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Snow Leopard Reports encourages exchange amongst snow leopard practitioners and researchers. The journal aims to collate and make available the latest information on snow leopard biology and conservation through contributions that capture the ecological and conservation status of the species and its wider habitat.

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SLR Logo: illustrated by Boqiao Liang

Cover Photo: (*top*) Radio-tracking VHF collared snow leopards proved to be extremely challenging, requiring team members to seek high vantage points for obtaining bearings for triangulation. It frequently took all-day for the one or two teams to obtain single one or a few locations. Moving around this rugged terrain was very demanding and time-consuming.
(*below*) image of a female and her two dependent cubs from the first camera trap study conducted in Hemis National Park, India (Jackson et al. 2006, Wildlife Society Bulletin 34(3):772–781).

Photos Credit: © Rodney Jackson

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Editorial

Snow Leopard Reports: On scaling up from research to conservation action

I WRITE this forward to this issue of Snow Leopard Reports from a personal perspective encompassing 40 plus years dedicated to snow leopard research and conservation. When I started field work in 1976, the snow leopard had just been listed as "Endangered" with very little known about its distribution, ecology or natural history. In fact, the existing scientific knowledge literally covered the space of a postage stamp! But soon the snow leopard catapulted into public attention with Peter Matthiessen's award-winning book *The Snow Leopard* and biologist George B. Schaller's remarkable National Geographic photograph of a female staring intently from a cliff ledge in Pakistan. George's photo and field reports in the New York Zoological Society's (now WCS, the Wildlife Conservation Society) magazine captured my attention, and provided impetus to visit Nepal's Himalayan mountains before returning to Africa, my birthplace, where I hoped to study the common leopard.

I spent two months in mid-winter in the Langu Valley, a very remote part of Western Nepal, never seeing a snow leopard but frequently encountering its sign, while also documenting the local people's annual winter hunts for blue sheep and musk deer. A sizable portion of their annual cash income accrued from selling the male musk deer's pod or scent gland to middlemen—by weight valued more than gold. In 1979 I published my observations in Biological Conservation entitled, "Aboriginal hunting in West Nepal with reference to musk deer (*Moschus moschiferus moschiferus*) and snow leopard (*Panthera uncia*)."

After encountering the skinned carcass of a snow leopard that the village poacher hoped would bring several hundred dollars, I realized this valley offered a good study site for mounting research on this rare and elusive cat. But the challenge of securing research funding for live-trapping and collaring a few cats presented an enormous obstacle, especially as Dr. Schaller's efforts to trap and collar a snow leopard in Pakistan failed. In his words, "almost perversely the cats eluded my repeated efforts study them". In 1981 with extraordinary luck, clearly coupled with a sound understanding of the challenges and workable solutions from my recent visit to the Langu, I was awarded the prestigious Rolex Award for Enterprise. This award brought much-needed seed funding, and my good fortune continued when the King of Nepal and the country's newly established wildlife department officially authorized the project, which required a minimum 12-day walk to access prime snow leopard habitat, carrying all food, camping gear and scientific live-trapping and tracking equipment. Over the next four years, with a small Nepalese team and associate Gary Alhborn, we radio-tagged five snow leopards (3 males; 2 females), gathering the first baseline information on this species' movements, activity patterns, habitat use, home range metrics and social interactions without benefit of GPS, Google Earth or mobile phones – summarized in my doctoral thesis from the University of London and 1986 National Geographic Magazine cover story. Our effort remained seminal research for almost 20 years, until the advent of satellite transmitters and a growing cadre of national and international biologists drawing on new techniques.

I spent the next 10-15 years collaborating with range-country and international biologists and rangers conducting status surveys across snow leopard range, in tandem with training and refining census techniques. Other projects included the first camera trap surveys in Ladakh, India, and piloting non-invasive snow leopard genetics in Nepal, Mongolia and China.

In 2012, the Global Snow Leopard Protection Plan (GSLEP) was ratified with wide support from the private sector, The World Bank and other multi-lateral agencies and all 12 range country governments. This initiative expressed concern for high elevation snow leopard landscapes which form headwaters of 20 major river basins and provide important water sources for 22 countries with an estimated 2 billion people living in low-elevation downstream basins. The snow leopard range also provides vital habitat for a small and sparsely distributed population of semi-agriculturalists and pastoral herders, about 40% of whom live below national poverty levels. These mountain landscapes house an array of unique high-altitude wildlife and offer other life-sustaining natural resources to local and downslope human settlements.

A 2021 report by World Wildlife Fund (WWF) on the state of knowledge covering a century of snow leopard research highlighted the rapid progress in information made as global interest and commitment toward protecting this unique high-mountain feline grew. The authors reviewed over 100 years of published research on snow leopards, especially early efforts mobilized in the 1970s and 1990's, and increasing exponentially since. They reported that most work was associated with four hotspots experiencing multi-year research, covering about 23% of snow leopard range. Nepal, India and China represented the most activity, followed by Mongolia and Pakistan. The majority of ecological studies focused on estimating the number and distribution of snow leopards and prey species, though the WWF team reported less than 3% of the total range

Radio-tracking VHF collared snow leopards proved to be extremely challenging, requiring team members to seek high vantage points for obtaining bearings for triangulation. It frequently took all-day for the one or two teams to obtain single one or a few locations. Moving around this rugged terrain was very demanding and time-consuming. (Photo credit: Rodney Jackson)

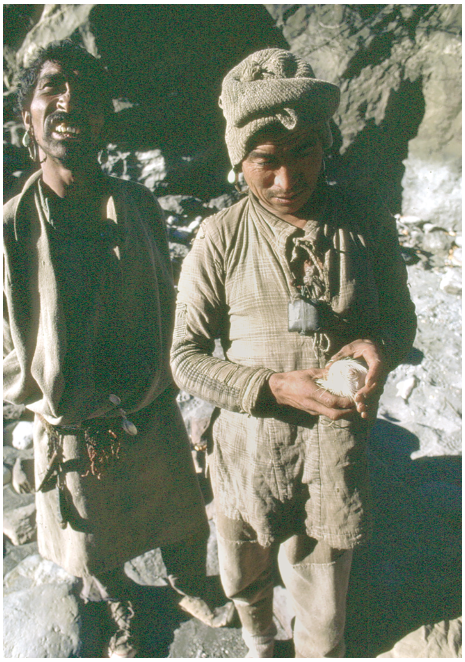
In this 1980's pioneering study we set two camera traps for a total of 561 nights, but obtained only three snow leopard images – all, including the cover image, were published in the National Geographic story. Luckily all cats were facing the camera! See page 797 of the June 9186 magazine for set-up information on this first snow leopard camera trap. (Photo credit: Rodney Jackson © National Geographic Society 1986) had been sampled using rigorous and scientifically acceptable abundance estimation approaches – testament to the sheer difficulty of research on this elusive species. The report found the lack of attention to human and especially socio-economic dimensions of conservation to be particularly stark.

In 2016, the IUCN Red List reclassified the snow leopard global endangerment level from "Endangered" to "Vulnerable" (one notch lower in threat level), while recognizing the need for intensifying monitoring and protection efforts. There was considerable pushback from some countries and sectors of the global conservation community claiming the numbers did not warrant such a conclusion. Others, citing increased visual sightings (including females with offspring) along with ever-increasing reports of attacks on livestock, suggesting the species rarity may have been overstated.

Since the re-listing substantial funding and research have gone into status surveys through the GSLEP-driven PAWS initiative (*Population Assessment of the World's Snow Leopards*). PAWS strives for robust answers to the question of "how many snow leopards remain in the wild?". In reality, this goal continues to remain elusive. Generating robust spatially extensive population estimates using camera trapping techniques has proven exceptionally difficult. Challenges include placing, maintaining and monitoring traps in remote, rugged areas. Also, resolving errors related to individual identification requires rigorous matching of each "capture" in order to reconcile bilateral pelage spotting and rosette pattern differences (as unique as human fingerprints). It is becoming apparent that not all age and gender classes have equal trapping probability, despite both male and female snow leopards depositing often abundant sign from scent-marking and defecations in prominent, mostly predictable places. Basically due to political reasons the use of non-invasive genotyping sampling remains significantly under-exploited. Many geneticists view scat and hair collection and genotyping as potentially more informative, provided they are imbedded in repeated monitoring visits that account for aging of sign such as scats and scrapes.

Meantime, efforts to document and address human-wildlife conflict are now incorporating more stakeholder participation that include shared decision-making. However, fiscal investment in predator-proofing night-time livestock corrals lags significantly in proportion to continued emphasis on status, habitat and ecological assessments. To be truly effective, snow leopard conservation urgently merits more emphasis on incentives and behavioral change to bring about on-the-ground community-driven mitigative measures. The good news is that social scientists are increasingly involved in engaging communities for locally-adapted solutions. After all, how much longer can the scientific and conservation community defer remedial actions to reduce livestock losses, while continuing to depend upon willing cooperation and goodwill of local people to not kill predators? I fear we may lose their trust by not improving existing

Photos of poaching from my 1976 field visit



Village hunters displaying a musk gland or "pod" from a male musk deer killed using poisoned spears they placed in the forests of the upper Langu Valley, Nepal (Photo credit: ©Rodney Jackson)

Poisoned bamboo spears placed along wildlife trails and used in impale and kill wildlife like the musk deer, blue sheep and snow leopard (Photo credit: Rodney Jackson © National Geographic Society 1986)

Village hunter showing a snow leopard for sale in 1976 for less than $30. This cat was also killed using the same technique. (Photo credit: Rodney Jackson © National Geographic Society 1986)

Carcass of this snow leopard, left at the trap site in the Langu gorge to attract other predators. The hunter who set the traps stands in the background. (Photo credit: Rodney Jackson © National Geographic Society 1986)

compensation schemes that ensure they are both workable and equitable. At the same time, greater emphasis must be placed on mobilizing traditional knowledge to problem solving, including the ability for communities to reliably monitor fraudulent or socially biased claims for compensation. Shafqat Hussain's, *The Snow Leopard and the Goat*, covers the politics of conservation from the herders' perspectives.

To date, too few practitioners have attempted to evaluate the impacts and effectiveness of different conservation interventions, which remains a notable and significant evidence-based knowledge gap. Hopefully, university students and researchers, with support from NGOs will step forward to provide this much needed service, and incrementally expand to our knowledge base on effective conservation planning for snow leopards and the sustainable management of the multiple uses of land shared with humans, especially in light of the impending threat from climate change. We also need more concerted effort and progress toward blending traditional knowledge with western scientific approaches. A deeper understanding is needed for these different approaches to nature, indeed the protection of all lifeforms from different cultural value systems.

Most studies to date have focused only on economic incentives. While certainly essential, recognition of cultural values and perceived social obligations traditional people have to the environment should not be ignored. The Land of the Snow Leopard (LOSL) was formed in 2013 to enable Indigenous Peoples to reverse threats facing the snow leopard and its ecosystems, as well as cultural continuity in peoples' own communities. Across Central Asia, communities of Indigenous Peoples relate to the snow leopard as the cosmic axis of ancient traditions—protector of sacred mountains, unifying force, and source of spiritual power and wisdom; it is also an important indicator of ecological health of mountain landscapes and cultural integrity of their communities. The LOSL network brings together 100 + members with strong local institutional capacity and deep commitment to their intrinsic responsibility for guardianship of Mother Earth. LOSL enabled direct involvement of Indigenous Cultural Practitioners (ICPs) in high level planning for Snow Leopard Survival. The term "ICP" includes shamans, sacred site guardians, respected leaders of regional faiths, and revered Elders.

That said, I am extremely impressed by the exponential increase in numbers and the breadth of local professionals dedicated to furthering our knowledge and understanding snow leopards and their ecosystems. This is clearly demonstrated in the current edition of *Snow Leopard Reports*, with articles ranging from an unusual low elevation sighting in Nepal to scat genotyping in Kyrgyzstan and eco-education in Mongolia. Ground-breaking research and conservation endeavors spring from deeply passionate and dedicated individuals that readily give up comforts to endure the hardships of field research. The snow leopard truly benefits from a broad representation of such pioneers, some of whom shared their special connection in the book, *Snow Leopard: Stories from the Roof of the World*, edited by Don Hunter. Mentoring the next generation of snow leopard conservationists has been especially satisfying for me: I know that individuals like Ms. Tshiring Lhamo Lamu from Dolpo and Mr. Rinzin Phuntsog Lama of Humla, Nepal will have a substantial role toward empowering local people and their communities to become the snow leopards' strongest advocates and stewards for restoring its fragile mountain ecosystem. In 2022, Rinzin was the second person to be honored with the Rolex Award for Enterprise in recognition of his commitment toward protecting the iconic snow leopard.

I have great hope that 2025 will bring many more contributions to *Snow Leopard Reports*, and to that end wish its readers every success with their effort to ensure snow leopards will not only survive but thrive for all time.

Thank-you,
Rodney Jackson

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Research Note

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Harnessing Drones for Snow Leopard Prey Surveys

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Abstract

Surveying snow leopard prey species such as argali, ibex or blue sheep through traditional ground-based observations is time-consuming, expensive, and challenging. Aerial drones present a promising alternative. We tested using thermal-sensor-equipped drones to count ungulate populations in Mongolia's Ikh Nart Nature Reserve, surveying ~400km of transects along five fixed routes for forty-three missions. Drones detected 235 prey animals and 209 livestock; 26% of all sightings were in areas that would not have been visible to hypothetical ground-based observers. Our tests reinforced the utility of drones for counting snow leopard prey and highlighted important issues and future advances for supporting largely autonomous prey surveys. We recommend biologists build upon existing technology to attain an inexpensive, easy to use,

and field ready set of equipment and procedures that can reliably improve or replace traditional transect or point count methods for large prey species.

Introduction

Unmanned aerial vehicles (UAVs) or drones are being increasingly employed in wildlife surveys (Corcoran et al. 2020; Mo and Bonatakis, 2022; Wirsing et al. 2022; Elmore et al. 2023). To our knowledge no papers have been published on drone use for counting snow leopard (*Panthera uncia*) prey numbers: rather, these prey are surveyed by humans on foot using traditional transect or fixed observation count methods (Suryawanshi et al. 2012; Thapa et al. 2021). Mongolia's Ikh Nart Nature Reserve staff conduct argali (*Ovis ammon*) and ibex (*Capra sibirica*) counts annually in late summer in predefined 8km^2 survey blocks by walking along 4km transects and tallying sightings within 1km on either side (Wingard et al. 2011). Distance sampling is used to fit empirical "sightability" curves to help account for imperfect detection in subsequent population estimates (Buckland et al. 2001) and double observer techniques further help quantify detectability (Suryawanshi et al. 2012).

Our study originally aimed at assessing aerial counts from drones flown at the same time of year as Ikh Nart's annual surveys. We predicted that an aerial vehicle, moving faster and looking forward/downward from a consistent height would have significantly less obstructed views, and would therefore detect ungulates missed by ground based observers. Even in level terrain, scattered shrubs, rocky outcrops and drainages conceal animals from ground-based observers. However, a drone flying at 60-100m above the ground benefits from unobscured views of the landscape. The drone's ability to detect cryptic ungulates is further enhanced through deploying onboard thermal sensors (Burke et al. 2018).

In this paper, we offer preliminary findings and recommendations for using thermal-equipped drones to enhance surveys of snow leopard ungulate prey.

Methods

The study was conducted in Mongolia's Ikh Nart Nature Reserve (Wingard et al. 2011; Wingard et al. 2023). We deployed three quadcopters: Matrice 210, newer M30T (©SZ DJI Technology Co., Ltd., Shenzhen, China), and the Autel Evo II 640T (©Autel Robotics, Bothell, WA), each fitted with 640 x 512 30Hz thermal sensors. Flights were conducted August 22 –September 4, 2019, and August 23 – September 2, 2022, immediately prior to the annual ground-based counts.

We chose five representative survey block transects from the Reserve's ten long-term argali and ibex monitoring survey design. In each block, we established two fixed rectangular transect routes, one on either side of the block's centerline, notated as North and South survey sectors (Figures 1 and 2). Each 9-11km transect route comprised an outward 4 km leg, a sharp 90° turn with short 0.75-1.25km leg, ending with 4km homebound leg and was delineated by 4 fixed GPS waypoints. Each sector was flown in quick sequence between batter changes.

