local Porter
Prakash Thapa	Driver

Snow leopard assessment team, Kurung Kumey Forest Division, 2021

Participants	Designation
Subu Haniya	DFO
Singku Maga	RFO
Dani Take	HA i/c
Mokpe Taluk	UDC
Hura Taluk	Forest Guard
Tash Tagung	Forest Guard
Gichik Vijay	Forest Guard
Milli Jhon	Porter
Bengia Singa	Porter
Bengia Ragik	Porter
Bengia Achung	Porter
Bengia Pandey	Porter
Sije Kang	Porter
Watling Akai	Porter
Milli Rai	community volunteer
Ching Tapiap	community volunteer

Snow Leopard Assessment Team, Namdapha National Park & Tiger Reserve, 2021

Participants	Designation
Tapek Riba	CF & Field Director
Aduk Paron	Assistant Field Director
Tajum Yomcha	Research Officer
Tage Mali	RFO
Kenjum Membom	RFO
Tukam Kacha	Dy FR
Son Yowa Hade	Dy FR
Amit Prasad	Fgd
Mayur H. Variya	Field Biologist

Participants	Designation
Tatum Rumdo	Camera Technician
Anand Kurmi	STPF
Sherbahadur Thapa	STPF
Mansingh Tamang	STPF
Yokonia Yobin	STPF
Phiyosa Yobin	STPF
Anjan Kumar Deb	Receptionist
Sumit Gogoi	Elephant attendant
Garib Mahato	Elephant attendant
Anil Gogoi	Cookman
Gopal Chetry	Cookman
Anirudh Mahato	Boatman
Gautam Thapa	Boatman helper
Lokesh Mahato	WT attendant
Gantai Wangsa	Driver
Vicky Rajput	Driver

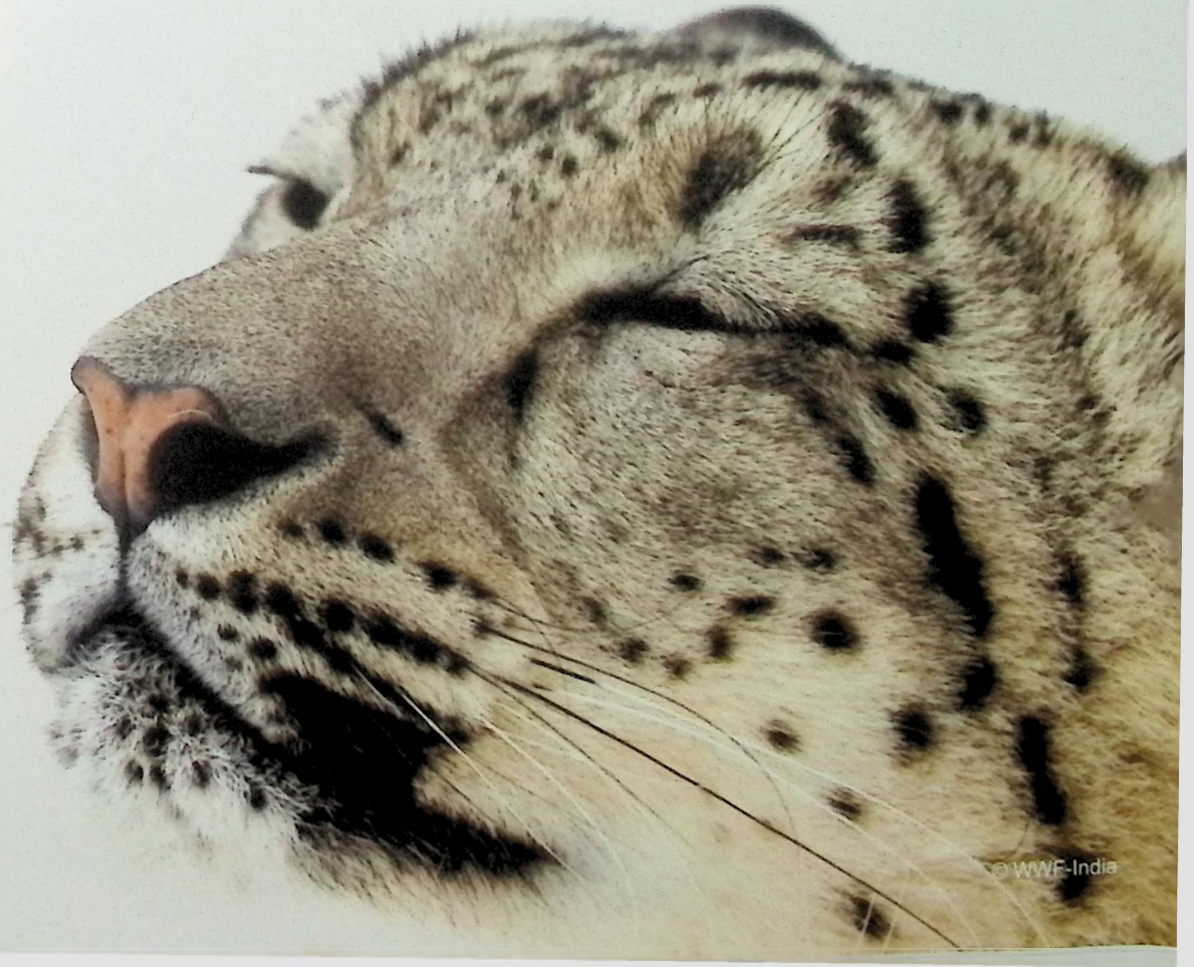
Snow Leopard Assessment Team, Seppa Forest Division, 2021

