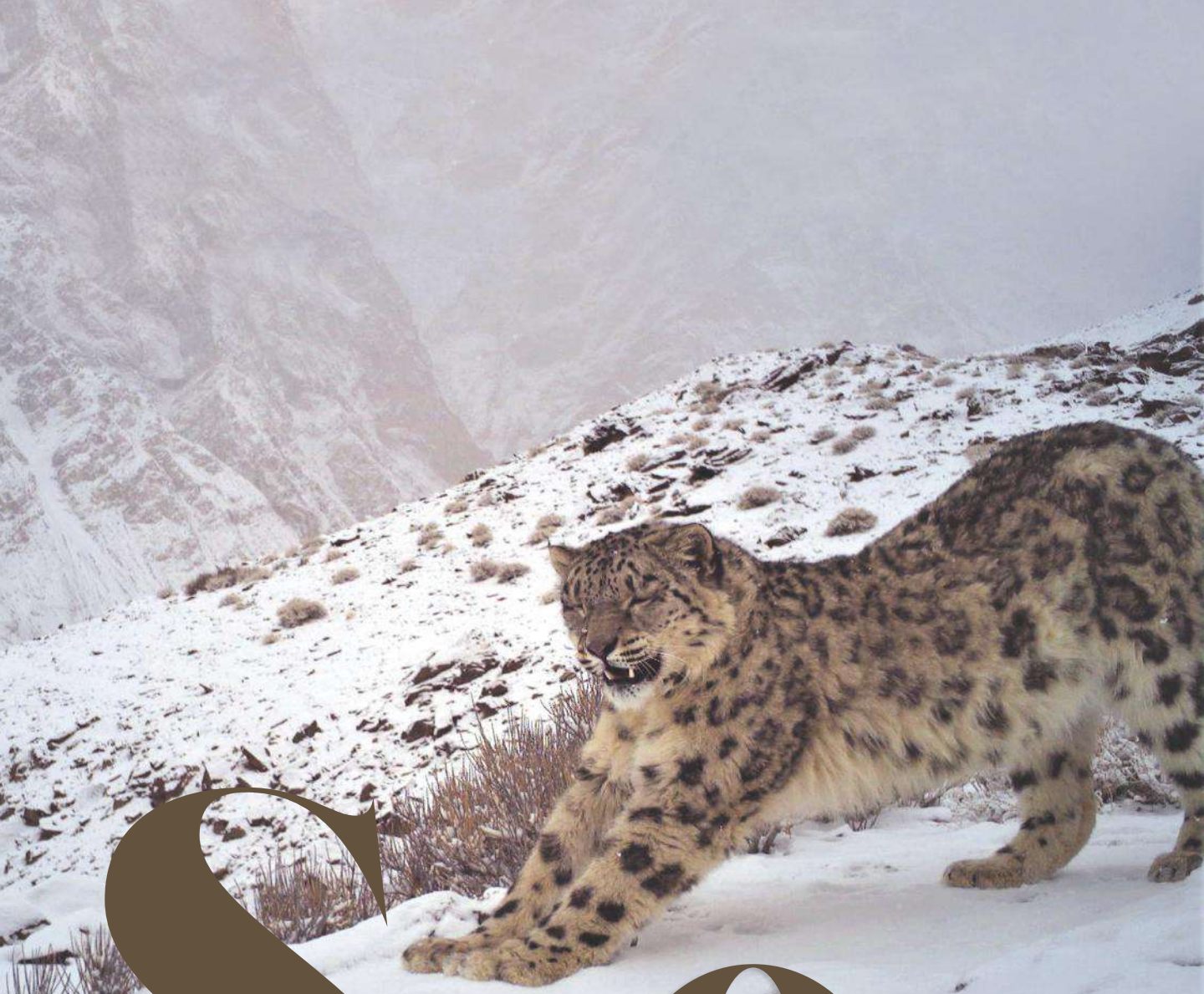
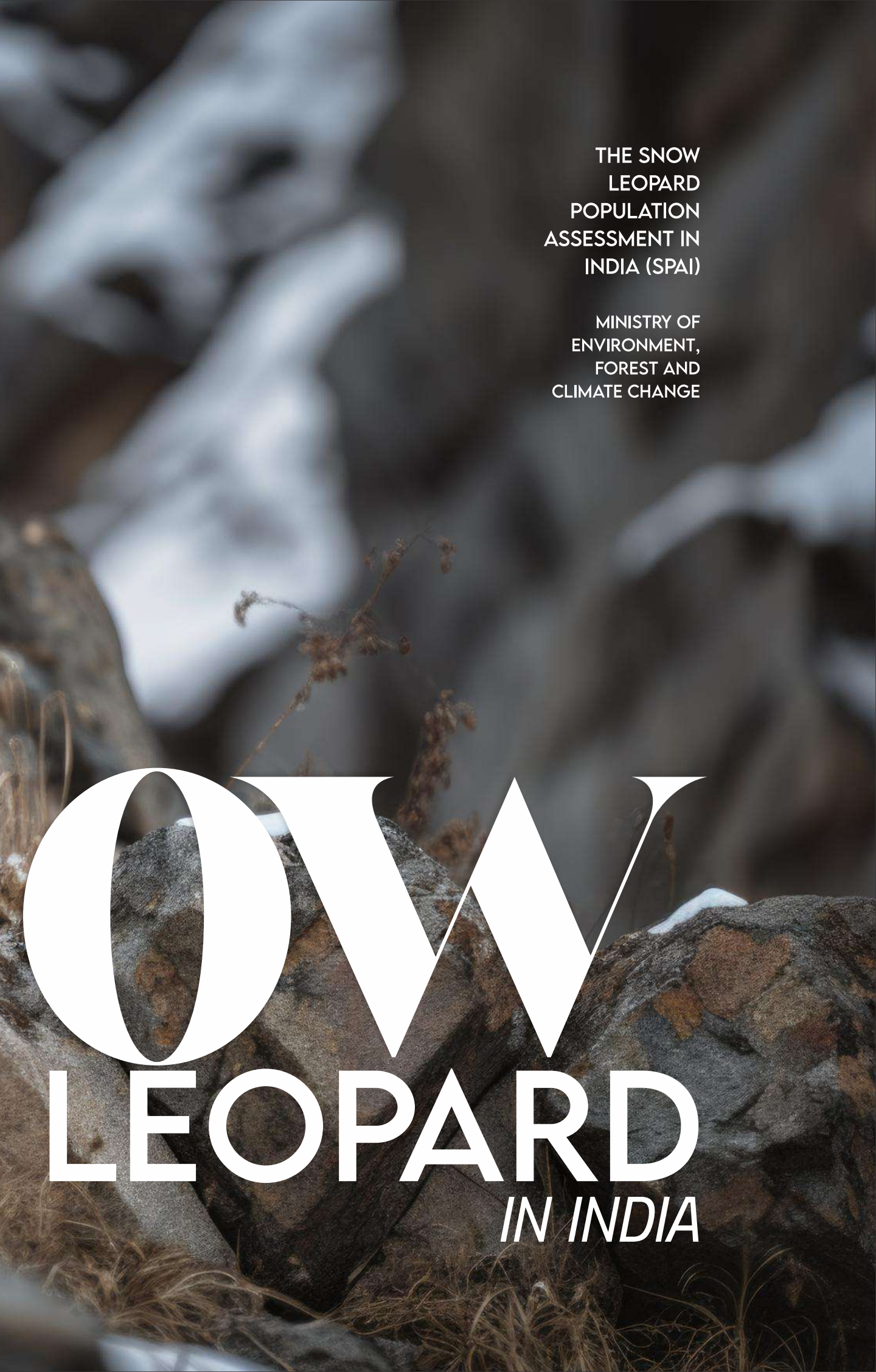