We followed standard flight routines (e.g., Hodgson et al. 2016), flying at elevations of 60-75m above take-off location with fixed speeds of 15m/sec (M30T) and 10m/sec (Autel, manufacturer's set maximum). Sensor gimbals were set at -22° below horizon,

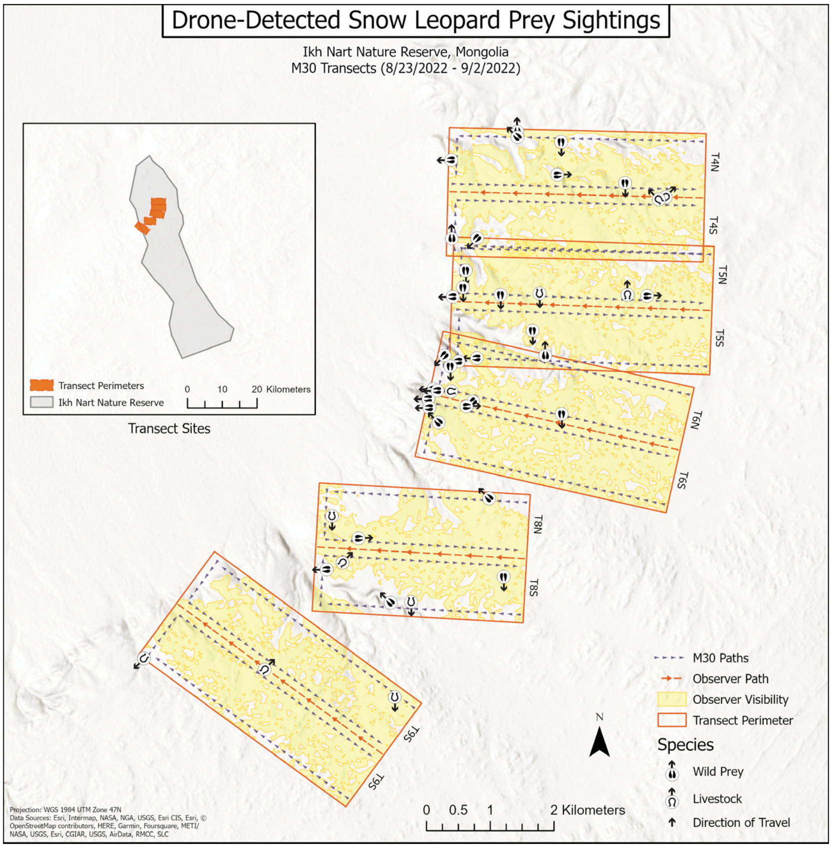
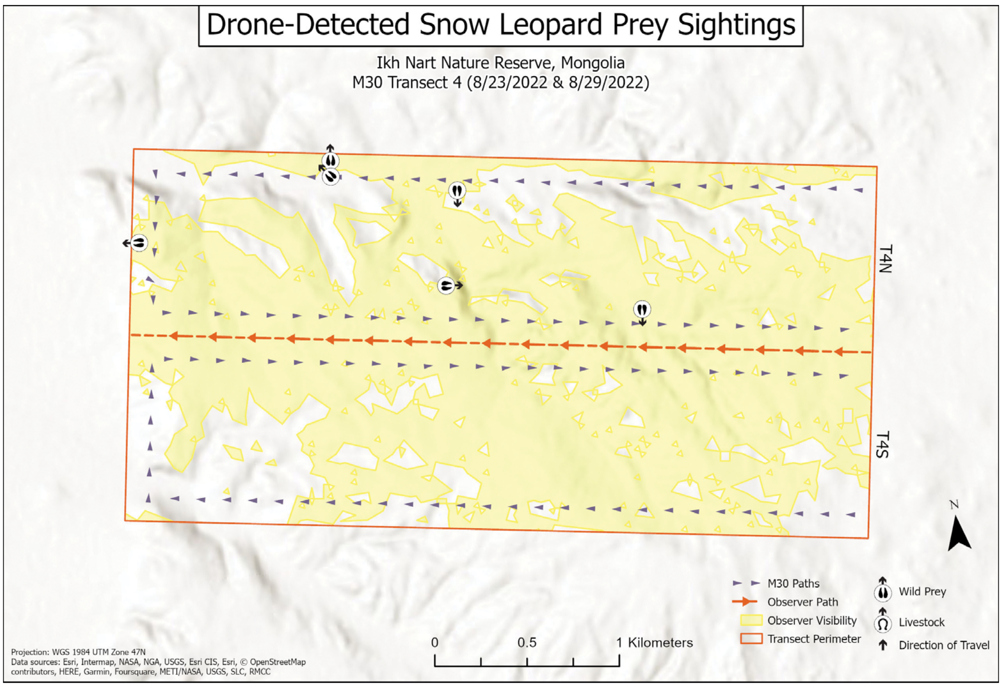


Figure 1: *Five survey blocks and transects sampled via drones in this study, indicating all ungulate sightings and the direction of travel with respect to fixed UAV flight pathways (each consisting of a single outward and return leg of 4km in length).*

Figure 2: *Viewshed map of Transect # 4 showing flight pathways and prey detections, including UAV travel direction and each animal's direction of flight in response to the approaching drone. Light gray depicts areas judged unlikely to be visible to observers conducting the traditional annual ground-based transect count; yellow areas are deemed visible to ground surveyors.*



resulting in a trapezoidal image frame, covering up to 500m in front of the drone. The M30T completed each transect in approximately 9 minutes (depending on wind conditions compared to Autel's 11-13 minutes. Drones continuously recorded RGB and thermal video, with data collection synchronized to start at each transect's beginning location and ending at its last waypoint, usually with the North sector flown first.

We used manufacturer-supplied software to conduct autonomous missions (see Appendix 1 for protocols, available upon request). All flights were conducted near dawn and were completed prior to thermal crossover – as the sun rises, land surfaces are warmed, thereby increasing difficulties of thermal image differentiation between animals and the surrounding back-ground – but before increasing wind speed impeded flight duration or safety. However, animal movement triggered by the drone's sound and/or movement greatly facilitated separating them from inanimate surfaces.

Footage from each mission flight was briefly reviewed in the field and backed up on hard drives. Later in computer facilities, three observers reviewed all collected imagery, to detect, enumerate and verify animals, using comparable methods including viewing split-screen thermal and RGB imagery with high-resolution monitors, noting animal movement and direction. Animal GPS locations (at the initial sighting) were approximated by comparing drone imagery and Google Earth© imagery.

To determine if the drone-observed animals would have been visible to hypothetical ground observers, we used ArcGIS software (ESRI, Inc, California, USA) to calculate the viewshed visible from human eye-level (about 2m above the ground) along the centerline of each survey block based on a 30m Digital Elevation Model (Figure 1 and 2).

Results & Discussion

We report only the M30T data as this drone flew uninterrupted at constant speed over all waypoints, providing smooth, unbroken video timestamps. By contrast, the Autel paused briefly at each waypoint, which required the pilot-in-charge to manually restart video recording, thus greatly complicating reconstruction of video timestamp records for GIS input and analysis.

We completed 43 missions covering transects from 5 traditional survey blocks for a total flight distance of almost 400km with 2-5 replicates per survey block. Figure 1 shows all sampled transects; Figure 2 illustrates the typical flight pattern with recorded animal detections, in this case survey block #4; Table 1 summarizes wild prey and live-stock sightings, including their position within the mapped viewshed.

A total of 235 wild prey and 209 livestock (cattle, horses, goats, and sheep) were detected. Figure 3 is a representative example of a small group of argali sheep captured with regular color and thermal imagery extracted from video recorded during a typical mission. These and other images illustrate how difficult it is to discern wild ungulates when body coloration blends closely with habitat background, shown here with little or no vegetation. Contrast that of the animals' warm body captured using the "WhiteHot" thermal infrared palette with the isotherm set to body temperature (25-31.7°C). While wild and domestic ungulates were relatively easy to detect thermally, especially if they moved, identifying species was more difficult.

GROUP/HERD SIGHTINGS							
Transect	Wild Prey in View	Livestock in View	Wild Prey Obscured	Livestock Obscured	Total in View	Total Obscured Detected	Total Drone
4	5	2	1	0	7	1	8
5	8	1	3	1	9	4	13
6	9	0	1	1	9	2	11
8	3	2	2	1	5	3	8
9	0	2	0	1	2	1	3
INDIVIDUAL SIGHTINGS							
Transect	Wild Prey in View	Wild Prey Obscured	Livestock in View	Livestock Obscured	Total in View	Total Obscured Detected	Total Drone
4	38	3	140	0	178	3	181
5	62	14	4	6	66	20	86
6	102	2	0	5	102	7	109
8	7	7	13	10	20	17	37
9	0	0	19	12	19	12	31
Totals	209	26	176	33	385	59	444
	Total Prey: 235				**Total Domestic: 209**		
Species	% of Type in View	% of Type Obscured	% of Total Animals in View	% of Total Obscured Animals	% of Drone Detections	Cumulative	Proportions
Wild Prey	88.9%	11.1%	54.3%	44.1%	52.9%	Total in View:	86.7%
Livestock	84.2%	15.8%	45.7%	55.9%	47.1%	Total Obscured:	13.3%

Table 1: *Total number of prey and domestic animals detected during 43 flights over 5 transects in Ikh Nart Nature Reserve.*

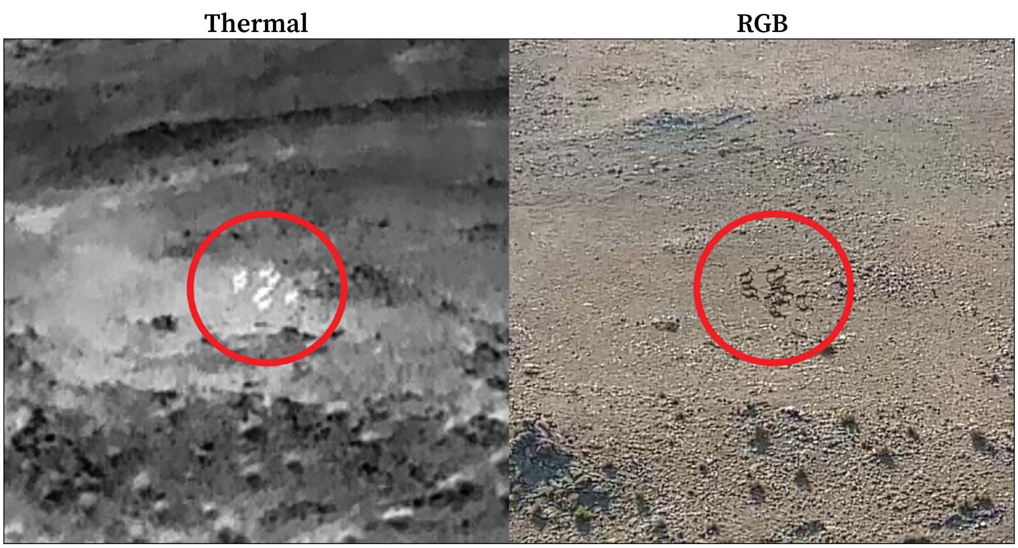


Figure 3: *Visual RGB color image (right) and thermal (left) image of argali sheep group comprised of 9 individuals detected in highly open habitat by the Autel UAV on August 25, 2022, while flying at an elevation of 75meters above ground level (640 x 512 pixels with 13mm focal length lens, abstracted from video clip).*

Transect Number	Total Area (km2)	Percent Within View	Percent Obscured
4	8.11	69.26	30.74
5	8.22	70.38	29.62
6	8.12	70.81	29.19
8	6.67	60.38	39.62
9	8.11	71.39	28.61
Totals	**39.23**	**68.75**	**31.25**

Table 2: *Proportion of each survey block located within view or obscured from human observers conducting ground-based "walking surveys."*

Viewshed Analysis

Figure 2 displays the viewshed map for Transect #4 with ungulate sightings and flight transect pathways along with each animal's flight direction in response to the approaching UAV. Lightly shaded gray areas are judged not visible to a human walking the central transect line (in red). Table 2 summarizes numbers of prey and domestic animals detected within and outside of the estimated viewshed for human observers conducting the annual count: on average, 31.3% of the survey land area, 26% of ungulate groups and 13.3% of the total number of animals observed were obscured from traditional ground-based viewsheds.

The thermal sensor has relatively few pixels (640 x 512), and a limited field-of-view (M30T 9mm; Autel 13mm), thus requiring relatively low flight heights of 60-75m resulting in a footprint of thermal-infrared survey coverage strip roughly 178m wide where the leading edge intersects the ground. We estimated about 50% of each survey block was covered by the thermal infrared sensor given flying height and gimbal angle settings, as suggested by Burke et al. (2018).

Figure 4 illustrates team members initiating a typical M30T mission. We found flight mission options sophisticated in this craft, which performed flawlessly except for a near catastrophic first flight forced landing. The incident affirmed concerns about wind resistance negatively impacting battery life and platform stability. A long flight with sudden change in wind velocity activated real-time responses by onboard sensors that directed the craft to "Return to Home," followed shortly afterwards by an automatic, autonomous emergency landing. Fortunately, the only damage affected two rotor-blades which were quickly replaced. We safeguarded against another such landing by eliminating four transect legs which reduced the total transect distance by 50% (i.e., 28km to 16km).

Conclusions & Next Steps

Overall, drones successfully detected large wild and domestic ungulates. Animal detection was facilitated by drones flushing prey for distances rangingfrom near zero meters (tolerance) to several km (presumably fear of mechanical noise), but more typically several hundred meters, typically halting after the drone has passed by. Transferring the technique to more typical snow leopard habitat will require a drone with better obstacle avoidance capabilities and reliable, robust terrain following flight controls. Given the combination of speed and aerial perspective, drone-based surveys have distinct advantages of being quicker to complete than ground surveys, while potentially enabling surveyors to cover a greater proportion of each survey block.

Going forward, we recommend that future developments in drone use for snow leopard prey surveys should center around refining transect designs, robust terrain

Figure 4: *Photograph of the study team launching the DJI Matrice M30T drone on a typical mission (left to right, Rodney Jackson, Don Hunter & Bayaraa Munkhtsog). Photo by Ben Hunter.*

following (e.g., Wubben et al 2022), employing Artificial Intelligence (AI) algorithms (e.g., Prakash et al. 2023) and modeling for double-counts and behavioral heterogeneity in detection. Research plans call for continued trial-testing in Colorado prior to resumed Mongolian flights in more rugged, viewshed-complex mountain habitats, comparing transect and point-count methods. Hopefully, these tests can include flights over radio-collared ungulates/snow leopards to assess flushing distance and movement behavior. Our team will also examine advanced fixed-winged drones that can fly for an hour or more, covering greater areas than possible with quadcopter drones. We fully envisage that within the decade wildlife biologists will have access to less expensive craft with greater capa-bilities. The key lies with continued collaboration, deployment, field testing and refinement among practitioners.

Acknowledgements

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Geospatial Centroid and Drone Center provided technical and/or managerial support. Lastly, thanks to Charleen Gavette, (SLC) and Daniel Rice (CSU) for GIS analysis and preparing the figures.

Conflicts of Interest

No known conflicts of interests

Literature Cited

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001) *Introduction to Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press.

Burke, C., Rashman, M., Wich, S., Symons, A., Theron, C., and Longmore, S. (2018) Optimising observing strategies for monitoring animals using drone-mounted thermal infrared cameras. International Journal of Remote Sensing: Drones. 30 pages, available at https://doi.org/10.48550/arXiv.1812.05498.

Corcoran, E., Winsen, M., Sudholtz, A., and Hamilton, G. (2021) Automated detection of wildlife using drones: Synthesis, opportunities and constraints. *Methods in Ecology and Evolution,* 12: 1103-1114.

Elmore, J.A., Schultz, E.A., Jones, L.R., Evans, K.O., Samiappan, S., Pfeiffer, M.B., Blackwell, B.F., and Iglay, R.B. (2023) Evidence on the efficacy of small unoccupied aircraft systems (UAS) as a survey tool for North American terrestrial, vertebrate animals: a systematic map. *Environmental Evidence, 12:3 available at* https://doi.org/10.1186/s13750-022-00294-8.

Hodgson, J.C., Baylis, S.M., Mott, R., Herrod, A., & Clarke, R.H. (2016) Precision wildlife monitoring using unmanned aerial vehicles. Scientific Reports, 6:22574.

Mo, M. and Bonatakis, K. (2022) Review: An examination of trends in the growing scientific literature on approaching wildlife with drones. Drone Syst. Appl. 10: 111–139 available at https://cdnsciencepub.com/doi/10.1139/dsa-2021-0003

Prakash, K.LNC., Ravva, S.K., Rathnamma, M/V., and Suryanarayana, G. (2023) AI Applications of Drones. Chapter 7 in: Drone Technology: Future Trends and Practical Applications, Editor(s): Sachi Nandan Mohanty, J.V.R. Ravindra, G. Surya Narayana, Chinmaya Ranjan Pattnaik, Y. Mohamed Sirajudeen. ISBN:9781394166534, Online ISBN:9781394168002; DOI:10.1002/9781394168002.© 2023 Scrivener Publishing LLC.

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

Thapa, K., Jackson, R., Gurung, L., Acharya, H.B., and Gurung, R.K. (2021) Applying the double observer methodology for assessing blue sheep population size in Nar Phu valley, Annapurna Conservation Area, Nepal. Wildlife Biology 2021 Issue 4, available at https://doi.org/10.2981/wlb.00877.

Wubben, J., Morales, C., Calafate, C.T., Hernández-Orallo, E., Cano, J.C., and Manzoni, P. (2022). Improving UAV Mission Quality and Safety through Topographic Awareness. MDPI-Drones 2022, 6, 74. available at https://doi.org/10.3390/drones6030074.

Wirsing, A.J., Johnston, A.N., and Kiszka, J.J. (2022) Foreword to the Special Issue on 'The rapidly expanding role of drones as a tool for wildlife research.' Wildlife Research, 49: i-x.

Wingard, G.J., Harris, R.B., Amgalanbaatar, S. and Reading, R.P. (2011) Estimating abundance of mountain ungulates incorporating imperfect detection: argali Ovis ammon in the Gobi Desert, Mongolia. Wildlife Biology, 17:93-101.

Wingard, G.J., et al. 2023. A new snow leopard record reflects the value of remote protected areas for connectivity. Oryx, 57(3):1-3.

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Camera trapping survey for snow leopard provides first photographic record of Woolly Flying Squirrel from Kishtwar Himalayas, India

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Abstract

The Woolly Flying Squirrel (*Eupetaurus cinereus*), considered native to Northern Pakistan and North-Western Himalaya has remained an elusive species because of its presence in high mountain rocky cliffs near the tree line. These montane habitats have remained inaccessible for research thus making it difficult to study their distribution. Here, we present the first photographic evidence of the Woolly Flying Squirrel from the Kishtwar region of Jammu and Kashmir obtained from camera-traps placed to detect snow leopard presence and distribution. This record adds valuable presence information to the existing distribution range of the species from the North-Western Himalaya.

Main Text

The Woolly Flying Squirrel (*Eupetaurus cinereus),* hereby abbreviated to WFS, is a member of the *Sciuridae* family and is considered among the largest flying squirrel species in the world. The species was first described by Thomas (1888) as a member of a new flying squirrel genus based on three specimens from Astor, Gilgit (presently in Gilgit-Baltistan province, Pakistan), and a speci-men from Tibet (Anderson, 1878). The species was observed up to 1925 in the areas around Hunza and Gilgit (Lorimer, 1925) and then was rediscovered in 1994 with the capture of a female squirrel from the same locality (Zahler, 1996). (Agrawal & Chakraborty, 1969) report the species from North Sikkim, India, based on a collected specimen. However, the identity of this species is considered doubtful (IUCN, 2020). Until recently, *E. cinereus* was considered the sole member of the genus, whereas morphometric and molecular analysis, based on analysis of 24 museum samples, have revealed three distinct species, *E. cinereus*, *E. tibetanus*, and *E. nivamons* across the Western, North Central and South Eastern margins of the Himalayas respectively (Jackson et al., 2022). The WFS has been reported from Gilgit-Baltistan, Pakistan (Dinets, 2011; Oshida et al., 2005; Qamar et al., 2012; Zahler, 1996). (Qamar et al., 2012) reported the species from Neelum Valley (Thomas, 1888) signaling an extension of the previously reported distributional range, whereas (Pal et al., 2019) reported camera trap records at 4800m elevation of the species from Baghirathi Basin, Uttrakhand, India, providing further evidence of its range extension and high elevation occurrence. Here, we present the first record of the WFS from Kishtwar Valley, Jammu and Kashmir, India, which may signal the presence of another population from the Kashmir Himalayas. Not only does the Woolly Flying Squirrel seem to share a large part of their distribution with snow leopards, they have also been identified as potential though obviously rare or very rare prey for snow leopards, *Panthera uncia* (Pal et al., 2020).