Participants	Designation
Vikas Swami, IFS	DFO
Dhawan Rawat, IFS	DFO
Atum Liyak	Forest Guard
Tafang Sono	Forest Guard
Nyeglu Puroik	Porter
Dao Puroik	Porter
Loma Puroik	Porter
Baro Puroik	Porter

Snow Leopard Assessment Team, Tawang Forest Division, 2021

Participants	Designation
Sange Tsering	Divisional Forest Officer, Tawang
Tage Haniya	Rage Forest Officer, Tawang
Nawang Gentsen	Range Forest Officer, Jang
Namgey Konchu	Driver
Jambey Dondu	Field Assistant
Dorjee Kelsang	Field Assistant
Lobsang Phuntso	Field Assistant
Pempa Tsering	Porter
Dorjee Norbu	Field Assistant/ Cook

Participants	Designation
Sange Gombu	Porter
Tallo Anthony	Field Assistant / camera man
Punyo Pushang	Field Assistant / camera man
Lobsang Wangchu	Forest Guard
Tashi Khandu	Driver
Lham Tsering Mento	Driver
Dorjee Leta	Porter
Dorjee Leta	Porter
Nima Tashi	Porter
Lham Tsering	Porter
Tenzing Lobsang	Porter
Tashi Dondu	Porter
Leki Kuncho	Porter
Supriyo Kumar Roy	Computer Operator/ Field Asstt
Sonam Tsetan	Porter
Lobsang Choidar	Porter
SEP Abin. R	Sepoy, C/o 27 Madras
Nk/SUB S.S Rao	Nayak, C/o 27 Madras
Maj. Tsewang Dorjee	Major, C/o 27 Madras
Hav R. Murugan	Havaldar, C/o 27 Madras
Nk Ramesh	Nayak, C/o 27 Madras



Division & PA wise acknowledgement (2022 and 2023)

Snow Leopard Assessment Team, Tawang Forest Division, 2022

Participants	Designation
Sange Tsering	Divisional Forest Officer, Tawang
Tage Haniya	Rage Forest Officer, Tawang
Nawang Gentsen	Range Forest Officer, Jang
Bomto Gara	LDC
Namgey Konchu	Driver
Millo Talo	Shresthadar
Hari Raju	Porter
Sonam Tashi	Driver
Phurpa Tsering	Porter
Tsetan Norbu	Porter
Pempa Tsering	Porter
Kime Taniyo	Forester
Taying Tatung	Special Forester
Jamey Sangey	Porter
Sonam Tashi	Porter / Filed asstt
Lobsang Gyatso	Porter
Norbu	Cook/ Field Asstt
Tenzin Wangchu	Porter
Lungtan Phuntso	Cook/ Field Asstt
Norbu	Porter /Field Asstt
Sangey Penjor	Porter/ Field Asstt
Tenzin Dondu	Porter
SEP Vyshnav. C	Sepoy, C/o 27 Madras
SEP Gajanand. G	Sepoy, C/o 27 Madras
SEP Sooraj Suresh	Sepoy, C/o 27 Madras

Snow Leopard Assessment team, Tawang Forest Division, 2023

Participants	Designation
Piyush A Gaikwad, IFS	DFO
Mr. Tage Haniya	Range Forest Officer
Mr. Bomto Gara	LDC
Mr. Sonam Tashi	Driver
Mr. Namgey Koncho	Driver
Mr. Lungtan Phuntso	Cook /field asstt
Mr. Kime Taniyo	Forester
Mr Chow Cholani Munglang	Forester
Mr. Sangey Gombu	Porter
Mr. Kesang Topgey	Porter
Mr. Norbu Tashi	Porter

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