STATUS OF SNOW LEOPARD IN INDIA

2023


STATUS OF



THE SNOW LEOPARD POPULATION ASSESSMENT IN INDIA (SPAI)

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

SNOW LEOPARD

IN INDIA

List of Contributors

Ministry of Environment, Forest and Climate Change, Government of India

Department of Wildlife Protection, Government of Ladakh

Department of Wildlife Protection, Jammu & Kashmir

Himachal Pradesh Forest Department

Uttarakhand Forest Department

Forest and Environment Department, Sikkim

Arunachal Pradesh Forest Department

Wildlife Institute of India (WII) - National Coordinator & Technical support for Ladakh & Uttarakhand

Shri Virendra Tiwari, Director
Dr. S. Sathyakumar, Scientist G

Nature Conservation Foundation (NCF)-Technical support for Jammu & Kashmir and Himachal Pradesh

Dr. Kulbhushansingh Suryawanshi
Mr. Munib Khaniyari

World Wildlife Fund, India (WWF)-Technical support for Sikkim & Aruncachal Pradesh

Mr. Ravi Singh, Secretory General
Dr. Dipankar Ghose, Director of Wildlife; Habitats Programme
Dr. Rishi Sharma, Leader Snow Leopard Conservation

Dr. Yashveer Bhatnagar, Head IUCN-India (formerly with NCF)

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श्रम एवं रोजगार
भारत सरकार

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
AND
LABOUR & EMPLOYMENT
GOVERNMENT OF INDIA

सत्यमेव जयते

एक कदम स्वच्छता की ओर

आज़ादी का अमृत महोत्सव

भूपेन्द्र यादव
BHUPENDER YADAV

संदेश

भारत की वन्यजीव संरक्षण में दीर्घकालिक सफलता को आधार बनाते हुए, अब हम अपनी प्रतिबद्धता को अद्वितीय हिम तेंदुए की ओर बढ़ा रहे हैं, जो कि एक शीर्ष परभक्षी है। इस प्रतिबद्धता में लगभग 1,20,000 किमी क्षेत्र में फैले महत्वपूर्ण हिम तेंदुए के आवास शामिल हैं, जो कि परा-हिमालयी क्षेत्र में फैला हुआ है। यह आकलन, आने वाले समय में हिमालय में पारिस्थितिकी संतुलन को बनाए रखने और संरक्षण को सुनिश्चित करने की दिशा में एक महत्वपूर्ण कदम है।

स्नो लेपर्ड पॉपुलेशन एस्टिमेशन इन इंडिया (एस.पी.ए.आई.) कार्यक्रम ने भारत में हिम तेंदुए की संख्या का प्रथम एवं संपूर्ण मूल्यांकन किया है। यह मूल्यांकन देश, विशेषकर हिम तेंदुए के विस्तार वाले राज्यों और केंद्र शासित प्रदेशों को वैज्ञानिक ज्ञान और उपकरणों से समृद्ध करेगा, जो इस प्रजाति पर मंडरा रहे ख़तरों को कम करने और इस विशिष्ट और संवेदनशील प्रजाति के संरक्षण के लिए आवश्यक है। इस मूल्यांकन के माध्यम से प्राप्त वैज्ञानिक आंकड़े न केवल हिम तेंदुए और इसकी शिकार से रक्षा में सहायक होंगे, बल्कि इसके आवास की पारिस्थितिकी को भी समझने में भी मददगार होंगे, इसके साथ ही इससे प्राप्त ज्ञान, हिम तेंदुए के आवास वाले क्षेत्रों में रहने वाले लोगों के लिए प्राकृतिक संसाधनों की सुरक्षा और इसका सतत उपयोग भी सुनिश्चित करेंगे।