Thirty-four camera traps were deployed on different trails for Snow Leopard population assessment in the Paddar region of Kishtwar, by a team of researchers from the Nature Conser-vation Foundation. The cameras were set for

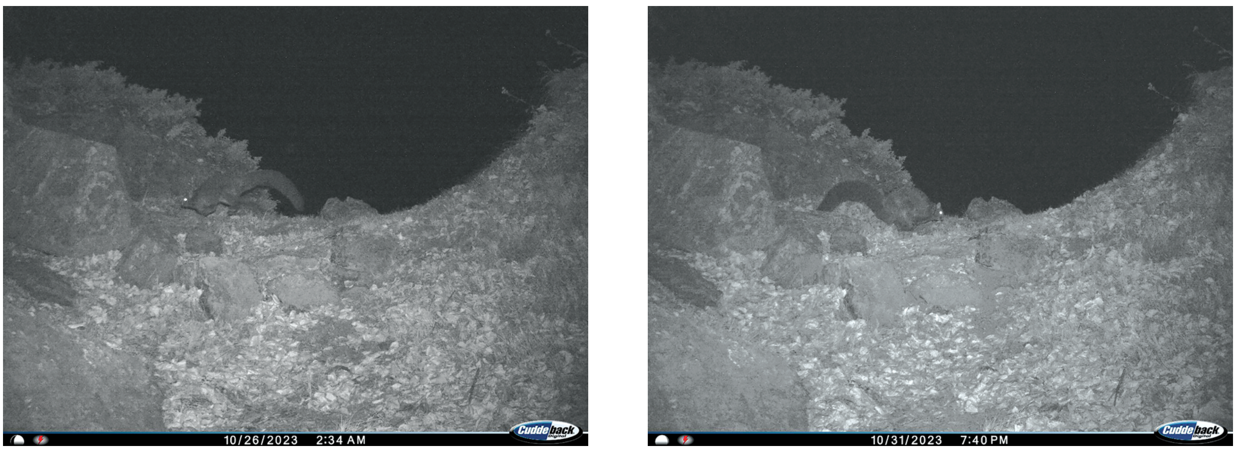

Figure 1: *Camera trap images of Woolly Flying Squirrel at 3500m elevation in Kishtwar region of Jammu & Kashmir.*

45 days between October-November 2023, primarily between 3000-4500m at different locations.Multiple camera trap images of the Woolly Flying Squirrel were captured on different dates between October and November 2023 from one camera (N33.38771, E76.40375, elevation = 3500m). The pictures were cross-checked and identified as Woolly Flying Squirrel (Fig 1) based on a thick, bushy, and cylindrical tail, dense fur, and visual size comparison with the lesser-known Woolly Flying Squirrel. The nearest known distribution of the Woolly Flying Squirrel (WFS) is ca 250km distant (Neelum Valley, Pakistan), whereas the southern most range extension record is from Harsil Valley, Uttarakhand, India, approximately 345km away. Finally, the role of this squirrel as the potential prey for snow leopards warrants further investigations.

Figure 2: *Habitat profile of the location. A camera trap was deployed near the Juniper patch on the right of the picture. Photo by Tanzin Thuktan.*

the Small Kashmir Flying Squirrel (*Euglaucomys fimbriatus fimbriatus*) from other areas. The habitat from where this record was obtained is a typical rocky cliff, with a Juniper *(Juniperus sp)* patch and few Birch *(Betula utilis)* trees around (Fig 2). The same camera trap also recorded the presence of an individual snow leopard. These photographic records document the first-ever evidence of this species from this Snow Leopard landscape and represent an important finding distinguishing its distribution with

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Conflict of Interest

No known conflict of interests.

Literature Cited

Agrawal, V. C., & Chakraborty, S. (1969). Occurrence of the Woolly Flying Squirrel, Eupetaurus Cinereus Thomas (Mammalia: Rodentia: Sciuridae) in North Sikkim. *Journal of the Bombay Natural History Society, 66*, 615–616.

Anderson, J. (1878). *Anatomical and zoological researches: Comprising an account of the zoological results of the two expeditions to western Yunnan in 1868 and 1875; and a monograph of the two cetacean genera, Platanista*. B. Quaritch,. https://doi.org/10.5962/bhl.title.50434

Dinets, V. (2011). Observations of the woolly flying squirrel Eupetaurus cinereus in Pakistan. *Mammalia, 75*(3), 277–280. https://doi.org/10.1515/mamm.2011.025

IUCN. (2020). *Eupetaurus cinereus: Krishna, M. & Ferguson, A.: The IUCN Red List of Threatened Species 2021: e.T8269A22251841* [dataset]. https://doi.org/10.2305/IUCN.UK.2021-2.RLTS.T8269A22251841.en

Jackson, S. M., Li, Q., Wan, T., Li, X.-Y., Yu, F.-H., Gao, G., He, L.-K., Helgen, K. M., & Jiang, X.-L. (2022). Across the great divide: Revision of the genus *Eupetaurus* (Sciuridae: Pteromyini), the woolly flying squirrels of the Himalayan region, with the description of twonew species. *Zoological Journal of the Linnean Society, 194*(2), 502–526. https://doi.org/10.1093/zoolinnean/zlab018

Lorimer, M. D. L. R. (1925). The Woolly Flying Squirrel. (Eupetaurus cinereus). *Journal of the Bombay Natural History Society (JBNHS), 30*(1–2), 219.

Oshida, T., Shafique, C. M., & Barkati, S. (2005). A note on a new habitat of the woolly flying squirrel Eupetaurus cinereus in the northern area of Pakistan. *Mammal Study, 30*(1), 73–76. https://doi.org/10.3106/1348-6160(2005)30[73:ANOANH]2.0.CO;2

Pal, R., Bhattacharya, T., & Sathyakumar, S. (2020). Woolly Flying Squirrel *Eupetaurus cinereus*: A New Addition to the Diet of Snow Leopard *Panthera uncia*. *Journal of the Bombay Natural History Society (JBNHS), 117*(0). https://doi.org/10.17087/jbnhs/2020/v117/142056

Pal, R., Thakur, S., Bhattacharya, T., & Sathyakumar, S. (2019). Range extension and high elevation record for the endangered woolly flying squirrel *Eupetaurus cinereus* in Western Himalaya, India. *Mammalia, 83*(4), 410–414. https://doi.org/10.1515 mammalia-2018-0097

Qamar, Q. Z., Ali, U., Minhas, R. A., Dar, N. I., & Anwar, M. (2012). New Distribution Information on Woolly Flying Squirrel (Eupetaurus cinereus Thomas, 1888) in Neelum Valley of Azad Jammu and Kashmir, Pakistan. *Pakistan Journal of Zoology, 44*(5), 1333–1342.

Thomas, O. (1888). On Eupetaurus, a new form of Flying Squirrel from Kashmir. *The Journal of the Asiatic Society of Bengal, 57,* 256–260.

Zahler, P. (1996). Rediscovery of the Woolly Flying Squirrel (Eupetaurus cinereus). *Journal of Mammalogy, 77*(1), 54–57. https://doi.org/10.2307/1382708

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Rare and unusual snow leopard encounters in the broadleaf forest of the Bhutanese Himalayas

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Abstract

The snow leopard *Panthera uncia*, a top predator in Central and South Asia, faces population declines due to habitat degradation, prey depletion, retaliatory killings, poaching, and climate change. In Bhutan, where the species is protected, we report two rare sightings in the Gedu region's broadleaved and fir forests, at 2,708 masl and 3,839 masl, respectively, which are lower than the typical species' prime habitats in Bhutan. These findings suggest that this area may function as an important corridor or a potential range expansion beyond typical high-altitude habitats (3,000 to 5,800 masl). This discovery underscores the species' ecological adaptability and highlights the need for enhanced conservation strategies, including habitat connectivity mapping and local community education. Additionally, it highlights

the importance of protecting and conserving habitats outside of protected areas for species' long-term persistence.

Introduction

The snow leopard *Panthera uncia* is a top predator in the high mountains of Central and South Asia. Listed as Vulnerable on the IUCN Red List of Threatened Species since 2017 (McCarthy et al., 2017), the global snow leopard population is estimated to be between 3,920 to 8,745 individuals (McCarthy et al., 2016), spanning 12 Asian countries. In the Himalayas, snow leopards are typically found at elevations between 3,000 to 5,800 meters above sea level (masl) (Lham et al., 2021). Despite its vast habitat, the snow leopard population faces a continual decline, primarily due to habitat degradation, dwindling prey populations, retaliatory killings, poaching, habitat degradation, ecotourism, and climate change (Bagchi & Mishra, 2006; DoFPS, 2016; Filla et al., 2022; Leki et al., 2018; McCarthy et al., 2017).

In Bhutan, the snow leopard is a protected species under Schedule I of the Forests and Nature Conservation Act of Bhutan 2023 (RGoB, 2023). The country is estimated to have a population of 134 individuals as of 2023 (DoFPS, 2023a). Conservation strategies in Bhutan are guided by a comprehensive snow leopard action plan (NCD, 2019), and the highland communities revere snow leopard as a mountain deity. Snow leopards are predominantly concentrated in the northern regions of the country in the protected areas such as Jigme Dorji National Park (JDNP), Wangchuck Centennial National Park (WCNP), and Jigme Khesar Strict Nature Reserve (JKSNR) (DoFPS, 2016). They are also found in alpine regions of Divisional Forests Office (DFO) of Paro and Thimphu, adjacent to these protected areas (DoFPS, 2016). Reports also indicate their presence in Bumdeling Wildlife Sanctuary (BWS) and Jigme Singye Wangchuck National Park (JSWNP) (NCD 2019; Letro et al., 2021).

Studies show that suitable snow leopard habitats in Bhutan are typically found within the elevation range of 3,500 to 5,500 masl, encompassing approximately 7206 km^2 of the country (Thinley et al., 2016; Lham et al., 2021). Based on the habitat characteristics and elevation, Dagala region in central Bhutan, located at the tri-junction of DFO Gedu (here on referred to as Gedu), DFO Thimphu and DFO Dagana (here on referred as Dagana), appears suitable for snow leopards (Letro et al., 2021) although no historical records of their presence exist in this region. Here, we report the rare captures of the snow leopard on two different camera traps in the cool broadleaved and fir forests of Gedu, on the lower stretches of the Dagala region, far away from prime snow leopard habitats in northern Bhutan. These observations provide evidence of this area being an important corridor or a potential species range expansion in the country, crucial for conservation planning and implementation of appropriate interventions.

Materials and methods

Study Area

Gedu has an area of 1879.77 km^2 (Rai & Phuntsho, 2016) and is the largest division among 14 divisional forest office areas aside the protected areas network in Bhutan. Gedu is located in south-western Bhutan covering the entire Chukha District (highest administrative body) and is bordered by Paro and Thimphu Districts in the North, Dagana in the East, Samtse District in the West, and Haa district in the North-East and India in the South (Figure 1). Gedu has diverse vegetation representation from alpine, temperate and subtropical ecological zones of Bhutan (Dhendup & Dorji, 2018; DoFPS, 2021) attributed to its wide elevation ranging from 150 to 4,450 masl. The assemblage of faunal species include but is not limited to tiger (*Panthera tigris*), clouded leopard (*Neofelis nebulosa*), dhole (*Cuon alpinus*), red panda (*Ailurus fulgens*), elephant (*Elephas maximus*), musk deer (*Moschus chrysogastor*), White-bellied heron (*Ardea insignis*) and Rufous-necked hornbill (*Aceros nipalensis*) (Dorji et al., 2021).

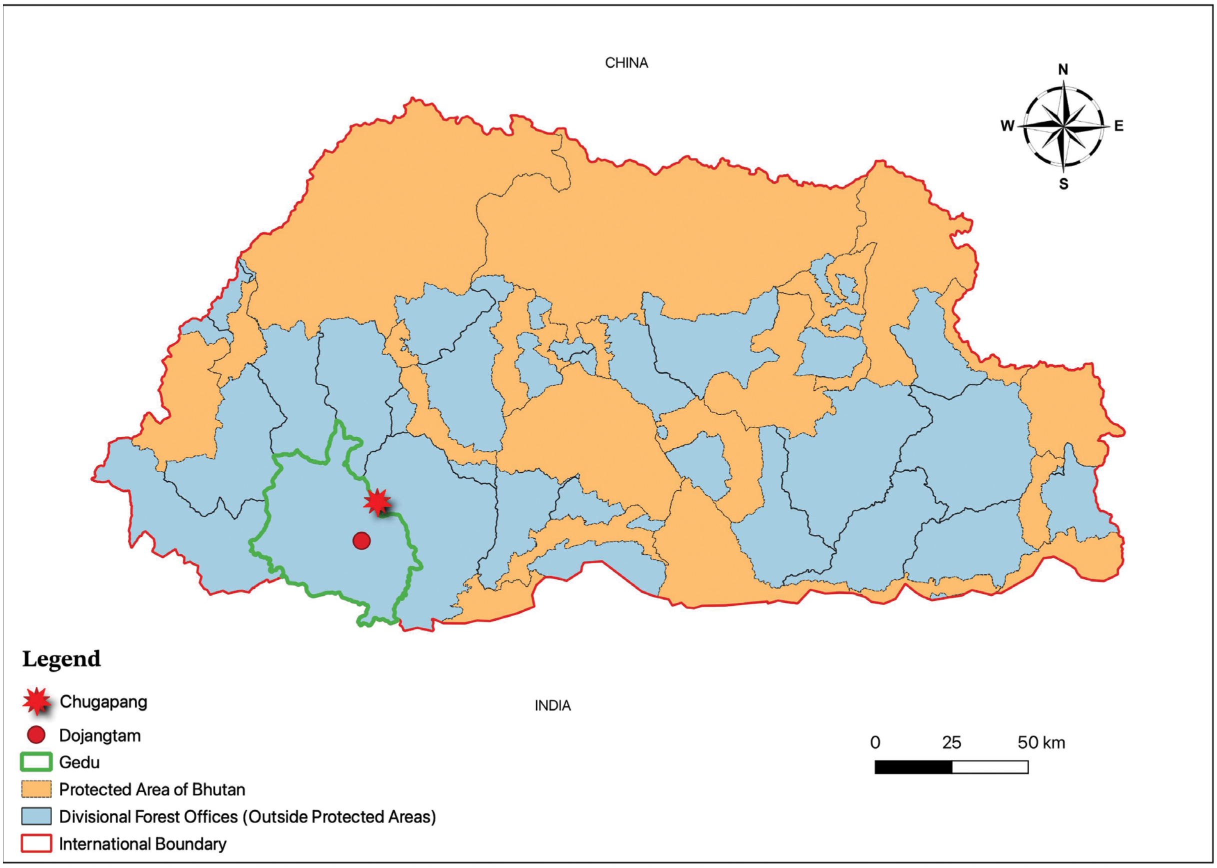

Figure 1: *Map showing location of Bhutan, Gedu and Snow Leopard capture locations.*

Data collection

We conducted the camera trapping exercise from 8th March to 31st May 2022 in Gedu as a part of the second National Tiger Survey of Bhutan by setting up 57 camera trap stations each in a grid cell of 5x5 square kilometer. This includes the survey area extended into southern Dagala (Dagala-Gaytala ridge) on the northeast of Gedu. A pair of remote camera-traps set at least 2 meters apart were placed in each of 57 camera trap stations at a height of 45 to 60 cm above ground on either side of the trail by maintaining a distance of 3 to 5 meters from the trail ensuring no two cameras were in the same line of view with 3 images per trigger (BTC, 2021; DoFPS, 2023b).

During the camera trap deployment, the location of every camera-trap station, vegetation composition within a 25 meters radius of each camera station and other information were recorded using Epicollect5 College (Imperial college London, 2021). The camera traps were monitored once in April 2022 to check the camera status, replace memory cards if full, and replace batteries if exhausted.

Results and Discussions

Snow leopards were captured at two camera trap stations: one in the fir forest zone at Chugapang at the border of Gedu and Dagana at an elevation of 3,839 masl and the other in the cool broadleaved forests in Dojangtam, Gedu at an elevation of 2,708 masl. The two camera traps captured a total of 1,161 images over 154 camera trap nights. The snow leopards were recorded on 20th March 2022 at Dojangtam, with five images taken between 15:49:17 and 16:48:15 hours, and on 26th March 2022 at Chugapang, with eight images taken between 14:40:05 and 14:40:10 hours (Figure 2). Eleven other mammal species were also recorded (Table 1). The images from the two camera traps were compared but we could not determine if they depicted the same individual due to insufficient imagery for rosette comparison. Additionally, the snow leopard images captured in two stations were compared with those from the national snow leopard survey of 2023 to check the recaptures but no matches were found.

These observations mark the first evidence of snow leopard presence in the Dagala region, suggesting either that this area represents an important corridor or a potential range expansion into Gedu, Thimphu, and Dagana. While the Chugapang location is closer to central alpine regions resembling typical snow leopard habitats, the Dojangtam location is in a cool broadleaved forest with 50 to 75 percent canopy cover, featuring species like *Castanopsis tribuloides, Quercus spp*., and other dense shrubs, climbers, and epiphytes. This habitat is not typical for snow leopards, which are generally associated with alpine and subalpine zones which suggests that these observations may represent a snow leopard corridor between more typical snow leopard habitats. These observations may, on the other hand, also suggest a potential range expansion that may be linked to prey availability (Lovari et al., 2013) and their adaptability to different ecological zones.

The snow leopard recorded at an elevation of 2,708 masl at Dojangtam in Gedu is lower than the predicted elevation range of 3,000 to 5,800 masl in the Bhutan Himalayas, suggesting unusual movement southward outside its preferred habitat (Lham et al., 2021; Thinley et al., 2016). In the Himalayan landscape, the lowest elevation at which snow leopards were previously recorded is 2,495 masl in the Great Himalayan National Park in India as reported by Bandyopadhyay et al. (2019). However, there are records of snow leopards inhabiting lower altitudes in China's Beita Mountain and southwestern Mongolia during autumn (Feng et al., 2006; McCarthy et al., 2005). The snow leopard in the two camera trap stations in our study was recorded in March 2022 after the

Figure 2: *(above) a. Snow leopard individual recorded in Dojangtam, Gedu and (right) b. Chugapang at the border of Gedu and Dagana.*

Table 1: *Mammalian species captured by camera traps along Dagala-Gaytala ridge under Gedu in the year 2022.*

Common Name	Scientific Name	Family	IUCN Red List category as of 2024
Snow leopard	*Panthera uncia*	Felidae	Vulnerable
Himalayan red panda	*Ailurus fulgens fulgens*	Ailuridae	Endangered
Dhole	*Cuon alpinus*	Canidae	Endangered
Tiger	*Panthera tigris tigris*	Felidae	Endangered
Barking deer	*Muntiacus muntjak*	Cervidae	Least Concern
Marbled cat	*Pardofelis marmorata*	Felidae	Near-Threatened
Sambar	*Rusa unicolor*	Cervidae	Vulnerable
Asiatic golden cat	*Catopuma temminckii*	Felidae	Near-Threatened
Wild boar	*Sus scrofa*	Suidae	Least Concern
Assam macaque	*Macaca assamensis ssp. assamensis*	Cercopithecidae	Near-Threatened
Leopard	*Panthera pardus*	Felidae	Vulnerable
Yellow-throated marten	*Martes flavigula*	Mustelidae	Least Concern

unusually heavy snowfall in the first week of February 2022 in most parts of Bhutan with records of snowfall to elevations as low as 1,700 masl in Gedu (Kuensel, 2022). This event may have driven snow leopards to seek lower elevations, highlighting their vulnerability to climate change impacts (Forrest et al., 2012).