यह एक महत्वपूर्ण क्षण है जब हम भारत में हिम तेंदुए की संख्या के आकलन की विस्तृत रिपोर्ट का अनावरण कर रहे हैं। इसके लिए मैं पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय, भारतीय वन्यजीव संस्थान, और सभी सहयोगी गैर-सरकारी संगठनों की सराहना करता हूँ जिनके अथक प्रयासों से हमने आज देश में हिम तेंदुए के प्रथम आकलन को साकार किया है। आइए हम साथ मिलकर, यह सुनिश्चित करें कि आने वाली पीढ़ियों के लिए ये अद्भुत जीव हिमालय के शिखरों को सदैव सुशोभित करते रहें।

तारीख : 12.01.2024

(भूपेन्द्र यादव)

पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली-110003, फोन : 011-20819190, 011-20819225, फैक्स: 011-20819299
Paryavaran Bhawan, Jor Bagh Road, New Delhi-110003, Tel.: 011-20819190, 011-20819225, Fax : 011-20819299
ईमेल / E-mail : mefcc@gov.in

आज़ादी का अमृत महोत्सव

अश्विनी कुमार चौबे
Ashwini Kumar Choubey

सत्यमेव जयते

आहारशुद्धौ सत्त्वशुद्धिः

स्वच्छ भारत

एक कदम स्वच्छता की ओर

राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण
भारत सरकार
MINISTER OF STATE
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CONSUMER AFFAIRS, FOOD & PUBLIC DISTRIBUTION
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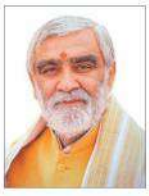


संदेश

भारत में हिम तेंदुए की संख्या का प्रथम एवं संपूर्ण आकलन, वन्यजीवों के संरक्षण के प्रति हमारी प्रतिबद्धता की यात्रा में एक महत्वपूर्ण उपलब्धि को दर्शाता है, इसके साथ ही यह हमें हिमालय के संवेदनशील पारिस्थितिकी तंत्र के दीर्घकालिक अस्तित्व को बनाए रखने की प्रेरणा भी देता है। भारत में हिमालय के उच्च क्षेत्रों में समृद्ध वन्यजीव प्रजातियां पाई जाती हैं, ये अपने विविध और अनूठे संयोजन के लिए जाने जाते हैं। इनमें से कुछ क्षेत्रो को तो वैश्विक जैव विविधता हॉटस्पॉट के रूप में मान्यता भी प्राप्त है। यह विविधता इस मूल्यांकन के महत्व को और भी बढ़ाती है।

इस आकलन के माध्यम से भारत में 57 से अधिक संरक्षित क्षेत्रों की पहचान की गई है, जिनमें हिम तेंदुए के आवास प्रमुख हैं। ये संरक्षित क्षेत्र इस मायावी परभक्षी को एक महत्वपूर्ण आश्रय प्रदान करते हैं। यह आकलन भारत में वन्यजीव संरक्षण के प्रयासों में महत्वपूर्ण घटक सिद्ध होगा। भारत में हिम तेंदुए की संख्या के आकलन के इस रिपोर्ट के अनावरण के साथ ही, हम एक परिवर्तित लक्ष्य को प्रारम्भ कर रहे हैं, जिसमें हम इन अद्वितीय वन्यजीवों के अस्तित्व को न सिर्फ निरंतर बनाए रखेंगे, बल्कि इनके भविष्य को समृद्ध एवं सुरक्षित भी करेंगे।

इस मूल्यांकन से प्राप्त वैज्ञानिक ज्ञान को एकत्र करके, हम न केवल वन्यजीव संरक्षण में वैश्विक नेतृत्व करने की दिशा में एक नया मार्ग स्थापित कर रहे हैं, बल्कि इसके साथ ही हम हिम तेंदुए की दीर्घकालिक संवृद्धि तथा इनके आवास के संरक्षण के साथ-साथ हिमालय के उच्च स्थानों में रहने वाले लोगों की भलाई के लिए भी प्रतिबद्ध हैं। इस प्रयास में परस्पर सहयोग, वैज्ञानिक उत्कृष्टता एवं सतत प्रतिबद्धता की आवश्यकता है, जिससे हिमालय के इस विस्मयकारी जीव के संरक्षण के साथ-साथ इस पारिस्थितिकी में शामिल सभी जीवों की सुरक्षा को सुनिश्चित किया जा सके।

मुझे आशा है कि यह आकलन भविष्य में हिम तेंदुए के संरक्षण एवं संवर्धन के लिए एक महत्वपूर्ण संसाधन सामाग्री के रूप में सहायक सिद्ध होगा।

(अश्विनी कुमार चौबे)

कार्यालय : 5वां तल, आकाश विंग, इंदिरा पर्यावरण भवन, जोर बाग रोड, नई दिल्ली-110003, दूरभाष: 011-20819418, 011-20819421, फैक्स: 011-20819207, ई-मेल : mos.akc@gov.in
Office : 5th Floor, Aakash Wing, Indira Paryavaran Bhawan, Jor Bagh Road, New Delhi-110003, Tel.: 011-20819418, 011-20819421, Fax : 011-20819207, E-mail : mos.akc@gov.in
कार्यालय: कमरा नं.173, कृषि भवन, नई दिल्ली-110001, दूरभाष : 011- 23380630, फैक्स: 011- 23380632
Office : Room No. 173, Krishi Bhawan, New Delhi-110001, Tel. : 011-23380630, Fax : 011-23380632
निवास: 30, डॉ. एपीजे अब्दुल कलाम रोड़, नई दिल्ली-110003, दूरभाष : 011-23794971, 23017049
Residence : 30, Dr. APJ Kalam Road, New Delhi-110003, Tel.: 011-23794971, 23017049

PREFACE

The Snow Leopard Population Estimation in India (SPAI) marks a significant first step in securing the future of these magnificent creatures. By systematically assessing 70% of their potential range, we have taken a major step towards safeguarding these elusive predators. This monumental undertaking, led by scientists, knowledge partners, forest personnel, and researchers, solidifies India's leadership in global wildlife conservation.