The unusual record of snow leopards in the broadleaf forests reported here suggests potential connectivity with snow leopard habitats in northern Bhutan. Previous species captures in Thimphu's alpine habitats, adjacent to JDNP, which harbors the largest number of snow leopards in the country (DoFPS, 2016), suggest a possible route through Dochula Pass (3,129 masl) between the prime snow leopard habitats, Dagala region, and Gedu (Figure 3). In Gedu's Dojangtam area, the camera trap captured both snow leopard and common leopard (*Panthera pardus*) at the same location, though at different times, likely to avoid interspecific aggression (Lovari et al., 2013). This indicates their co-occurrence at lower elevations in Bhutan. Similar overlaps and co-occurrences of snow leopards and common leopards were also reported in Nepal and Pakistan but at a higher elevation than what we recorded in this study (Bhatti et al., 2022).

Snow leopards typically rely on blue sheep as their prey in Bhutan, but this species is not

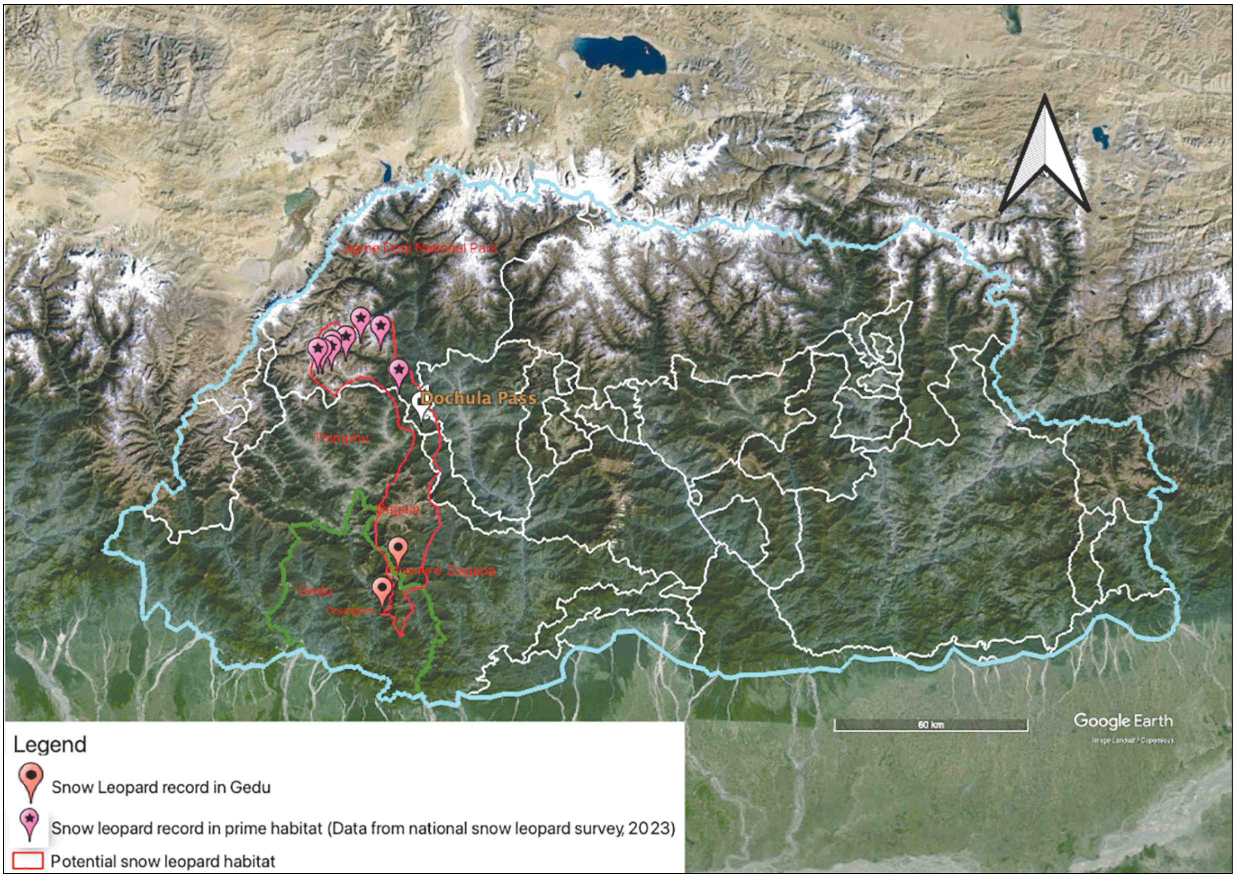

Figure 3: *Map showing locations of snow leopard presence and potential movement route.*

recorded in the Gedu area. Instead, other prey such as wild pig (*Sus scrofa*), Goral (*Naemorhedus goral*), Musk deer (*Moschus chrysogaster*), domestic yaks (*Bos grunniens*) and horses (*Equus caballus*) are found in the Dagala-Gaytala region (Thinley et al., 2016; Lham et al., 2021). There were no official records of livestock depredation by the snow leopards in the Dagala-Gaytala region of Gedu. However, habitat disturbances through grazing, lopping, and tree felling were observed during the survey. It is imperative to educate local yak herders of the Dagala and Gaytala regions in Gedu about the presence of snow leopards, their ecological importance, and the need for coexistence for the species' survival. Considering Dagala-Gaytala areas in Gedu for important conservation areas outside the protected area regime in securing the species' habitats is recommended. Further, a telemetry study, as suggested by Letro et al. (2021), could provide additional insights into the unusual movement of snow leopards into southern Bhutan coupled with a thorough camera trap survey along these ridges is needed to better understand how these habitats are used. Additionally, studying prey species in light of the absence of the main prey, blue sheep, in this region is essential.

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Conflicts of interest

The authors declare no conflicts of interest

References

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. https://doi.org/10.1111/j.1469-7998.2005.00030.x

Bandyopadhyay M., Dasgupta T. & Ramesh K. (2019). New records of snow leopard in Great Himalayan National Park, Western Himalaya. CATnews 70, 9–12.

BTC. (2021). *Camera Trapping Guideline and implementation modality for the national tiger survey 2021-2022, Bhutan Tiger Centre, Department of forests and park services, ministry of Agriculture and Forests, Gelephu, Bhutan (Pages 1-112).*

Dhendup, T., & Dorji, R. (2018). *Camera-trap records of small carnivores from Gedu Territorial Forest Division, Bhutan*. https://doi.org/10.13140/RG.2.2.21570.43202

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

DoFPS. (2021). *Guidelines for Wildlife Habitat Management, Department of Forests and Park Services,Ministry of Agriculture and Forests, Royal Government of Bhutan, Thimphu*. https://doi.org/10.13140/RG.2.2.21300.53129

DoFPS. (2023a). *National Snow Leopard Survey Report*. https://www.dofps.gov.bt/reports/

DoFPS. (2023b). *Status of Tigers in Bhutan: The National Tiger Survey Report 2021–2022. Bhutan Tiger Center, Department of Forests and Park Services, Ministry of Energy and Natural Resources, Royal Government of Bhutan.*

Dorji, R., Letro, L., Tandin, T., Pema, P., & Karma, K. (2021). *Baseline Biodiversity Report of Gedu Forest Division.*

Farrington, J. D., & Li, J. (2016). Chapter 8—Climate Change Impacts on Snow Leopard Range. In T. McCarthy & D. Mallon (Eds.), *Snow Leopards* (pp. 85–95). Academic Press. https://doi.org/10.1016/B978-0-12-802213-9.00008-0

Feng, Ma, M., Shou-jing, Y., & Munkhtsog, B. (2006). Autumn Habitat Selection by Snow Leopard (Uncia uncia) in Beita Mountain, Xinjiang, China. *Zoological Research*, *27*, 221–224.

Filla, M., Lama, R. P., Ghale, T. R., Filla, T., Heurich, M., Waltert, M., & Khorozyan, I. (2022). Blue sheep strongly affect snow leopard relative abundance but not livestock depredation in the Annapurna Conservation Area, Nepal. *Global Ecology and Conservation, 37,* e02153. https://doi.org/10.1016/j.gecco.2022.e02153

Forrest, J. L., Wikramanayake, E., Shrestha, R., Areendran, G., Gyeltshen, K., Maheshwari, A., ... & Thapa, K. (2012). Conservation and climate change: Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. *Biological Conservation, 150*(1), 129-135.

Imperial college London. (2021). *Epicollect5* [Computer software]. https://five.epicollect.net

Kuensel, B. D. N. (2022). *In Pictures: Snowfall 2022*. Kuensel Online. https://kuenselonline.com/in-pictures-snowfall-2022/

Leki, Rajaratnam, R., Shrestha, R., Thinley, P., Rajaratnam, R., & Shrestha, R. (2018). Establishing baseline estimates of blue sheep (Pseudois nayaur) abundance and density to sustain populations of the vulnerable snow leopard (Panthera uncia) in Western Bhutan. *Wildlife Research*, *45*(1), 38–46. https://doi.org/10.1071/WR16218

Letro, L., Duba, D., Tandin, T., & Wangdi, S. (2021). *Rare capture of snow leopard in Jigme Singye Wangchuck National Park, Bhutan*.

Lham, D., Cozzi, G., Sommer, S., Thinley, P., Wangchuk, N., Wangchuk, S., & Ozgul, A. (2021). Modeling Distribution and Habitat Suitability for the Snow Leopard in Bhutan. *Frontiers in Conservation Science*, *2*, 781085. https://doi.org/10.3389/fcosc.2021.781085

Lovari, S., Minder, I., Ferretti, F., Mucci, N., Randi, E., & Pellizzi, B. (2013). Common and snow leopards share prey, but not habitats: Competition avoidance by large predators? *Journal of Zoology*, *291*(2), 127–135. https://doi.org/10.1111/jzo.12053

McCarthy, T., Fuller, T., & Munkhtsog, B. (2005). Movements and activities of snow leopards in Southwestern Mongolia. *Biological Conservation*, *124*, 527–537. https://doi.org/10.1016/j.biocon.2005.03.003

McCarthy, T., Mallon, D., Jackson, R., Zahler, R., & McCarthy, K. (2017). *The IUCN Red List of Threatened Species*. IUCN Red List of Threatened Species.

McCarthy, T., Mallon, D., Sanderson, E., Zahler, P., & Fisher, K. (2016). *What is a Snow Leopard? Biogeography and Status Overview* (pp. 23–42). https://doi.org/10.1016/B978-0-12-802213-9.00003-1

NCD. (2019). *Bhutan Snow Leopard Conservation Action Plan*. https://globalsnowleopard.org/wp-content/uploads/2021/08/Bhutan-Snow-Leopard-Conservation-Action-Plan-2018-2023.pdf

Rai, A., & Phuntsho, P. (2016). *LAND USE AND LAND COVER OF BHUTAN 2016 MAPS AND STATISTICS*.

RGoB. (2023). *Forest and Nature Conservation Act of Bhutan*.

Thinley, P., Lham, D., & Wangchuk, N. (2016). *National Snow Leopard Survey of Bhutan – Phase I: Sign and Prey Base Survey*.

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Monitoring of snow leopards in the Sarychat-Ertash State Reserve (Kyrgyzstan), between 2011 and 2019, through scat genotyping

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Abstract

Snow leopards (*Panthera uncia*) are a keystone species of Asia's high mountain ecosystem. The species is assessed as Vulnerable by the IUCN Red List of Threatened Species and is elusive, limiting accurate population assessments that could inform conservation actions. Non-invasive genetic monitoring conducted by citizen scientists offers avenues to provide key data on this species. From 2011 to 2019, OSI-Panthera citizen science expeditions tracked signs of presence of snow leopards and collected scat samples along transects in the main valleys and crests of the Sarychat-Ertash State Reserve (Kyrgyzstan). Scat samples were genotyped at twenty autosomal microsatellite loci and at a X/Y locus (sex identification), allowing an estimation of a minimum of 17 individuals. The genetic recapture of 12 of them provided indications of individuals' habitat use throughout the reserve. We found putative family relationships between several individuals; however, further research is needed to validate these findings. Our results demonstrate the potential of a citizen science program to collect meaningful data that can inform the conservation management of snow leopards.

Introduction

Threats facing snow leopard (*Panthera uncia*) populations include habitat loss, loss of prey base, human-wildlife conflicts, and illegal killing (Jackson and Hunter 1996; McCarthy and Chapron 2003; McCarthy and Mallon 2016; Nowell, et al. 2016). Because of these, snow leopards were assessed as Endangered by the IUCN from 1986 to 2016. The species was down listed to Vulnerable (C1) in 2017. Estimates of the total number of mature individuals indicate between 3,500 and 7,000 snow leopards across the species range (McCarthy, et al. 2017; Snow Leopard Trust, 2021). However, many range countries lack up-to-date information on snow leopard population sizes and demographic trends. The elusive snow leopard inhabit remote mountainous regions, which makes ecological, behavioural and population studies particularly challenging (Macdonald and Loveridge 2010; McCarthy and Mallon 2016). Research that seeks to provide current and accurate demographic trends is a main priority highlighted in the Snow Leopard Survival Strategy (McCarthy and Chapron 2003; Snow Leopard Network 2014).

In Kyrgyzstan, snow leopard numbers have decreased at an alarming rate over the last few decades, with 650 to 800 individuals estimated in the 1990s, against 150 to 200 in 2000 (Koshkarev and Vyrypaev 2000). Latest estimates are around 350 to 400 individuals (National Academy of Sciences of Kyrgyzstan, unpublished data; McCarthy and Mallon 2016). Protection efforts in Kyrgyzstan have mainly focused on preventing illegal killing, one of the most important threats to wildlife since the country's transition in 1991 (Koshkarev and Vyrypaev 2000; McCarthy and Mallon 2016). The largest protected area, the Sarychat-Ertash State Reserve (SESR), established in 1995, is located in the Tien-Shan mountain range of Kyrgyzstan (Fig. 1). Besides illegal killing, major threats to biodiversity in the SESR include climate change, mining, overgrazing, and over-hunting (SER 2007). The SESR highlands are also surrounded by long-established ungulate hunting concessions, which increase pressure on snow leopards and their prey. The SESR is divided into fourteen districts, each monitored by a ranger. Several studies based on genetic analyses and camera trapping estimated the snow leopard population size in the SESR to be approximately 20 individuals (McCarthy, et al. 2008; Jumabay-Uulu, et al. 2014; McCarthy and Mallon 2016). However, a long term, accurate understanding of population status and changes is still lacking.

Non-invasive capture-mark-recapture methods, along with subsequent genetic analyses, are effective tools for estimating the demographic parameters needed to develop conservation plans (Bhagavatula and Singh 2006; Mondol, et al. 2009; Sugimoto, et al. 2012; Aziz, et al. 2017). The main objectives of the present study were to assess the suitability of

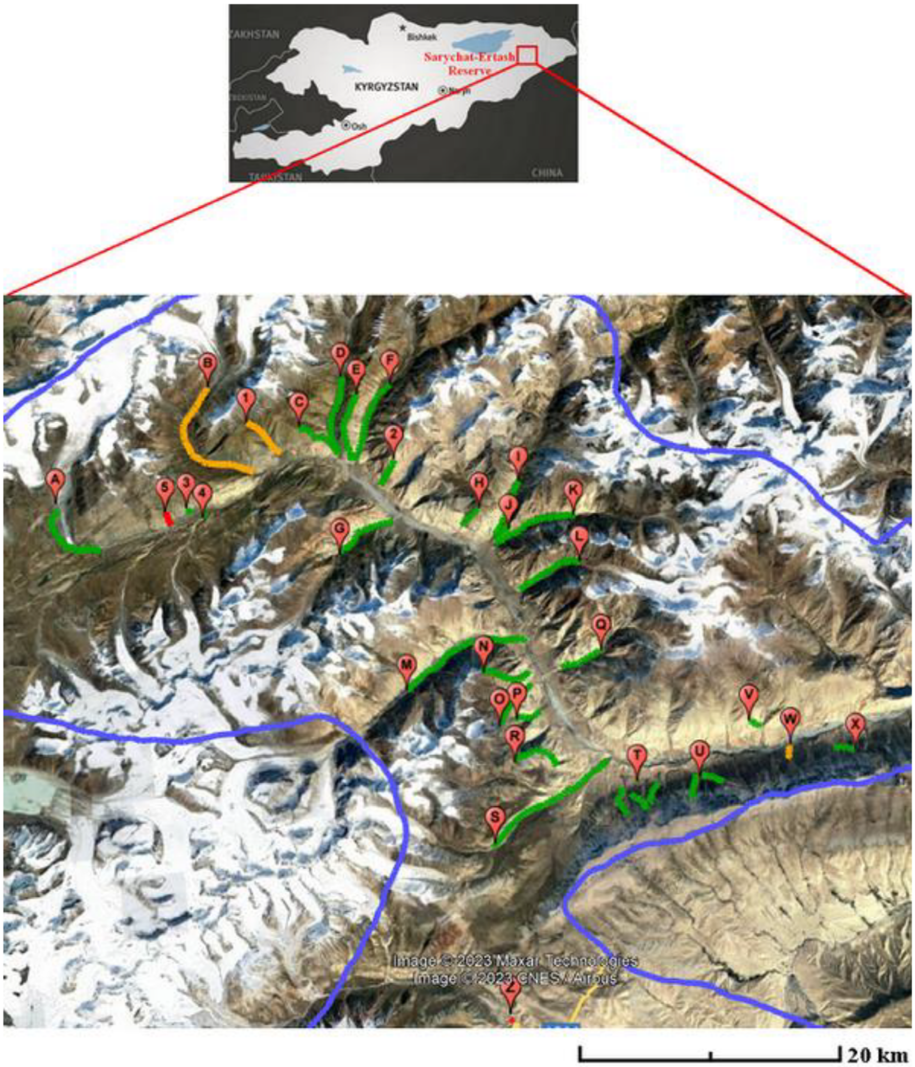

Figure 1: *Map of Sarychat-Ertash State Reserve (Kyrgyzstan) highlighting transects performed from 2011 to 2019, red indicates where no traces of snow leopards were found, orange indicates where some traces were found except scat and green were snow leopard traces and scat were collected. Letters and numbers corresponding to the location of transects are provided in (**Supplementary Table S1**) along with the dates of prospections.*

non-invasive genetic techniques for studying the snow leopard population in the SESR and to provide preliminary insights into genetic relatedness among individuals. All samples obtained in the field were collected through seasonal citizen science expeditions, where participants were trained by local rangers and scientific experts on the methodology of scat sampling.

Materials and methods

Study Area

Before 1995, the SESR served as a grazing area for herders from the USSR (Union of Soviet

Socialist Republics), who lived there year-round with livestock herds numbering in the thousands. The SESR boundary encompasses 1,340 km^2, with a 720 km^2 core zone and a 620 km^2 buffer zone (SER 2007) (Fig. 1). The relief is characterized by large flat valleys about one kilometer wide surrounded by high mountains of altitudes ranging from 2,000 to 5,500 m (SER 2007). The climate is continental, with low average temperatures even during the summer months (-21.5°C in January; +4.5°C in June). Vegetation types include arid grasslands and alpine meadows, with a majority of bushy and blanket cover type plants that are able to sustain the harsh and windy climate (SER 2007). Beside the snow leopard, several carnivores are found in the reserve, including wolves (*Canis lupus*), red foxes (*Vulpes vulpes*), Tian Shan brown bears (*Ursus arctos isabellinus*), Pallas's cat (*Otocolobus manul*), Eurasian lynx (*Lynx lynx isabellinus*), as well as several mustelids (*Martes foina, Mustela erminea*). Large and medium herbivores, which are snow leopard prey species, are also found, including Siberian ibex (*Capra sibirica*), argali (*Ovis ammon*), grey marmots (*Marmota baibacina*) and Tolai hares (*Lepus tolai*). Several species of birds are present, a few of which represent prey species for snow leopards, such as snowcocks (*Tetraogallus himalayensis*) and chukar partridges (*Alectoris chukar*) (SER 2007; McCarthy and Mallon 2016).

Monitoring of snow leopard presence

In this study, snow leopards within the SESR were monitored during citizen science expeditions led by the OSI-Panthera research program (osi-panthera.org). These two to four week expeditions were conducted by local rangers and guides, OSI scientific educators, and volunteers. Volunteers are eco-tourists, with around a half of them being ecology and wildlife students or professionals with diverse specialties such as botany or ornithology. Monitoring effort increased over time, with two expeditions conducted in 2011 (July and August), three both in 2012 and 2013 (June, July, and August each year), four in 2014 and 2015 (June, early July, straddling July and August and late August each year), three in 2016 (June, July, and August), three in 2017 (June, July, and August), one in 2018 (July and August) and two in 2019 (July and August).

Snow leopard presence was recorded based on specific signs (presence of scats, hairs, scratch marks, tracks, urine sprays on rocks, and carcasses of prey species), and based on pictures from camera traps set at known locations. Incidental species were also recorded to obtain information on prey presence and biodiversity level.

The protocol consisted of searching for snow leopard signs along transects (Fig. 1). As snow leopards are more likely found in steep and rocky environments and travel along topographic edges (McCarthy and Mallon 2016), transects were designed along waterbodies, ridgelines and cliffs, as well as in narrow valleys and canyons (McCarthy and Mallon 2016). Most transects were set within a sampling area of about 500 km^2 within the SESR core zone, around the main valley in which the Ertash River flows, and at the entry of secondary valleys (Fig. 1). For each expedition 10 to 15 transects were surveyed, with transect length ranging from several hundred meters in valley bottoms to more than three kilometers along crest lines. The same transects were surveyed on a regular basis over the years

(**Supplementary Table S1**).

Glaciers, which are not considered high quality habitat for snow leopards (McCarthy and Mallon 2016) were only searched once due to low accessibility and time constraints. As snow leopards are territorial (McCarthy and Mallon 2016), our large sampling area which was covering most of the SESR and included snow leopard's preferential habitats enabled us to estimate a minimum number of individuals at the reserve scale and gain insights on their habitat use within it. The list of ridgelines covered and information on the presence of putative snow leopards' signs and number of scat samples collected can be found in **Supplementary Table S1.**

Collection of scat samples

Putative snow leopard scats were identified based on size, shape, vegetation content, as well as proximity to tracks, scratch marks and carcasses. Because scats are used by snow leopards for territory marking, only a small portion of each was collected. Due to exposure to harsh weather conditions in high mountain environments (such as UV rays, rainfall, wind, and trampling), the scats degraded within several months and could thus not be retrieved from one year to the next. This was supported through GPS recordings and reports from science coordinators across the years.

Each sample was collected with disposable latex gloves, and stored in a tube, with silicagel at room temperature for several weeks before being frozen and later sent to the lab for genotyping. Timeline to process samples following collection and freezing ranged from several months to several years. To avoid cross-contamination, individual sampling kits were prepared before each expedition. Different volunteers collected samples on a given transect, to prevent the manipulation of different samples by the same person and to minimize potential cross contamination. Samples that had signs of humidity were dried in open air to prevent molding and degradation. In 2015, the storage and DNA preservation protocol was improved by including systematic drying, and use of a coffee filter to protect the samples from the silicagel. These improvements were combined with a shortened processing time between sample collection and genotyping, which led to an increase in the number of samples successfully genotyped. A total of 151 putative snow leopard scat samples were collected and processed (6 in 2011, 11 in 2012, 18 in 2013, 21 in 2014, 8 in 2015, 18 in 2016, 25 in 2017, 16 in 2018 and 28 in 2019).

DNA extraction

DNA extraction of each sample was conducted under sterile conditions in a designated area of the lab. The mucosal layer of each sample was swabbed to collect animal cells that were placed in a numbered microtube to proceed to DNA extraction. Sample tubes were surrounded by both negative extraction controls (blanks) and positive extraction controls consisting of snow leopard samples previously analyzed and validated in terms of DNA quality and genotyping success on microsatellite markers. Samples, as well as positive and negative extraction controls, were lysed overnight at 56°C, DNA was isolated and purified using purification columns and vacuum filtration according to the manufacturer's instructions (Nucleospin 96 Tissue Kit, Macherey-Nagel).

Microsatellite markers genotyping and sex identification

For each DNA sample, 20 microsatellite markers (Menotti-Raymond, et al. 1999) and one marker for sex identification (ZFXY) (Pilgrim, et al. 2005) were amplified in three multiplex PCRs (Polymerase Chain Reaction) referred to as A (6 loci), B (9 loci), and C (8 loci) (**Supplementary Table S2**) and genotyped with an automated sequencer. Each DNA sample was genotyped twice (multiple-tube approach) (Taberlet, et al. 1996). Previous research conducted in our lab on non-invasive samples from various species compared the results obtained from using two versus three replicates, and only little improvement was gained when adding a third replicate. Therefore, using two replicates effectively minimized costs while preserving the maximum number of samples for further analysis.

PCR reactions were prepared step-by-step following a unidirectional workflow. Three negative controls (blanks) and three positive controls (DNA previously analysed and validated in terms of genotyping success and quality) were included per PCR reaction plate. PCR amplifications were then performed in a 8 or 10 µl final volume containing 4 or 5 µl of mastermix Taq Polymerase (Type-It Microsatellite PCR Kit, Qiagen), 0.91 µL of pool A, 0.80 µL of pool B, or 1.66 µL of pool C, with primers pair concentrations ranging from 0.12 µM to 1.00 µM, and a mean of 30 ng of genomic DNA. For each pair of primers, one was coupled to a fluorescent dye. Our PCR thermal protocol consisted of 95°C for five minutes, followed by 35 cycles of 95°C for 30 seconds, 57°C (A) or 59°C (B) or 56.8°C (C) for 90 seconds, and 72°C for 30 (A&B) or 45 (C) seconds, ending with an extension of 60°C for 30 minutes.

PCR products were resolved on a calibrated ABI PRISM 3130 XL capillary sequencer (ThermoFisher Scientific) under denaturing conditions (HiDi Formamide, ThermoFisher Scientific) with an internal size marker prepared once and dispatched equally in all sample wells of each marker run. This internal size marker guarantees the same calibration for all samples. As all the samples were distributed on multiple plates and each plate contained the same positive reference controls (previously genotyped once), all positive controls were run multiple times on each marker to guarantee both amplification and capillary resolution repeatability.

The electropherograms were analysed using GENEMAPPER 4.1 (ThermoFisher Scientific) and independently assessed by two analysts to determine the allele sizes for each marker for each sample. Analysts are trained to differentiate between peaks due to true alleles and those due to artefacts. They only kept annotations corresponding to true alleles and erased those due to artefacts. Thus, any remaining allele after analysts scoring was considered a true allele and retained in the consensus genotype of the sample. When the genotypes identified by each analyst did not match, the electropherograms were read again, and reading errors were resolved to create a consensus genotype for each sample. In addition, markers with more than two true alleles retained, or with alleles for which a persistent disagreement occurred on the call, were subsequently considered missing data. The genotype of each positive control was compared to its known reference to ensure the repeatability of the analyses. A quality index (QI) was calculated for each sample by comparing each replicate genotype at each marker to the consensus genotype (Miquel, et al. 2006). The QI were averaged over all repeats for each locus, and then over all loci for each sample to obtain a QI per sample. Only samples presenting a QI superior to 0.5, or a minimum of ten markers successfully amplified were included in the subsequent analyses.

Genetic recaptures and genotyping error rates

Genotypes were pairwise compared among all samples. Samples with identical or very close genotypes were associated to a single individual, specifically, when all markers were identical, or when a difference from the consensus on one or two markers occurred and could be attributed to allelic dropout or to a false allele.

The different genotypes assigned to an individual were compared to the individual consensus to calculate residual allelic dropout and false allele by direct counting over all loci and all samples.

Species confirmation

To confirm the species of the identified individuals, the mitochondrial cytochrome b sequence was amplified and sequenced using a cocktail of designed primers, including three forward and three reverse primers:

PCa-Cytb-F1
(5’-ATGACCAACATYCGAAAATCRYACC-3’),
PCa-Cytb-F2
(5’-ATGACCAACATYCGAAAAYCYCACC-3’),
PCa-Cytb-F3
(5’-ATGACCAACATTCGYAAAACYCACC-3’),
PCa-Cytb-R1
(5’-AGGATRAARTGGAARGCGAAGAATCG-3’),
PCa-Cytb-R2
(5’-AGGATGAARTGGAATGCRAARAATCG-3’),
and PCa-Cytb-R3
(5’-AGGATRAAGTGGAARGCRAAGAATCG-3’).

This standard set of primers was designed to amplify cytochrome b sequences from all mammal species. PCR reactions were performed in a final volume of 10 µl, containing 5 µl of mastermix Taq Polymerase (Type-It PCR Kit, Qiagen), 0.21 µM of each primer pair and 2 µl of DNA extract of the highest quality sample assigned to each individual. The PCR thermal protocol consisted of 95°C for 5 minutes, followed by 40 cycles of 95°C for 30 seconds, 55°C for 90 seconds, and 72°C for 45 seconds, ending with an extension step of 60°C for 30 minutes. The PCR products were sequenced bidirectionally following the Sanger method with the BigDye® Terminator v3.1 Cycle Sequencing Kit (Life Technologies) and the same primers. Following purification, the sequences were analyzed using an ABI PRISM 3130 XL capillary sequencer (Applied Biosystems), with electropherograms inter-preted using SeqMan Pro software (DNASTAR). For each sample, the resulting consensus sequence was compared to public databases with the BLAST online software (http://blast.ncbi.nlm.nih.gov/Blast.cgi). We then analyzed identity scores and E-values to determine the species of each sample (cf. **Supplementary Table S8**).

Test of Hardy-Weinberg Proportions

Hardy-Weinberg proportions were tested for each locus using ML Relate (Kalinowski, et al. 2006) with a 5% threshold. To consider multiple comparisons, the threshold was modified using the Bonferroni correction (Bonferroni, 1936).

Because such correction is often too stringent to allow for the detection of true positives, we also used a less stringent approach, the Benjamini-Hochberg procedure (Benjamini and Hochberg, 1995) to control for false discovery.

Distribution of pairwise genetic distances according to kinship

Monitoring individuals requires the ability to identify them based on their respective genotypes. To do so, the probability that two unrelated individuals would have the same genotype ($P_{uni\ (unrelated)}$) and the probability that two individuals with the same genotype are full siblings ($P_{uni\ (sib)}$)) were estimated (Evett and Weir, 1998).

We also computed the expected distribution of the genetic distance (the number of different alleles between individuals) for each type of relationship, including parent-offspring, full siblings, half siblings, and unrelated. As there is no simple formula to calculate genetic distance greater than zero, an R script was used to compute these distributions using simulations (Pairwise_distance_genotypes.r in GitHub "jmorode/Genetics") based on genotypes pairs generated for each type of relationship.

The simulated genotypes were generated as follows:

- for two unrelated individuals, at each locus, the allele frequencies in the SESR population were used to generate the genotype of each individual by randomly sampling two alleles;
- for parent-offspring, the parent genotype was generated as above. The genotype of the offspring was generated by sampling one allele randomly from its parent and the other randomly following the allele frequencies in the population;
- for full siblings, both unrelated parents were generated as unrelated individuals. Each offspring was then generated by randomly sampling one allele from each parent;
- for half siblings, two unrelated fathers and one mother were first generated as unrelated individuals. One offspring was then generated by randomly sampling one allele from the mother and the other from one father. The other offspring was generated by randomly sampling one allele from the same mother and the other from the other father.

For each kind of relationship, one thousand simulations were performed to estimate the empirical distribution of pairwise genetic distances for a given relationship. Data analyses were carried out in the R statistical environment (version 3.4.3) (R Core Team 2021).

Estimation of genealogical relationships

Relatedness between individual snow leopards was tested using ML Relate software (Kalinowski, et al. 2006). To assess the accuracy of the genealogical relationships inferred by the software, one thousand families of known genotypes were simulated as describe above, using the R script GenerateIndividual.r available on GitHub "jmorode/Genetics". A mother, two unrelated fathers, two full siblings and two pairs of half siblings were generated in each family to test the four ML Relate relationships: parent-offspring, full siblings, half siblings and unrelated. For each family, for the six unrelated individuals, the pair of full siblings, both pairs of half siblings and the six pairs of parent-offspring, the ML Relate inferred relationship was compared to the known one. The accuracy of the software was then estimated based on the percentage of correct relationships found by ML Relate over the 1,000 families.

Results

Scat genotypes

Among the samples gathered during the 2011 to 2019 sampling sessions in the SESR, DNA was extracted from 151 putative snow leopard scat samples, which were genotyped at 20 microsatellite loci. Of these, 65% (n = 98) had a QI equal to or above 0.50 or at least ten markers were successfully genotyped (mean QI of the 98 samples = 0.81) (**Supplementary Table S3**). For comparison, the 53 unusable samples had a mean QI of 0.19. On average, out of the 98 usable samples, 18 loci were successfully genotyped per sample, with 19 to 20 loci genotyped for 57 samples, and 10 to 18 loci genotyped for the other 41 samples.

Direct counting estimated 0.0008 of residual false alleles and 0.011 of residual allelic dropouts over all samples.

Twenty-one unique genotypes were identified from the 98 samples successfully genotyped.

Species confirmation

Mitochondrial cytochrome b sequences of 503 bp were obtained for 16 of these individuals (excluding SL17, for which the best sample did not yield a sufficiently high quality sequence for analysis). All 16 individuals presented the same haplotype. Using the NCBI BLAST tool, this sequence matched with 100% percent identity over its entire length with one haplotype (GenBank accession number KP202269.1) which was identified in several sequences obtained from snow leopard *Panthera uncia* samples (GenBank accession numbers MT423701.1 to MT423723.1 for example). This confirms that the sampled individuals were snow leopards and highlights the low polymorphism of this mitochondrial region at the geographical scale studied.

Test of Hardy-Weinberg Proportions

At the 5% threshold, Hardy-Weinberg proportions were rejected for two loci. However, when multiple testing was considered, either with the Bonferoni correction or with the Benjamini-Hochberg procedure, no locus showed a significant deviation from Hardy-Weinberg proportions (**Supplementary Table S6**). As no significant heterozygote deficiency could be found, there was no evidence of inbreeding and/or population structuring and/or null alleles.

Observed distributions of genetic distances

Genetic distances, defined as the number of different alleles between two individuals, were computed between the 21 unique genotypes. Most distances were between 14 and 24. Very few distances were smaller or equal to three (Fig. 2, Table 1).

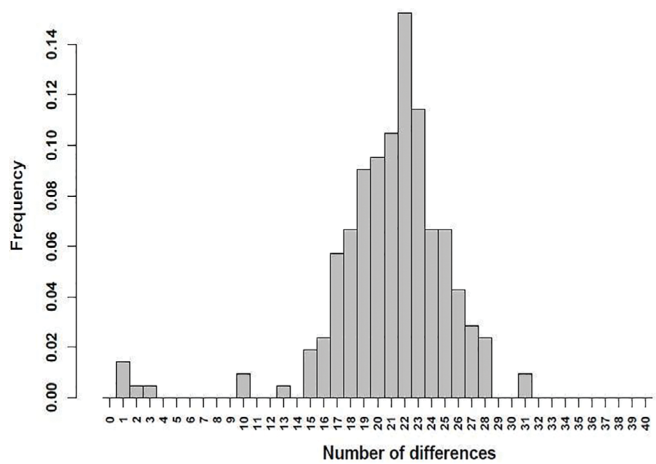

Figure 2: *Distribution of pairwise allelic difference counts between individuals.*

Expected distribution of genetic distances according to genealogical relationships

The calculated $P_{uni\ (unrelated)}$ and $P_{uni\ (sib)}$ were low ($P_{uni\ (unrelated)}$ = 1.13e-13 and $P_{uni\ (sib}$ = 2.18e-6). Using simulations, we also obtained the expected distribution of genetic distances according to kinship level, considering allele frequencies at each locus in the population (**Supplementary Fig. S3**). Considering only distances with a probability > 5%, we found that genetic distances should be in the range of 15 to 22 differences for unrelated individuals, 9 to 14 for parent-offspring, 7 to 14 for full siblings, and 12 to 18 for half siblings.

This indicates that a genetic distance smaller or equal to three would be very unlikely even between full siblings (1 on 1000, Figure S4), and would more likely result from genotyping errors between samples from a same individual. For genotypes with such small distances between them, a consensus genotype was built by retaining the most frequent allele at the locus with probable errors. With this method, the 21 unique genotypes originally identified were assumed to correspond to 17 snow leopards (11 males and 6 females; **Supplementary Table S5**).

Allele frequencies and expected and observed heterozygosity were computed for these 17 individuals (**Supplementary Table S6**).

Relationships between snow leopards

We computed the relationships between snow leopards by using ML Relate on the 17 unique individuals identified (**Supplementary Table S7**) and identified seven parent-offspring, two full siblings, and 16 half-siblings relationships. Each individual was related to at least one and up to six other individuals (Fig. 3).