Through meticulous implementation of a two-step survey process and alignment with the global "PAWS" (Population Assessment of World's Snow Leopard) Program, SPAI contributes significantly to the global estimate of snow leopard populations, paving the way for more effective conservation strategies.

Beyond revealing their population status and distribution within India, the report also sheds light on the critical threats they face: habitat loss/degradation, poaching and climate change. However, by prioritizing scientific research, international collaboration, and local community engagement, we remain steadfast in our commitment to securing the long-term survival of these iconic predators and their fragile Himalayan ecosystem.

This document serves as a powerful symbol of our unwavering dedication to environmental stewardship and inspires continued hand-in-hand efforts with all stakeholders. The SPAI exercise carried out at regular intervals of time will help us understand trends in population. Let us join together to strengthen India's position as a global leader in conservation and ensure the snow leopard, a flagship species of the Himalaya, thrives long into the future.

Virendra R. Tiwari
Director, Wildlife Institute of India

ACKNOWLEDGEMENTS

We extend our heartfelt gratitude to the Ministry of Environment, Forest, and Climate Change for launching the Snow Leopard Population Assessment in India (SPAI) in 2019. This initiative took shape following consultations of MoEFCC with the Chief Wildlife Wardens of the snow leopard range states and Union Territories and wildlife biologists. We express our sincere appreciation to Shri Bivash Ranjan, ADG (WL) and his predecessors, Shri Soumitra Das Gupta and Dr. S. P. Yadav. We sincerely thank the senior officers of the Wildlife Division, MoEFCC for their invaluable support throughout this exercise. This project was carried out as a collaborative effort by the Department of Wildlife Protection, Ladakh; Department of Wildlife Protection, Jammu & Kashmir; Himachal Pradesh Forest Department; Uttarakhand Forest Department; Forest and Environment Department, Sikkim; Arunachal Pradesh Forest Department; the Wildlife Institute of India; NCF and WWF-India. We extend our gratitude to all the PCCF (WL) and Senior officials of the aforementioned UTs and states for their crucial support and cooperation during the exercise.

We acknowledge the guidance and support of Shri Virendra Tiwari, Director, WII and his predecessors, Dr. S.P. Yadav and Dr. Dhananjai Mohan throughout the various stages of implementation of SPAI and report compilation process. We acknowledge the funding support by MoEFCC to the Snow Leopard range States/UTs and to WII Pan-India IDWH project Snow Leopard component. The tireless efforts of CCFs, CFs, DFOs, ACFs, FROs, Foresters, Forest guards, and other forest department personnel, as well as researchers from WII, NCF, WWF and their collaborating partners, were essential in accomplishing the task of SPAI. Lastly, we extend our appreciation to the Indian Army, Indo Tibetan Border Police, Border Security Force, PWD, and the local community for their support during the surveys, without which this work would not have been possible.

S. Sathyakumar
Scientist-G
Wildlife Institute of India

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 is anticipated to lead to 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 UTs the SPAI sampling exercise was effectively executed across the Union Territories of Ladakh and J & K, 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.

This multifaceted approach contributed to a comprehensive understanding of snow leopard populations in these critical regions. 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.

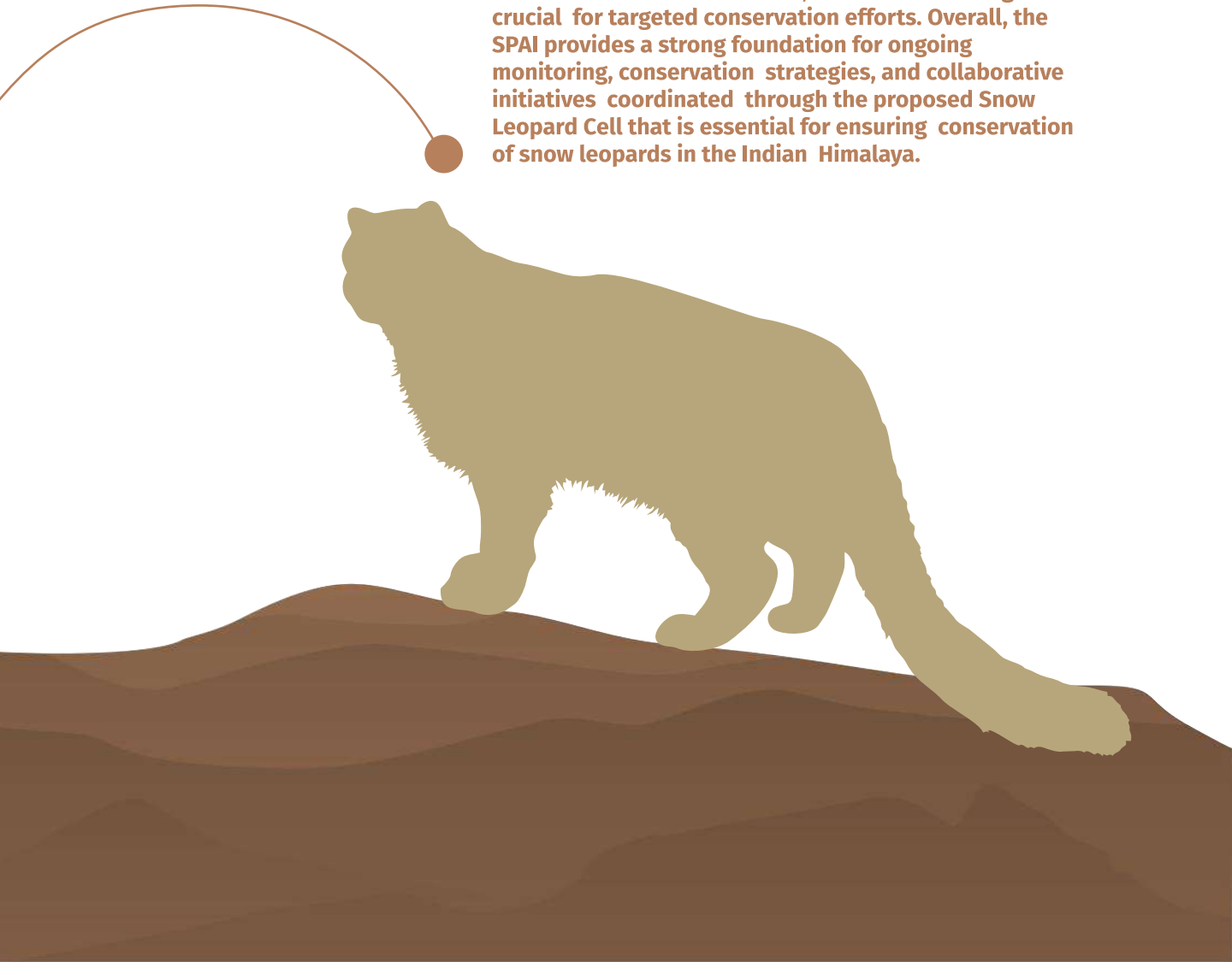
Snow leopard range was undefined until recent years due to lack of extensive country wide assessment for this vulnerable felid species. Till 2016, a substantial third of the snow leopard range (spanning ca. 100,347 km^2) had not received research attention, which was reduced to just 5%, mainly in small 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 1971 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, underscoring the significance of this exercise for long term conservation of snow leopard in the country.