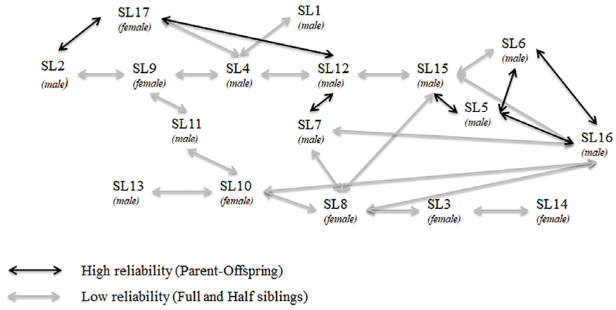

Figure 3: *Relationships between the different individuals and their reliability inferred using the ML-Relate software.*

To determine the reliability of the results from MLRelate, we assessed whether the program was able to accurately identify the relationships between the simulated genotypes of individuals of known kinship. The program has an overall identification accuracy rate of 74%, as it properly identified 93% of parent-offspring relationships, 67% of full-sibling relationships, 58% of half-sibling relationships, and 81% of unrelated individuals.

Monitoring of individuals

Over the study period, 12 individuals were sampled several times (Fig. 4, Table 1). The other five (SL8 (female), SL10 (female), SL11 (male), SL16 (female), and SL17 (male)) were sampled only once, respectively in Uch Baital in 2012, Jaman-suu glacier in 2015, Uch Baital in 2015, Tchong saryetchki in 2019, and Chomoi in 2019. Among the 12 individuals sampled several times, two were sampled only during one year, with SL1 (male) sampled twice in Solomo and once at a location in front of Bashkul (2011), and SL7 (male) sampled three times at Djili suu (2014).

On the contrary, SL2 (male) was sampled multiple times during the study, in 2012, 2013, 2014, 2016, and 2017, in several locations all

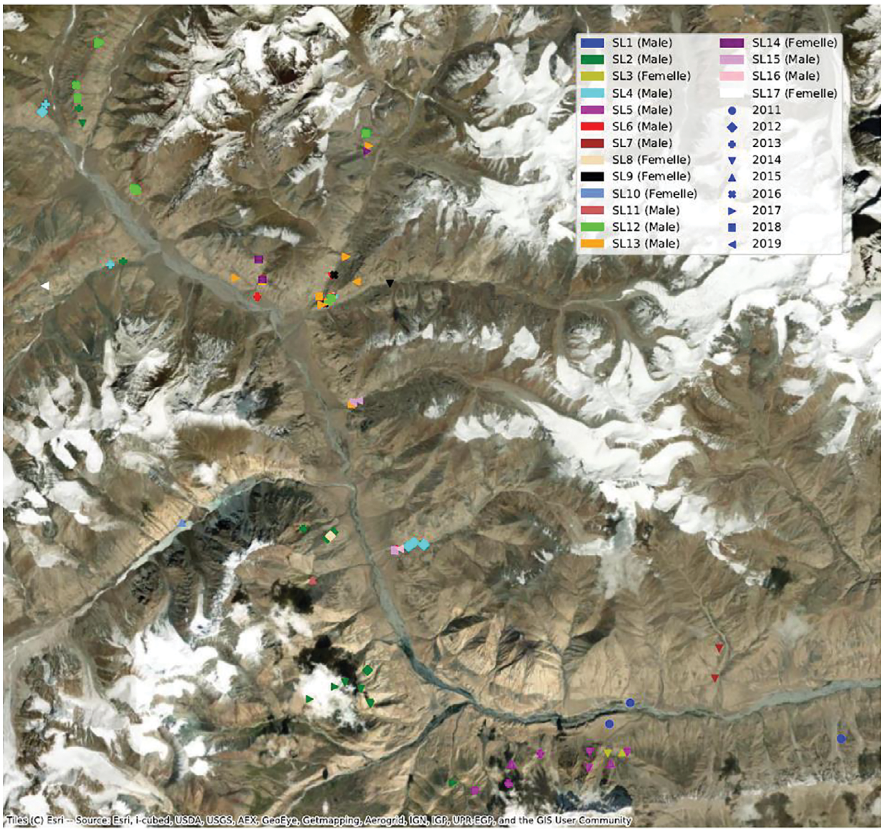

Figure 4: *Map of sampled and genotyped snow leopards inside the SESR from 2011 to 2019. Individual snow leopards are highlighted in different colors and years are indicated with different symbols.*

	Recapture	Sex	SL1	SL1_bis	SL1_ter	SL2	SL2_bis	SL3	SL4	SL5	SL5_bis	SL6	SL7	SL8	SL9	SL10	SL11	SL12	SL13	SL14	SL15	SL16	SL17
SL1	1	Male																					
SL1_bis	1	Male	2																				
SL1_ter	1	Male	1	3																			
SL2	10	Male	21	23	22																		
SL2_bis	7	Male	21	23	22	1																	
SL3	2	Female	20	19	19	21	21																
SL4	10	Male	17	15	18	15	16	19															
SL5	9	Male	19	19	20	22	23	26	21														
SL5_bis	1	Male	19	19	20	23	23	26	22	1													
SL6	12	Male	17	16	18	23	23	26	19	10	10												
SL7	3	Male	24	23	23	22	22	19	25	20	20	21											
SL8	1	Female	22	21	21	23	23	19	21	20	20	18	15										
SL9	4	Female	23	21	22	20	19	22	15	24	24	21	24	22									
SL10	1	Female	23	22	22	21	22	18	23	19	20	20	16	13	25								
SL11	1	Male	23	21	22	17	18	20	17	24	25	23	25	20	18	17							
SL12	12	Male	22	21	23	18	17	23	17	22	22	20	19	17	22	21	24						
SL13	13	Male	26	26	27	22	23	27	21	26	27	24	25	25	26	18	23	25					
SL14	3	Female	20	19	21	18	18	18	16	22	22	20	23	25	22	22	22	24	22				
SL15	4	Male	22	21	23	20	20	19	19	18	18	19	20	19	23	22	22	16	24	21			
SL16	1	Male	27	25	28	24	24	27	26	17	17	18	20	21	23	22	28	24	31	25	21		
SL17	1	Female	22	24	22	17	17	26	21	28	28	25	28	24	20	27	25	22	31	25	25	19	

Table 1: *Pairwise allelic difference counts between individuals. Red background: distance = 1; blue background: distance = 2; green background: distance = 3*

along and on both banks of the Ertash River with a total of 17 scats retrieved. SL5 (male) was also sampled 4 years in a row, from 2013 to 2016, in the Solomo and Sirdibai (ten scats in total).

Other individuals were resampled in different areas of the reserve for two or three years. On the male side: SL6 (12 scats) in 2013, 2014, 2016 and SL12 (12 scats) from 2016 to 2019, both on the upper part of the Ertash River; SL4 (ten scats) in 2012 and 2013 along the Ertash River; SL13 (13 scats) from 2016 to 2019, centered on and around the Koilou valley; and SL15 (four scats) sampled three times in Kitchi Sary Etchki (2018 and 2019), and once in Tchong Sary Etchki (2018). For the three remaining females, SL3 (two scats) was sampled in Solomo in 2014 and 2015; SL9 (four scats) in Kitchi Koilou in 2014 and Chong Koilou and Ortho Koilou in 2016; finally SL14 (three scats) was sampled in Chong Koilou and Kirk choro in 2017-2018.

We detected new individuals every year, and thus far this number has not plateaued (Fig. 5).

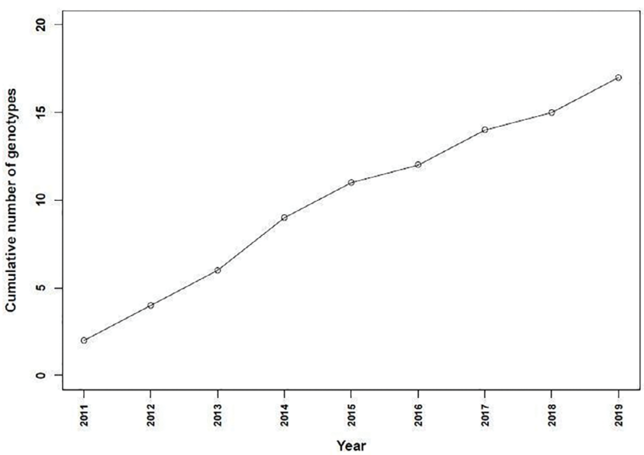

Figure 5: *Cumulative number of identified individual snow leopards by year based on the minimum number of individuals retrieved by grouping samples with genotyping errors (cf. text).*

Discussion

A total of 98 of the 151 collected samples (65%) were genotyped with at least ten markers and a QI equal to or above 0.5. Samples were presumably difficult to genotype because of their degradation due to high mountain weather conditions and UV light, which led to 53 unusable samples (mean QI = 0.19). For the remaining 98 usable samples, genotyping was rather robust based on mean QI (0.81) as well as resulting dropout (0.011) and false allele (0.0008) rates. From 2015, the improvement of the storing protocol – systematic drying, use of silicagel and a coffee filter to protect from the silicagel – appeared to help slow DNA degradation. Reduced time between sample collection and DNA extraction was also linked to an increase in the number of samples successfully genotyped.

From the genotyped samples, 17 individuals were identified in the SESR, with a sex ratio of 11:6 male to female. This number of snow leopards is similar to previous estimates from genetic sampling (18 in 2009) and camera trapping (15 in 2014) performed within the SESR (McCarthy and Mallon 2016). At present, there are more males than females, but snow leopard sex ratio is known to be highly variable (Sharma, et al. 2014), and hence it should be re-examined in the coming years to note any changes.

New individuals were sampled every year, which could be explained by

i) a partial sampling of the whole population each year;
ii) the presence of new offspring in the area; or
iii) individuals dispersing or moving in or through the SESR from outside areas.

Genealogical relationships

With our data set, some putative relationships were identified: seven parent-offspring relationships, two full siblings and 16 half-siblings. However, these results should be interpreted with caution until further verification is conducted. The seven identified parent-offspring relationships included SL6 and SL5 (both sampled between 2013 and 2016); SL5 and SL15 (sampled in 2018 and 2019); SL16 (sampled in 2019) with both SL5 and SL6; SL12 and SL7, respectively sampled from 2016 to 2018 and in 2014; and finally SL17 (sampled in 2019) with both SL2 (sampled between 2011 and 2017) and SL12 (sampled from 2016 to 2018). Using simulated data, ML Relate identified parent-offspring relationships effectively, achieving 93% accuracy rate. This suggests that the observed relationships may have some degree of validity. However, SL16 and SL17 have incomplete genotypes, making their genealogical relationships less reliable. In the future, more data and more evidence to support parent-offspring relationships could be gathered by camera trapping as it is possible to observe cubs with their mother over two years before dispersal (Jackson, et al. 2006; Alexander, et al. 2016; Rode, et al. 2021). Other full-siblings and half-sibling relationships are less certain, as we found that ML Relate was unable to effectively identify these relationships using simulated genotypes, achieving identification rates of 67% and 58%, respectively.

Monitoring of individuals over time

Among the 17 identified individuals, 12 were detected multiple times. Males have been shown to have larger home ranges than females (Johansson, et al. 2015). SL2 was detected across the largest area within the reserve, with samples collected from seven different transects along both banks of the Ertash River. The transects were located approximately 25 kilometers apart at their furthest points. Other individuals were detected around a couple of valleys at various locations along the Ertash River and nearby. In addition, some individuals were detected on both banks of the Ertash River, for which there is no documented evidence that they cross yet.

The close proximity of samples collected from different individuals indicates that various snow leopards may visit marking areas; however, collar data from other studies suggests that snow leopards are generally territorial (Ahlborn and Jackson 1988; McCarthy, et al. 2005; Johansson et al. 2016; Rode, et al. 2021).

It is also worth noting that feces from juveniles (under one year old) were likely missed because they are difficult to recognize and may degrade faster than adult's scats, as observed for other species such as the brown bear (Sentilles, Delrieu & Quenette, 2016). Furthermore, in May 2018, the WWF carried out a genetic study in the SESR and collected all samples identified as snow leopard scats within a week. Consequently, during our subsequent missions that year, we missed part of the scats deposited earlier in the year and were only able to collect those deposited after May.

While this microsatellite-based genetic study represents a costly monitoring effort, it offers valuable insights that complement camera-trap analyses by providing a deeper understanding of the genetic status of the SESR snow leopard population, including potential insights into inbreeding and kinship.

Cross-referencing the results of this study with camera-trap data from the same area would yield additional information on behavior, precise sighting dates, and litter composition.

Citizen sciences sample collection

The citizen science program of OSI Panthera has allowed the sampling of snow leopard feces over nine summer seasons inside the SESR. In addition, the program fulfils an educational mission by raising awareness among volunteers about the importance of protecting wildlife and ecosystems. It trains participants in non-invasive wildlife observation techniques, specifically focusing on detecting signs of snow leopard presence. Another of the program's educational aims is to enhance the training of park rangers in data collection methodologies, empowering them to effectively apply their naturalist expertise for wildlife and ecosystem research. The program is financially supported by paid registrants, with volunteers going in the field to support scientists while they perform the collection of samples and other environmental data, and set up/control camera traps. As a result, data retrieval is not solely dependent on research grants and could, in some circumstances, be more sustainable in the long term (Couvet, et al. 2008).

Conclusion

This study allowed us to gather information on the snow leopard population of the SESR between 2011 and 2019, during which we identified a minimum of 17 individuals. The recapture of 12 individuals over the years provided insights into the areas they were utilizing within the SESR. Additionally, we attempted to assess genetic relationships between individuals, although this requires further validation. We will continue the long-term monitoring of this population through non-invasive sampling and by incorporating data obtained from camera traps. This approach will further refine our understanding of the population status, which is crucial for informing future conservation actions.

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Ethics approval

An authorization from the Kirgiz Ministry of Natural Resources, Ecology and Technical Oversight was given to OSI-Panthera program allowing scat collection, in accordance to the Nagoya protocol.

Competing Interests

No known conflicts of interests.

Data Availability

All data are available in supplementary materials.

Literature Cited

Ahlborn GG, Jackson RM. 1988. Marking in free-ranging snow leopards in west Nepal : A preliminary assessment. In Proceedings of the Fifth International Snow Leopard Symposium (p. 2549).

Alexander JS, Zhang C, Shi K, Riordan P. 2016. A granular view of a snow leopard population using camera traps in Central China. Biological Conservation 197:27-31.

Aziz MA, Tollington S, Barlow A, Greenwood C, Goodrich JM, Smith O, Shamsuddoha M, Islam MA, Groombridge JJ. 2017. Using non-invasively collected genetic data to estimate density and population size of tigers in the Bangladesh Sundarbans. Global Ecology and Conservation 12:272-282.

Bhagavatula J, Singh L. 2006. Genotyping faecal samples of Bengal tiger *Panthera tigris tigris* for population estimation: A pilot study. BMC Genetics 7:48.

Benjamini, Y., Hochberg, Y. 1995. Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. Journal of the Royal Statistical Society. Series B (Methodological), 57(1), 289–300.

Bonferroni, C. 1936. Bonferroni, C. (1936). Teoria statistica delle classi e calcolo delle probabilita. Pubblicazioni del R Istituto Superiore di Scienze Economiche e Commericiali di Firenze, 8, 3-62.

Couvet D, Jiguet F, Julliard R, Levrel H, Teyssedre A. 2008. Enhancing citizen contributions to biodiversity science and public policy. Interdisciplinary Science Reviews 33:95-103.

Evett, I. W. and B. S. Weir (1998). Interpreting DNA evidence: statistical genetics for forensic scientists. Sunderland, Sinauer Associates Inc.).

Jackson RM, Hunter DO. 1996. Snow Leopard Survey and Conservation Handbook. International Snow Leopard Trust, Seattle, Washington and U.S. Geological Survey, Fort Collins Science Center, Colorado.

Jackson RM, Roe JD, Wangchuk R, Hunter DO. 2006. Estimating Snow Leopard Population Abundance Using Photography and Capture-Recapture Techniques. Wildlife Society Bulletin (1973-2006) 34:772-781.

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.

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.

Jumabay-Uulu K, Wegge P, Mishra C, Sharma K. 2014. Large carnivores and low diversity of optimal prey: a comparison of the diets of snow leopards *Panthera uncia* and wolves *Canis lupus* in Sarychat-Ertash Reserve in Kyrgyzstan. Oryx 48:529-535.

Kalinowski ST, Wagner AP, Taper ML. 2006. ML-RELATE: a computer program for maximum likelihood estimation of relatedness and relationship. Molecular Ecology Notes 6:576-579.

Koivisto I, Wahlberg C, Muuronen P. 1977. Breeding endangered species in captivity. International Zoo Yearbook 17:39-44.

Koshkarev E, Vyrypaev V. 2000. What has happened to the snow leopard since the break-up of the Soviet Union? Cat News 32:9–11.

Macdonald D, Loveridge A. 2010. The biology and conservation of wild felids: Oxford University Press.

McCarthy KP, Fuller TK, Ming M, McCarthy TM, Waits L, Jumabaev K. 2008. Assessing Estimators of Snow Leopard Abundance. Journal of Wildlife Management 72:1826-1833.

McCarthy T, Mallon D, Jackson R, Zahler P, McCarthy K. 2017. *Panthera uncia* The IUCN Red List of Threatened Species 2017: e.T22732A50664030.

McCarthy TM, Chapron G. 2003. Snow Leopard Survival Strategy. International Snow Leopard Trust and Snow Leopard Network. Seattle, USA.

McCarthy TM, Fuller TK, Munkhtsog B. 2005. Movements and activities of snow leopards in Southwestern Mongolia. Biological Conservation 124:527-537.

McCarthy TM, Mallon D. 2016. Snow leopards. Biodiversity of the World: Conservation from Genes to Landscapes. London, UK: Academic Press.

Menotti-Raymond M, David VA, Lyons LA, Schäffer AA, Tomlin JF, Hutton MK, O'Brien SJ. 1999. A Genetic Linkage Map of Microsatellites in the Domestic Cat (Felis catus). Genomics 57:9-23.

Miquel C, Bellemain E, Poillot C, BessiÈRe J, Durand A, Taberlet P. 2006. Quality indexes to assess the reliability of genotypes in studies using noninvasive sampling and multiple-tube approach. Molecular Ecology Notes 6:985-988.

Mondol S, Ullas Karanth K, Samba Kumar N, Gopalaswamy AM, Andheria A, Ramakrishnan U. 2009. Evaluation of non-invasive genetic sampling methods for estimating tiger population size. Biological Conservation 142:2350-2360.

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

Pacifici, M., Santini, L., Di Marco, M., Baisero, D., Francucci, L., Marasini, G. G., Visconti P., Rondinini, C. 2013. Generation length for mammals. Nature Conservation, 5, 89-94.

Pilgrim KL, McKelvey KS, Riddle AE, Schwartz MK. 2005. Felid sex identification based on noninvasive genetic samples. Molecular Ecology Notes 5:60-61.

R Core Team. 2021. R: A Language and Environment for Statistical Computing. Vienna, Austria.: R Foundation for Statistical Computing.

Rieger I. 1980. Some aspects of the history of ounce knowledge. Book of Snow Leopards 2:1-36.

Rode J, Lambert C, Marescot L, Chaix B, Beesau J, Bastian S, Kyrbashev J, Cabanat A-L. 2021. Population monitoring of snow leopards using camera trapping in Naryn State Nature Reserve, Kyrgyzstan, between 2016 and 2019. Global Ecology and Conservation 31:e01850.

SER. 2007. The Sarychat-Ertash State Reserve Management Plan 2007–2015. Bishkek, Kyrgyzstan. In.

Sentilles J., Delrieu N. & Quenette P.-Y. 2016. Un chien pour la détection de fèces : premiers résultats pour le suivi de l'ours brun dans les Pyrénées. Faune sauvage, bulletin de l'ONCFS, 312, pp.22-26

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.

Snow Leopard Network. 2014. Snow Leopard Survival Strategy. Revised 2014 Version Snow Leopard Network, Seattle, Washington, USA.

Sugimoto T, Nagata J, Aramilev VV, McCullough DR. 2012. Population size estimation of Amur tigers in Russian Far East using noninvasive genetic samples. Journal of Mammalogy 93:93-101.

Taberlet P, Griffin S, Goossens B, Questiau S, Manceau V, Escaravage N, Waits LP, Bouvet J. 1996. Reliable Genotyping of Samples with Very Low DNA Quantities Using PCR. Nucleic Acids Research 24:3189-3194.

Snow Leopard Trust. (2021). Where are the snow leopards? Snow Leopard Trust: https://snowleopard.org/where-are-the-snow-leopards/

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Snow leopard digging for water in an arid environment

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Abstract

Adaptations to arid environments, involving strategies to conserve and utilize water, are vital for wildlife. Water availability in these regions depends on seasonal rainfall, and subsequently affect species distribution and behavior. This note documents a snow leopard (*Panthera uncia*) in the Tost Mountains of southern Mongolia digging for water, a previously undocumented behavior. The first author identified evidence of snow leopards digging for water. Camera traps were then used in an attempt to document this behavior. Unique pelt patterns identified one snow leopard digging for water in the summer of 2022, with drinking observed. Other species also drank at the site, suggesting snow leopards could act as ecological engineers by providing water for other species. Four other snow leopards were observed to visit

the site in the late fall, winter, and early spring of 2022 and 2023. These snow leopards did not dig or drink, but this may largely have been related to subzero temperatures (-15°C to -30°C) and the ground being frozen for most of this period. The snow leopard digging for and exposing water may help to support biodiversity in desert ecosystems. However, further research is needed to determine its prevalence and impact. Understanding these strategies is crucial for conservation, especially with increasing droughts and extreme weather in arid landscapes.

Main text

Adaptations to arid environments among wildlife represent an evolutionary strategy aimed at water conservation and utilization (Rymer et al. 2016). These adaptations, encompassing anatomical, physiological, and behavioral facets, are crucial for survival in regions where water is a scarce and limited resource (Rymer et al. 2016; Cain et al. 2006; Gedir et al. 2020). Water availability in arid and semi-arid environments depends on rainfall, which often varies greatly among and within years, with most of the annual precipitation falling during a few months of the year (Perrin et al. 2012). Seasonal variation in rainfall determines water levels and its availability, which can shape the dynamics of communities and influence species distribution and behavior (Miranda et al. 2011, Kaczensky et al. 2010, de Boer et al. 2010).

Here we report on the observation of a snow leopard (*Panthera uncia*) digging for water in a desert ecosystem in the Tost Mountains in southern Mongolia (43.2° N, 100.7° E). Snow leopards are large carnivores adapted to the rugged terrain of High Asia (Fox et al. 2023). While much attention has been directed towards understanding their ecology and behaviors, their strategies for coping with arid conditions is poorly described. There are also limited observations of large felids digging for water.

The first author, who was born and raised in the Tost Mountains, identified evidence of a snow leopard digging to possibly access water, by observing distinct paw marks and scrape marks at a temporary water hole near his home. We used camera traps to assess this behavior further and evaluate the potential role of snow leopards as ecological engineers.

Ecological engineers are species that directly or indirectly shape the environment in ways that impact other organisms (Hastings et al. 2007). Our study explores how snow leopards, through their digging behavior, modify the environment to access subsurface water sources, thereby possibly providing water sources for other species.

We placed two camera-traps at the site where the first author had noted evidence of snow leopards digging for water, capturing videos to ensure continuous images of any activity. This site was located in a rocky valley in the southern part of the Tost Mountains. The soil was sandy and surrounded by rocky outcrops, typical of the area. The desert here receives less than 130 mm of precipitation per year. We deployed camera traps from May 5 to July 17, 2022 and again between October 10 to March 17, 2023 to examine if the same behaviour could be observed during the autumn, winter or spring seasons. The snow leopards captured on the cameras were identified by their unique pelt pattern (Johansson et al. 2020).

In the spring and early summer of 2022, we identified two occurrences where the same snow leopard engaged in digging behavior

Figure 1. *Snow leopard (top left panel) digging for water in the Tost Mountains in southern Mongolia. Also shown are other species that appeared to drink from where the snow leopard was digging for water (stone marten top right panel, chukar lower left panel, and red fox lower right panel).*

(Figure 1). The snow leopard, that we identified as a male from previous camera trapping work, was photographed drinking water on both of these occasions, which suggests that the digging may have been related to accessing water or uncovering food sources beneath the surface. The observed digging behavior involved the snow leopard raising its front paws one by one. It positioned each paw on the ground and then pulled them back with sufficient force to displace the dirt beneath. This action likely aimed to create a depression for drinking or to uncover water sources hidden beneath the surface. We also observed the following species appearing to drink at the site after the snow leopard had been digging: red fox (*Vulpes vulpes*), chukar (*Alectoris chukar*) and stone marten (*Martes foina*) (Figure 1).

In the late fall, winter, and early spring of 2022 and 2023, when temperatures were mostly subzero and the ground was frozen most of the time, the cameras captured fifteen instances of four different snow leopards walking by the cameras, with one smelling the site. The snow leopards did not appear to drink during any of these fifteen visits. Other wildlife photographed during this period included red foxes, Siberian ibex (*Capra sibirica*), chukars, and hares (*Lepus sp.*). We also documented one free-ranging dog (*Canis lupus familiaris*) and one goat (*Capra aegagrus hircus*). None of these animals appeared to drink at the site.

By digging for water, the snow leopard may have provided water for other animals, potentially contributing to the maintenance of biodiversity in this desert ecosystem. However, our study is limited to one snow leopard digging for water and we do not know how common this behavior is among snow leopards in arid landscapes or if it is a behavior learned by this specific individual. Further research is therefore needed to comprehensively assess the extent and broader implications of this behavior. In particular, investigations into the influence of water availability on the behavior and population dynamics of snow leopards and associated species would be of interest.

This observation provides a glimpse into snow leopard behaviors in arid landscapes. Droughts are common in the South Gobi of Mongolia and can occur even during the cold winter (Begzsuren et al 2004). In extreme cases, winter droughts and "dzuds" (extreme weather conditions) result in mass die-offs of livestock (Begzsuren et al 2004). Some wildlife, including the Khulan (*Equus hemionus hemionus*), cope with localized catastrophic weather events by being highly mobile, but this requires habitat connectivity at a landscape level and the protection of critical habitats that function as dispersal corridors (Kaczensky et al 2010). However, there is little knowledge on how other species, such as snow leopards, cope with droughts and other catastrophic weather events. We therefore recommend further studies to assess how common it is for snow leopards to dig for water, why they dig for water, and how this supports other species in desert ecosystems.

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References

Begzsuren, S., Ellis, J. E., Ojima, D. S., Coughenour, M. B., & Chuluun, T. (2004). Livestock responses to droughts and severe winter weather in the Gobi Three Beauty National Park, Mongolia. *Journal of Arid Environments, 59*(4), 785–796. DOI: 10.1016/j.jaridenv.2004.02.001

Cain III, J. W., Krausman, P. R., & Rosenstock, S. S. (2006). Mechanisms of thermoregulation and water balance in desert ungulates. *Wildlife Society Bulletin, 34*(4), 570–581.

de Boer, W. F., Vis, M. J. P., de Knegt, H. J., Rowles, C., Kohi, E. M., van Langevelde, F., Peel, M., Pretorius, Y., Skidmore, A. K., Slotow, R., van Wieren, S. E., & Prins, H. H. T. (2010). Spatial distribution of lion kills determined by the water dependency of prey species. *Journal of Mammalogy, 91,* 1280-1286.

Fox, J. L., Chundawat, R. S., Kachel, S., Tallian, A., & Johansson, O. (2023). What is a snow leopard? Behavior and ecology. In T. McCarthy, D. Mallon, & K. R. Schwartz (Eds.), *Snow leopards: Biodiversity of the world: Conservation from genes to landscapes* (pp. 15-29). Academic Press.

Gedir, J. V., Cain III, J. W., Swetnam, T. L., Krausman, P. R., & Morgart, J. R. (2020). Extreme drought and adaptive resource selection by a desert mammal. *Ecosphere, 11*(7), e03175. DOI: 10.1002/ecs2.3175

Hastings, et al. (2007). Ecosystem engineering in space and time. *Ecology Letters, 10,* 153-164.

Johansson, Ö., Samelius, G., Wikberg, E., Chapron, G., Mishra, C., & Low, M. (2020). Identification errors in camera-trap studies result in systematic population overestimation. *Scientific Reports, 10*(1), 6393.

Kaczensky, P., Dresley, V., Vetter, D., Otgonbayar, H., & Walzer, C. (2010). Water use of Asiatic wild asses in the Mongolian Gobi. *Erforschung Biologischer Ressourcen der Mongolei, 11,* 291-298.

Miranda, J. D., Armas, C., Padilla, F. M., & Pugnaire, F. I. (2011). Climatic change and rainfall patterns: Effects on semi-arid plant communities of the Iberian Southeast. *Journal of Arid Environments, 75,* 1302-1309. Retrieved from Science Direct Journal of Arid Environments journal homepage: www.elsevier.com/locate/jaridenv

Perrin, J., Ferrant, S., Massuel, S., Dewandel, B., Maréchal, J. C., Aulong, S., & Ahmed, S. (2012). Assessing water availability in a semi-arid watershed of southern India using a semi-distributed model. *Journal of Hydrology, 460,* 143-155.

Rymer, T. L., Pillay, N., & Schradin, C. (2016). Resilience to droughts in mammals: a conceptual framework for estimating vulnerability of a single species. *The Quarterly Review of Biology, 91*(2). Retrieved from University of Chicago Press.

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Snow leopards and water: high waterhole visitation rate by a breeding female in summer

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Abstract

Water is a limiting resource in arid environments where space use of animals is often driven by access to water during the dry times of the year. Here we report on a breeding female snow leopard visiting a waterhole 37 times in June and July in 2015. These observations show that space use of snow leopards can be driven strongly by access to water during certain times of the year such as when lactating and the need for water is increased. Strong dependence on water during certain times of the year suggest that climate change and high human pressure on limited water sources may have negative impact on snow leopards and other wildlife in the mountains of High Asia.

Introduction

Water is essential for all life and is a limiting resource in arid environments where space use of animals is often driven by access to water during the dry times of the year (Valeix et al. 2010, Davidson et al. 2013, Davies et al. 2017). For example, lions often congregate around waterholes during the dry period which appears to be related both to the congregation of their prey at these waterholes but also by the increased need for water by the lions themselves (Valeix et al. 2010, Davidson et al. 2013). The need for water may also be greater during certain life stages such as when mammals are lactating (Oswald et al. 1996, Adams and Hayes 2008). Here we report of a breeding female snow leopard (*Panthera uncia*) that visited a waterhole in Sevrei Mountains in southern Mongolia 37 times in June and July in 2015.

Methods

The observations reported here were made as part of camera-monitoring of snow leopards in southern Mongolia following Sharma et al. (2014). Specifically, the observations reported here were made at a waterhole in Sevrei Mountains (43.6° N, 102.0° E) in June and July 2015. The Sevrei Mountains are part of the Gobi Desert with annual precipitation less than 130 mm and the temperature ranging between -35 in winter and 40° C in summer. The vegetation is sparse and consists mainly of short grasses, dwarf shrubs, and patches of shrubs. We deployed the camera at the waterhole on 2 June and collected it on 1 August 2015. The size of the waterhole varied between about 30 by 30 cm and 50 by 50 cm and did not appear to contain more than a few liters during this study. The cat reported here often turned around when at the waterhole which allowed us to identify both sides of the body. We considered visits to the waterhole that were less than 1 hour apart as the same visit. We also had a camera deployed at the waterhole in the summer of 2016 when the cat reported here was followed by a one-year old cub. This allowed us to confirm that it was a female and that she gave birth in 2015 given that snow leopards are seasonal breeders that give birth in May and June (Johansson et al. 2020).

Results

The female snow leopard visited the waterhole 37 times in June and July in 2015 which corresponds to one visit every 1.6 days on average (range between visits = 1 hour and 32 minutes to 144 hours and 19 minutes, Figure 1). On nine days she visited the waterhole twice and one day she visited the waterhole three times (Figure 2). The longest time between visits was six days (13-19 June and 19-25 June) and second longest time between visit was five days (14-19 July). The average length of the visits to the waterhole was 11 minutes and 11 seconds (range = 5 seconds to 32 minutes and 41 seconds). Twenty of the visits were during the night, two during dusk, and fifteen during the day (Figure 2). We saw her drink at the waterhole on 27 of the 37 visits. The female visited the waterhole with a one-year old cub on 31 May in 2016 (Figure 3). Other visitors to the waterhole in June and July 2015 were one male snow leopard visiting the waterhole six times, one visit by a herd of goats (*Capra hircus*) and sheep (*Ovis aries*), eight visits by ibex (*Capra sibirica*) where all

Figure 1. *The female drinking at the waterhole on 8 July in 2015. The red arrows are highlighting three distinct rosettes with two small dots below them that are highlighted also in Figure 3.*

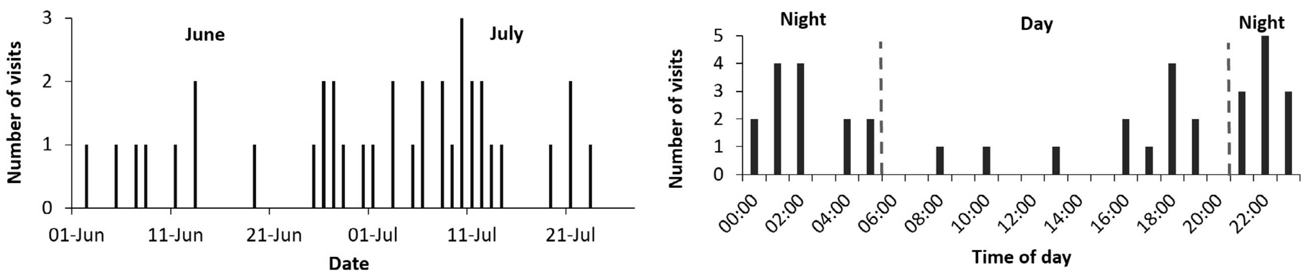

Figure 2. *Time of day (right) and dates (left) when the female snow leopard visited the waterhole in the Sevrei Mountains in June and July 2015. The sun raises at 05:40 and sets at 21:00 on 1 July in the Sevrei Mountains.*

Figure 3. *The female (walking to the left) with a one-year old cub (laying down) at the waterhole on 31 May in 2016. The red arrows are highlighting three distinct rosettes with two small dots below them that are highlighted also in Figure 1.*

visits were by one individual per visit, and several visits by red foxes (*Vulpes vulpes*), stone martens (*Martes foina*), and chukar partridges (*Alectoris chukar*).

Discussion

The breeding female visiting the waterhole 37 times in June and July shows that space use of snow leopards can be driven strongly by access to water during certain times of the year. The female giving birth in 2015 also suggests that the high visitation rate to the waterhole was related to increased need for water when producing milk and lactating the young and that her den was located near the waterhole (Oswald et al. 1996, Adams and Hayes 2008). We commonly see snow leopards visiting waterholes also at other locations but have not seen the same individual visiting a waterhole more than 10 times during two to three months of camera-trapping in the neighboring Tost Mountains in 2009 to 2023 (Snow Leopard Trust and Snow Leopard Conservation Foundation, unpublished material). We suggest that the den of the female reported here was likely located close to the waterhole and that visiting the waterhole as frequently as reported here therefore had limited impact on the time available for hunting and other behaviors.

Central Asia is warming at more than twice the average rate than the rest of the northern hemisphere and climate induced changes in the water dynamics may have negative effects on the ecology of snow leopards and other wildlife in High Asia (Liu and Chen 2000, Chen et al. 2009). For example, climate warming and changes in the water dynamics can have negative impact on the number of lactating bats and our results suggest that the impact of climate change and reduction in access to water could have similar effects on reproductive output of snow leopards and other animals in the mountains of Central Asia (Adams and Hayes 2008). Growing human pressures on limited water sources may also affect access to water for snow leopards and other wildlife in that large-scale mining activities and increasing livestock numbers may affect the water sources negatively (Andrew et al. 1997, Kaczensky et al. 2010, Boldy et al. 2021). A better understanding of the importance of water for the ecology of snow leopards and other wildlife is therefore important for wildlife conservation in High Asia.

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References

Adams R.A. and Hayes M.A. 2008. Water availability and successful lactation by bats as related to climate change in arid regions of western North America. Journal of Animal Ecology 77: 1115-1121.

Andrew N.G., Lesicka L.M. and Bleich V.C. 1997. An improved fence design to protect water sources for native ungulates. Wildlife Society Bulletin 25: 823-825.

Boldy R., Santini T., Annandale M., Erskine P.D. and Sonter L.J. 2021: Understanding the impacts of mining on ecosystem services through a systematic review. The Extractive Industries and Society 8: 457-466.

Chen F.,Wang J., Jin L., Zhang Q., Li J. and Chen J. 2009. Rapid warming in mid-latitude central Asia for the past 100 years. Frontiers of Earth Science 3: 42-50.

Davidson Z., Valeix M., Van Kesteren F., Loveridge A.J., Hunt J.E., Murindagomo F. and Macdonald D.W. 2013. Seasonal diet and prey preference of the African lion in a waterhole-driven semi-arid savanna. PLoS ONE 8: e55182.

Davies J.A., Kerezsy A. and Nicol S. 2017. Springs: conserving perennial water is critical in arid landscapes. Biological Conservation 211: 30-35.

Johansson Ö., Ausilio G., Low M., Lkhagvajav P. Weckworth B. and Sharma K. 2020. The timing of breeding and independence for snow leopard females and their cubs. Mammalian Biology 101: 173-180.

Kaczensky P. Dresley V., Vetter D., Otgonbayar H. and Walzer C. 2010. Water use of Asiatic wild asses in the Mongolian Gobi. Erforschung Biologischer Ressourcen der Mongolei 11: 291-298.

Liu X. and Chen B. 2000. Climatic warming in the Tibetan Plateau during recent decades. International Journal of Climatology 20: 1729-1742.