Overall, 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. The Union Territory of Jammu & Kashmir, on the other hand led to detection of 9 unique individuals across the snow leopard range in this UT with 135 camera trap locations. The estimated density was 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 summary, the SPAI excercise has led to the first ever rigorous examination of snow leopard populations in India, employing advanced methods such as occupancy modeling and camera trapping. The findings not only contribute significantly to our understanding of snow leopard ecology but also emphasize the ecological importance of the high-altitude environments they inhabit. The state/UT-level assessments, spanning from Ladakh to Arunachal Pradesh, offer valuable insights crucial for targeted conservation efforts. Overall, the SPAI provides a strong foundation for ongoing monitoring, conservation strategies, and collaborative initiatives coordinated through the proposed Snow Leopard Cell that is essential for ensuring conservation of snow leopards in the Indian Himalaya.



INTRODUCTION
01

Precise enumeration of the vulnerable snow leopard (*Panthera uncia*) 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). Accurate 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 snow leopard, besides its ecological significance, holds cultural and economic importance, embodying a symbolic representation for local communities (Chetri et al., 2017). 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 (McCarthy et al., 2017). The resultant dataset not only contributes to the preservation of the snow leopard but also fosters a comprehensive understanding of the intricate ecological dynamics characterizing its habitat (Alexander et al., 2016).

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 demographic dynamics of the snow leopard, holding considerable cultural, ecological, and economic significance within the region.

The geographic distribution of the snow leopard across Himalaya encompasses the union territories of Ladakh, and Jammu and Kashmir besides the states of Himachal Pradesh and Uttarakhand in the western Himalayan region, and Sikkim and Arunachal Pradesh in the eastern Himalayan regions. 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.

The snow leopard, designated as Vulnerable by the International Union for Conservation of Nature (IUCN), confronts multifaceted threats, including overgrazing, human-wildlife conflicts, poaching, free-ranging dogs, and habitat degradation due to tourism and infrastructural development. The imperative for a systematic assessment of the snow leopard population stems from the exigency to address critical knowledge gaps and formulate evidence-based conservation strategies for this elusive and enigmatic species. To safeguard and conserve India's unique natural heritage of high altitude wildlife populations and habitats, the MoEF&CC launched Project Snow Leopard (PSL) in 2009. The project aimed to promote conservation through the implementation of participatory policies and actions.

Snow Leopard Population Assessment in India (SPAI) program

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.

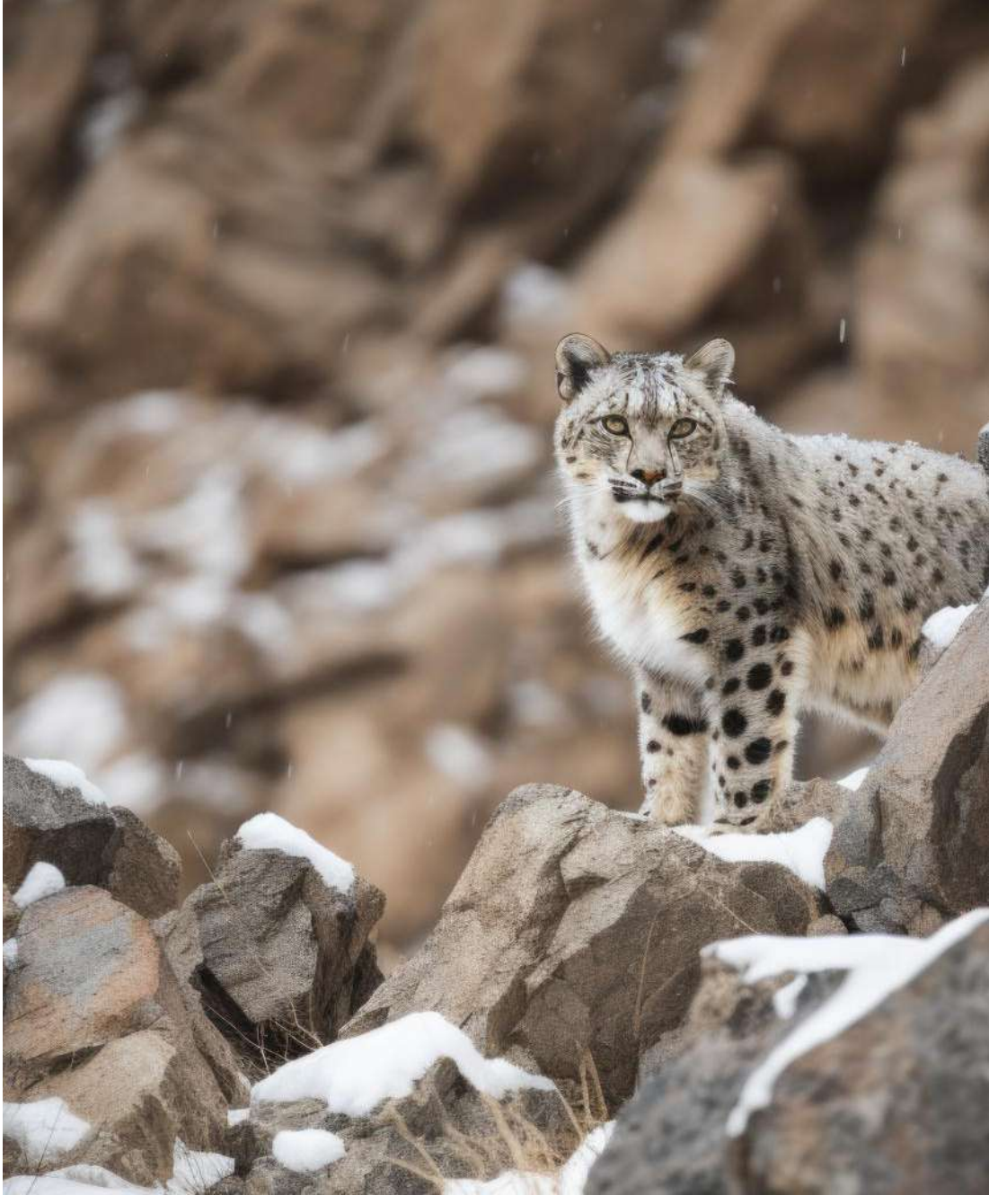
Given the methodological intricacies associated with precisely estimating snow leopard populations owing to their cryptic behavior and the expansive, rugged nature of their habitats, the imperative for standardized methodologies becomes paramount. WII along with NCF and WWF, has meticulously formulated guidelines to ensure methodological consistency (MoEFCC, 2019). This inclusive approach entails active participation from the forest departments of all snow leopard range states and UTs, with technical support from national conservation partners. The outcomes of this collaborative scientific undertaking will serve as a pivotal

Status of Knowledge on 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 (Ghoshal et al., 2019; Maheshwari et al., 2013; 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 meters in the Greater Himalaya around 2700 meters (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) (Fig. 1). Snow leopards primarily prey on Asiatic ibex (Capra sibirica) and Blue sheep (Pseudois nayaur), with their diet also encompassing various other species of wild sheep, goats, deer, and smaller prey (Schaller, 1977; Lyngdoh et al., 2014).

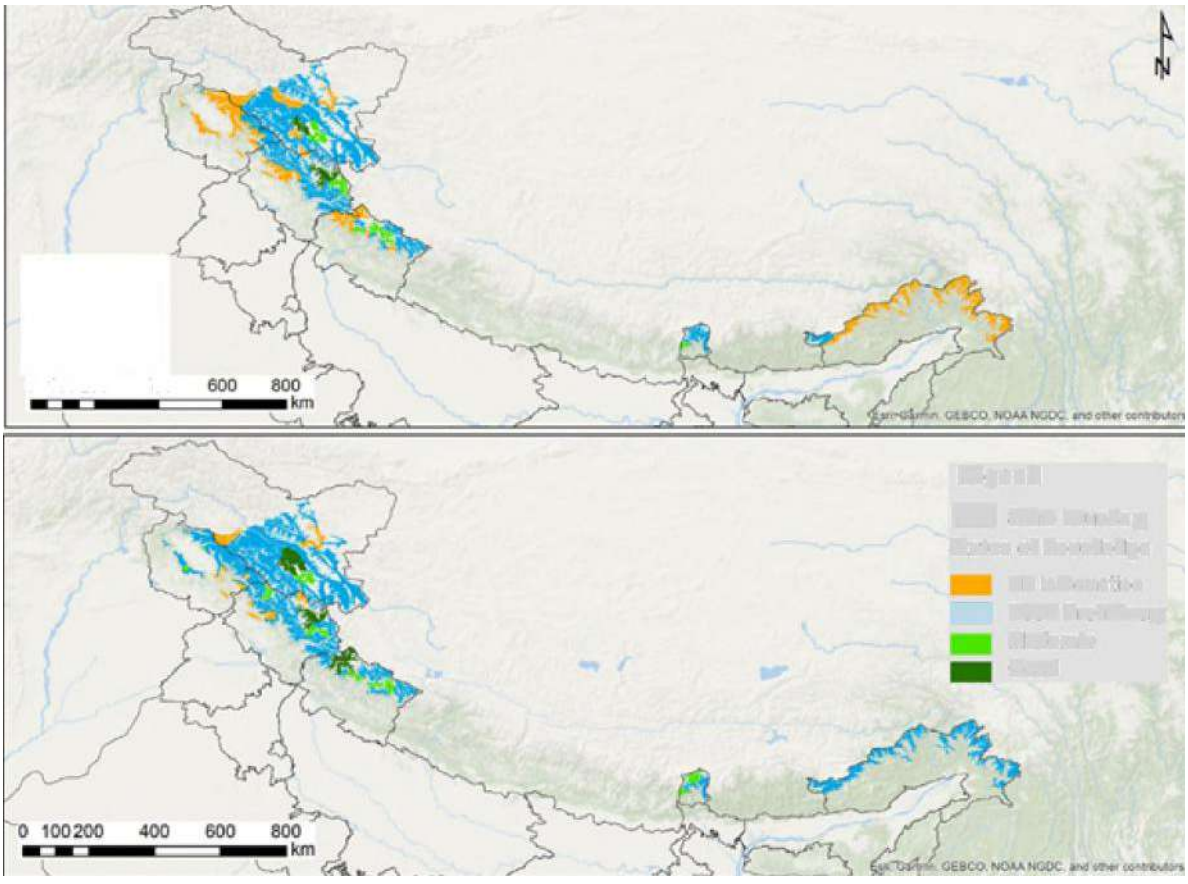


Fig. 1. Potential snow leopard range in India (3200-5200m) showing the information gaps. Status of knowledge on snow leopard and prey species in India in 2021 (bottom) and 2016 (top), as assessed by attributing values to 311 tertiary catchments within snow leopard range ranked as good (3), moderate (2), 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).

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 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. There was an urgent need to make a revised estimate of snow leopard abundance using improved methodology, especially since reliable density estimates are now available. This resulted in the current SPAI exercise, the detailed protocol for which has been described in detail.

STATUS OF
Snow LEOPARD
IN INDIA

METHODS

02

2.1

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 (Myers et al., 2000; Olson and Dinerstein, 1998). 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 meters, these nonforested tracts are the preferred domains for snow leopards (Chundawat, 1992; Fox et al., 1991). The ramifications of the snow leopard's presence extend beyond its immediate habitat. 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.

2.2

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 MoEFCC 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 leopards and stratify potential snow leopard habitats. In the second step, the abundance of snow leopards 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 distribution

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 in the form of 448 questionnaires from 42 (15x15 km) grids.

Key informants (tour guides, porters, herders, 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 the species from the images and

were unable to provide reliable information on location of species detection, were excluded from the analyses.

Information received for 15x15 grids from each division was compiled into excel sheets. The occurrence information gathered from questionnaire surveys were 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 modeled 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).

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.

Spatial capture recapture

The resulting spatial encounter history data were analyzed 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. In case of Ladakh, the individuals were identified using the program CaTRAT that uses artificial intelligence and machine learning approaches. It was subsequently checked by multiple biologists and personnel. 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.

Individuals which 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, individuals for captured on both sides, that is, right and left flank and individuals with one side flank for whom maximum captures were recorded, were used (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. Matrix of individual capture histories, camera trap operation (effort) and camera trap locations were prepared for the SCR analysis. Cubs captured with their mother were not included in the analysis.

Prey Estimation

For estimating the prey, Camera Trap Distance Sampling (CTDS) and doubleo observer survey methodology was used. To obtain the prey species estimates selectively in the specific regions, the double-observer survey methodology was used to divide each survey site into smaller blocks for manageability. During the survey, three key assumptions were considered: complete visual block coverage, operation by two independent teams, and ungulate group identification based on factors like herd composition and location. This approach draws from mark-recapture theory, focusing on recognizing temporary groupings of individual mountain ungulates using characteristics like size and composition. In this technique, the marked and recaptured unit is the individual ungulate group. Estimation of wild prey per site employed a Bayesian framework with the 'BBRecapture' package in the R statistical and programming environment.

For future surveys, it is advisable to consider the utilization of advanced methods like Camera Trap Distance Sampling (CTDS) and Random Encounter Models (REM) to estimate the spatial densities of prey species across extensive landscapes within the snow leopard habitat. These innovative techniques can provide valuable insights into not only the snow leopard populations but also their prey base, contributing to a more comprehensive understanding of the ecological dynamics in the region. Incorporating prey species estimation in the next survey will enable a holistic assessment of the landscape and support more informed conservation strategies for snow leopards.

To account for the fact that snow leopards are unlikely have circular space-use patterns, the ecological distance SCR model was used, that allows for non euclidean distance estimation (Sutherland et al. 2015). Using this least cost path approach enables estimation of one or more resistance parameters that quantitate how movement is

influenced by local landscape structure (Sutherland et al., 2019). Because sex is a partially observed individual attribute, the data was analyzed using the class-structured likelihood that allows for missing sex information (Royle et al. 2015). The state space was defined (the area within which detectable snow leopard activity centers 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 centers 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, >5300m), that is, that have a negligible probability of containing snow leopard activity centers, were excluded from the state space.

The data was analyzed in multi session framework which allows combining data from several sessions and enables the fitting of models with parameters values that apply across sessions. The camera trapping data from all the areas were arranged in three sessions based on sampling period. For understanding the influence of terrain on snow leopard movement, layers of mean slope and ruggedness were generated. The effect of both euclidean and ecological distance models on snow leopard movement was tested, and the best model was used to fit the rest of the parameters: density (D), detection (p) and space use (a). Negligible temporal variation in detectability within each session was assumed and all encounters were collapsed into a single count. Density was modeled and tested 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 effect of sex, and camera trapping effort. Space use was modeled for sex and session. Models were selected 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 centers per state space pixel, Morin et al. 2017).

RESULTS
03

3.1

Snow leopard population estimation 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 and genetic analysis. Furthermore, comprehensive abundance assessments have been conducted for the primary prey species at selected sites. This multifaceted approach contributes to an in-depth understanding of snow leopard populations in these critical regions.

Overall, the assessment examined snow leopard populations in India using a substantial network of camera traps. In total, the SPAI sampling exercise involved 1971 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).

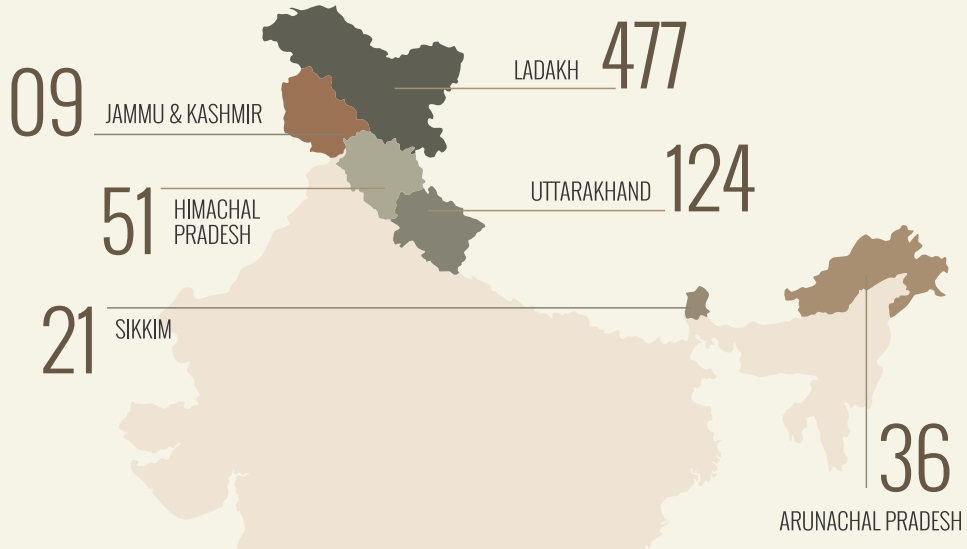


Fig. 2. Snow leopard estimates for each state and union territory. The results indicate the highest estimates form Ladakh (477) followed by Uttarakhand (124) and Himachal Pradesh (51).

Table 1. Snow leopard population estimates in two Union Territories (Ladakh and J&K) 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 in this UT 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).

3.2

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 leopards in the Union Territory of Ladakh was calculated to be 477 (± 51) individuals, with an estimated density of 0.34 individuals/100 km^2, Notably, Ladakh and the Spiti region of Himachal Pradesh offer expansive and contiguous habitats, coupled with high prey population densities, creating favorable conditions for the snow leopard population.

Habitat suitability for snow leopards is observed to be at its peak in western Ladakh, gradually diminishing towards the Eastern part of the landscape. This trend can be attributed to the presence of elevations higher than the optimal range and terrain ruggedness lower than the optimum in eastern Ladakh. The relatively weak influence of prey density on snow leopard habitat suitability arises from a trade-off between physical habitat features such as elevation and ruggedness, and the availability of prey. These findings provide valuable insights into the habitat preferences and distribution of snow leopards in the region. 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.

3.3

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 SECR method in the current sampling effort, the likely snow leopard population size was estimated to be between 7 to 14 individuals. However, it's noteworthy that four individuals were excluded from the analysis due to poor image quality and unfavorable capture angles. Nonetheless, it's 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 and Kashmir.

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% CIs: 0.18-0.72), 0.36 (95% CIs: 0.18-0.73), and 0.3 (95% CIs: 0.15 - 0.59) snow leopards/100 km^2, respectively. Conversely, Bhaga from the low stratum recorded the lowest density of 0.05 (95% CIs: 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% CIs: 0.21 - 0.42) snow leopards/100 km^2, while the low occupancy stratum displayed a lower density of 0.08 (95%CIs: 0.05 -0.12). Additionally, the previously unsampled stratum reported a density of 0.08 (95% CIs: 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.

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 "UKFD – WII (2023). Snow leopard population assessment of India- Uttarakhand State, Survey Report", Uttarakhand Forest Department and Wildlife Institute of India, Dehradun.

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 leopards 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 "Status of Snow Leopard in Sikkim", Sikkim Forest Department and WWF- India.

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.

THE WAY FORWARD

04

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.

Projects like Project Snow Leopard (PSL) and GSLEP have been instrumental in this shift, collectively covering close to half of India's snow leopard range. This represents a noteworthy transition from the exclusive focus on protected areas to collaborative landscape management over the past decade.

As part of the PAWS initiative, the 'Snow Leopard Population Assessment in India (SPAI)' program initiated by the MoEFCC and developed in collaboration with state forest/wildlife departments, WII, NCF, and WWF-India, aims to provide precise population estimates and guide conservation efforts. Yet, consistent monitoring is essential to ensuring snow leopards' long-term survival. For the same, states and UTs can consider adopting a periodic population estimation approach (every 4^{th} year) in the snow leopard range as like the AITE. These regular assessments will offer valuable insights for identifying challenges, addressing threats, and formulating effective conservation strategies.

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, developmental agencies, the military, and other stakeholders. Programs such as GSLEP, PSL and PAWS will play a crucial role in this regard.

Given that a significant portion of snow leopard habitat borders neighbouring countries such as Pakistan, Nepal, Bhutan, and China, and is patrolled by Indian security forces, these border forces become vital stakeholders. 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.

Limitation and Constrains

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.

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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. WII, in conjunction with NCF and WWF, has meticulously formulated guidelines to ensure methodological consistency (MoEFCC, 2019). This inclusive approach entails active participation from the forest/wildlife departments of all snow leopard range states and UTs, with technical support from national conservation partners. The outcomes of this collaborative scientific undertaking will serve as a pivotal contribution toward addressing the existing knowledge and advancing evidence-based conservation strategies for the snow leopard in India.