Oswald C., Fonken P., Atkinson D. and Palladino M. 1996. Lactational water balance and recycling in white-footed mice, red-backed voles, and gerbils. Journal of Mammalogy 74: 963-970.

Sharma K., Bayrakcismith R., Tumursukh L., Johansson O., Sevger P., McCarthy T., and 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.

Valeix M., Loveridge A.J., Davidson Z., Madzikanda H., Fritz H. and Macdonald D.W. 2010. How key habitat features influence large terrestrial carnivore movements: waterholes and African lions in a semi-arid savanna of north-western Zimbabwe. Landscape Ecology 25:337-351

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An unusual lowest elevation record of snow leopard (*Panthera uncia*) in Nepal

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Abstract

The snow leopard, *Panthera uncia,* is a flagship species of the mountainous region in South and Central Asia. In Nepal Himalayas, the species is distributed from 3000 to 6000 m. The present finding of a snow leopard on 23 January 2024 at an elevation of 146 m. in Charghare, Urlabari of Morang District was an unusual record. This is the first recorded case of a snow leopard at such a lower elevation. Fortunately, the leopard was rescued promptly and subsequently transferred to the Central Zoo, located in Jawalakhel, Lalitpur for further treatment. An observation of leopard behaviors obtained from a week's CCTV footage reveals that the leopard was very elusive. Two snow leopard scats were collected within a week from the enclosure. These scats were then analyzed using fecal analysis techniques to

identify the prey hair remains in the scats. The analysis revealed that the leopard had consumed naur (*Pseudoys nayaur*) and an unidentified rodent species, as evidenced by the hair samples present in the scats. Additionally, several claws, likely from small rodents, were also recorded, which remain unidentified. This finding strongly suggests that the snow leopard had descended from its usual higher elevations. It is plausible that the leopard may have lost its way and ended up in densely populated human settlements. This has opened a new avenue for research in this area. There is now a pressing need for joint collaborative research to assess the corridors and connectivity crucial for the survival of these magnificent species.

Introduction

The snow leopard, *Panthera uncia*, is a flagship species of the mountainous region in South and Central Asia. They are sparsely distributed across twelve countries in Central Asia. Research on this species has been limited due to its elusive nature and the harsh habitats it inhabits. Several threats have been identified and documented throughout their distributional ranges. Major threats included are – retaliatory killing due to livestock depredation, poaching, and degradation of habitat due to anthropogenic activities and global climate change (McCarthy et al. 2017). The species is listed as Vulnerable on the International Union for the Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species (McCarthy et al. 2017). Snow leopards are also listed in Appendix I of the Convention of International Trade in Endangered Species (CITES). In Nepal, the species is protected under the National Park and Wildlife Conservation Act, 1973, and is listed as Endangered in the National Red List Series (Jnawali et al. 2011). The range of the Snow Leopard extends from the Himalayas in the south, across the Qinghai-Tibet Plateau and the mountains of Central Asia to the mountains of southern Siberia in the north (McCarthy et al. 2027). According to McCarthy et al. (2017), the estimated number of mature individuals in the wild is roughly in the range of 2710-3386. In Nepal, a robust estimate is still unavailable, however, it is believed to be in the range of 301-400 (MoFSC, 2017).

Snow leopards inhabit mountainous range at elevations of 3000 to 6000 m in the Himalayas and Tibetan Plateau but can also found as low as 500 m in the Altai region of Mongolia (Snow Leopard Network 2014). Although snow leopards are known to exist in relatively flat or rolling areas such as in parts of Mongolia and the Tibetan Plateau (Schaller et al. 1998, McCarthy 2000), within their habitat, they favor steep, rugged, and broken terrain and rocky outcrops (Jackson et al. 2010). There is substantial variation in the reported home range sizes for snow leopards. In Nepal, Jackson and Ahlborn (1989), using ground based very high frequency (VHF) tracking reported home ranges of five individuals between 12 and 39 km^2, with substantial overlap between individuals and sexes. McCarthy et al. (2005) reported the home range size of four snow leopards based on VHF tracking in Mongolia to range between 13 and 141 km^2. Recently, based on 16 GPS collars snow leopards, Johanson et al. (2016) estimated that the mean home range size based on the local convex hulls (LoCoH) was 207 km^2 ± 63 SD for adult males and 124 km^2 ± 41 SD for adult females. These estimates were 6–44 times larger than earlier estimates based on VHF technology.

Dispersal is a key component of population dynamics and plays a critical role in the expansion of species distribution and helps in recolonization and maintaining the genetic structure of animal populations (Bohrer et al. 2005, Clobert et al. 2009, Zimmermann et al. 2005, Morales-González et al. 2021, Marucco et al. 2022). In snow leopard, dispersal behaviors are typically observed when cubs reach 20-22 months (Johanson et al. 2021). However, the age of dispersal showed much variation ranging from 23 to ≥ 33 months in both males and females (Johanson et al. 2021). Johanson et al. (2024) observed that both male and female made a long exploratory foray after natal dispersal, often repeating these until they find a suitable area for settling. One female had four excursions before findings a suitable place for settlement. During her excursion, she traveled at least 84 km and turned back to her natal place covering a total distance of at least 157 km. (Johanson et al. 2024). Using GPS collar on three young leopards (2F, 1M), Johannson et al. (2024), found that they traveled a cumulative distance ranging from 16 to 157 km, making multiple attempts until they settled permanently.

The snow leopard recorded in the month of January 2024 from the lowland Tarai region of Nepal at an elevation of 146 m have raised many questions among conservationists (Photo 1). Here, we aim to present possible explanations with regarding the presence of snow leopard in lowland Tarai area of Nepal.

Photo 1. *The snow leopard at bamoo clumps at Chareghare, Urlabari, Morang, in Nepal. The snow leopard hides in bamboo clumps from where it was rescued successfully. (Photo Credit: Gopal Dahal).*

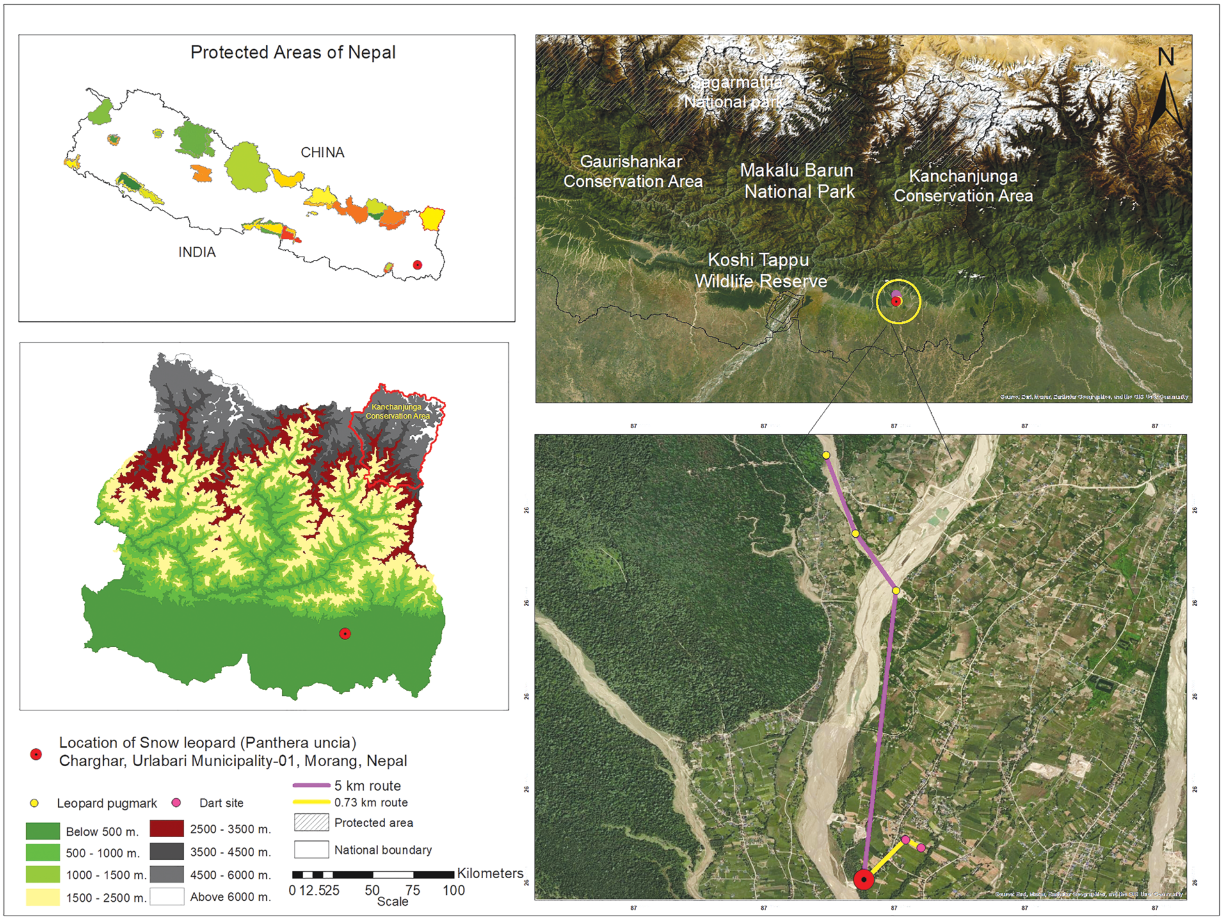

Figure 1. *Location map of the field site where snow leopard was found in lowland Tarai, Nepal.*
Note: The nearest aerial distance at an elevation range of 2500-3500m. from the snow leopard location is between 47 to 57.5 km.

Methods

Field Survey

Between January 28-30, 2024, a team comprised of officials from the subdivision forest office, Urlabari and the National Trust for Nature Conservation-Koshi Conservation Center (NTNC-KCC), visited the snow leopard's first sighting site (Fig 1). The team thoroughly examined the area and interacted with the residents of Charghare. In the Northern part, Bakra Khola (river) is connected to the foothills of the Churia range. A 5 km transect walk on foot along both banks of the dry riverbeds was walked/conducted to search signs such as pugmarks and scrapes.

Behavioral observation and scat analysis

The snow leopard which has been rescued from the lowland Tarai (on 23 January 2024), was carefully monitored within the confines of NTNC Central Zoo, Jawalakhel, Lalitpur. The Zoo is located at an elevation of 1320 m. The leopard was kept in a specialized intensive care zone where it is being nourished with chicken and buffalo meat. The leopard was under CCTV surveillance to monitor its behavior and activities. After six days of rescue, on 29 January 2024, the first scat was found within the enclosure. Following this on 30 January 2024, another scat was collected by zookeepers. The collected scats were analyzed using micro-histological techniques (Chetri et al. 2017) to determine the presence of any remains of wild prey hairs in the scat samples.

Results

Field survey

The team visited the first sighting spot and collected a few hair samples. A five km transect walk along both sides of dry riverbeds at Bakra Khola revealed leopard pugmarks in three distinct locations (Fig 1). However, it was difficult from the pugmarks to identify that it belonged to the same leopard. Field observation revealed that a farmer first spotted the cat around 9:30 hrs on 23 January 2024 in the mustard farm and thought it to be a domestic cat. The farmer hit the leopard with a big mud block and the leopard ran in the opposite direction. When the animal escaped, the farmer realized it was not a domestic cat and started shouting and calling nearby neighbors. Residents then started chasing the animal. The leopard found a secure place amidst a bamboo bush to hide (see Photo 1). Approximately, 400 people gathered, encircling the hiding leopard, and used bamboo sticks from all sides to trap the animal. A resident promptly relayed the message to the Division Forest Office, and immediately, the team from the forest department and NTNC-KCC technicians visited the site and rescued the animal. As the leopard was very weak and injured, it was subsequently transferred to the NTNC-Central Zoo Animal Hospital for further treatment and care. The weight of the leopard was 37 kg. Based on canine and premolar teeth observation, the present leopard is a sub-adult male possibly between 1.5 to 2 years (Stander 1997). The claws are intact, with no enamel flaking and no tearing of the canine and premolar teeth (Photo 2). In addition, no wound marks on the forehead or body parts.

Behavioral observation and scat analysis

The leopard was under CCTV surveillance for observation. We scan the video footage of the leopard movement and behavior for 3 days from 24 to 27 January 2024. The first movement was observed on 25 January 2024 at 4:00 hrs. The leopard woke up; checked his meal, i.e., chicken breast and leg piece and water pot, and started licking the water. He licked the water for 4 minutes, and 17 seconds, remained quiet for another 42 seconds, and settled down. On 26 January 2024, he woke up at 3:53 hrs., checked the meal, and ate the chicken very slowly until 4:02 hrs. From 4:02 to 4:04 hrs. he licks the water, checks the water pots and the cage turning his head around. Later, he bites and crushes the aluminum pot. On 27 January 2024, he started the movement at 20:55 hrs., stretched his body, and seemed quite relaxed. He sat down and licked the water for one minute, shook his body, and again started licking the water, stopped, and turned around to inspect the cage. Later on, he ate the meal very slowly from 20:57 to 21:04 hrs. and settled down. On 12 March 2024, the leopard was shifted to a bigger enclosure.

Two scat samples that were obtained from the cage were analyzed using the methods adopted by Chetri et al. 2017. First, the scats were washed using warm soapy water,

Photo 2. a) *Photo of snow leopard showing its dentition. There is no enamel flaking, full canine eruption, teeth white with no wear. Photo taken after 15 days of rescue, i.e. 06.02.2024.*
b) *Snow leopard in aggressive mood, photo taken after 39 days of rescue, i.e., 01.03.2024 after shifted to bigger enclosure in intensive care zone at Central Zoo.*
(Photo Credit: Madhu Chetri).

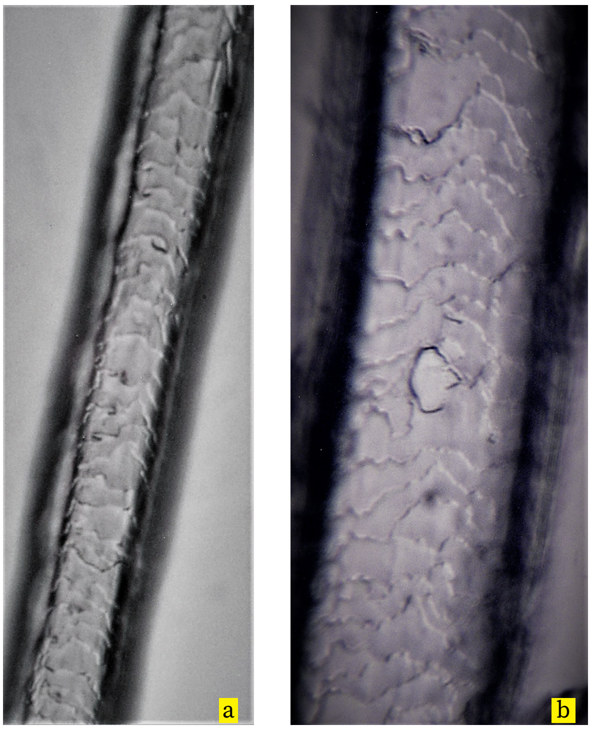

Photo 3. a) *Cuticular section of original naur hair sample,* **b)** *hair impression obtained from scat (Apical section); 200x magnification.*

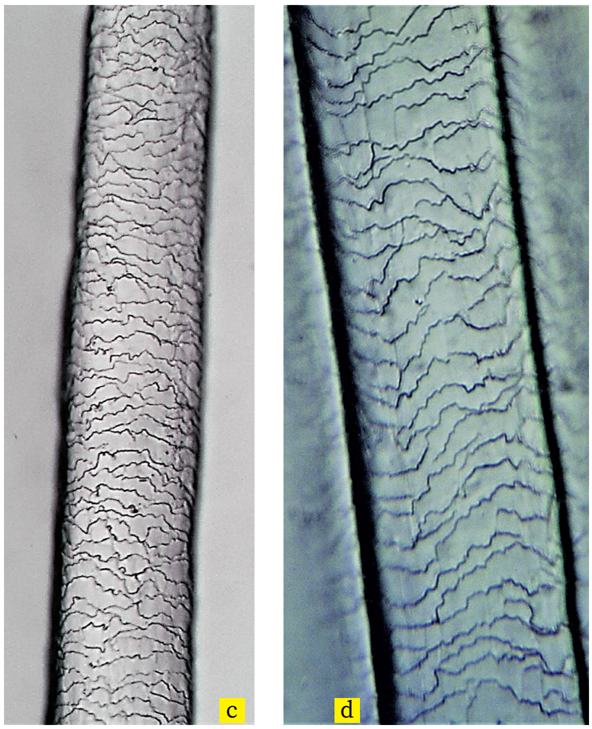

Photo 3. c) *Cuticular section of original naur hair sample,* **d)** *hair impression obtained from scat (medial section); 200x magnification.*

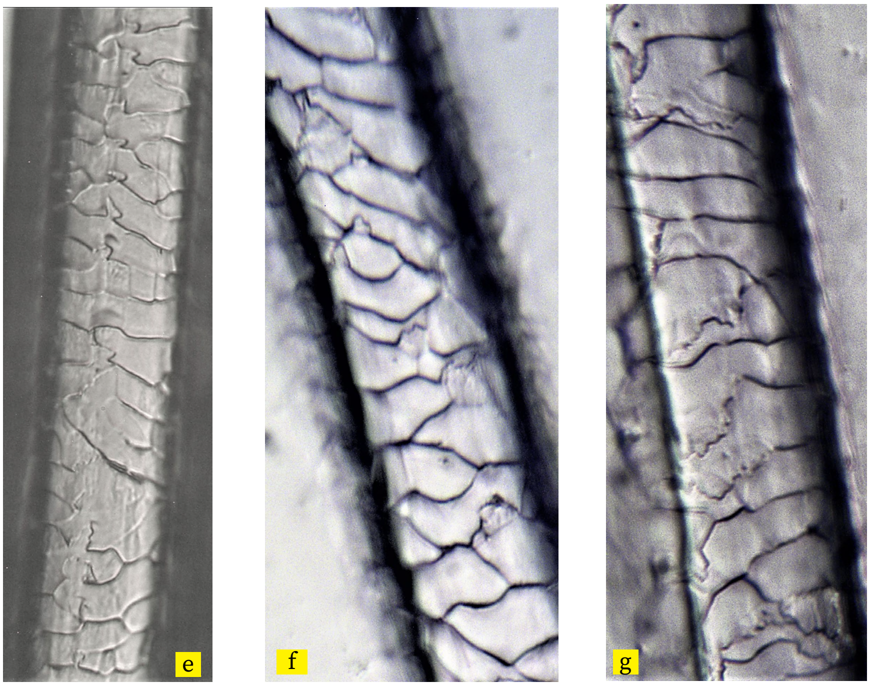

Photo 3. e) *Cuticular section of original naur hair sample,*
f & g) *hair impression obtained from scat (basal section); 400x magnification.*

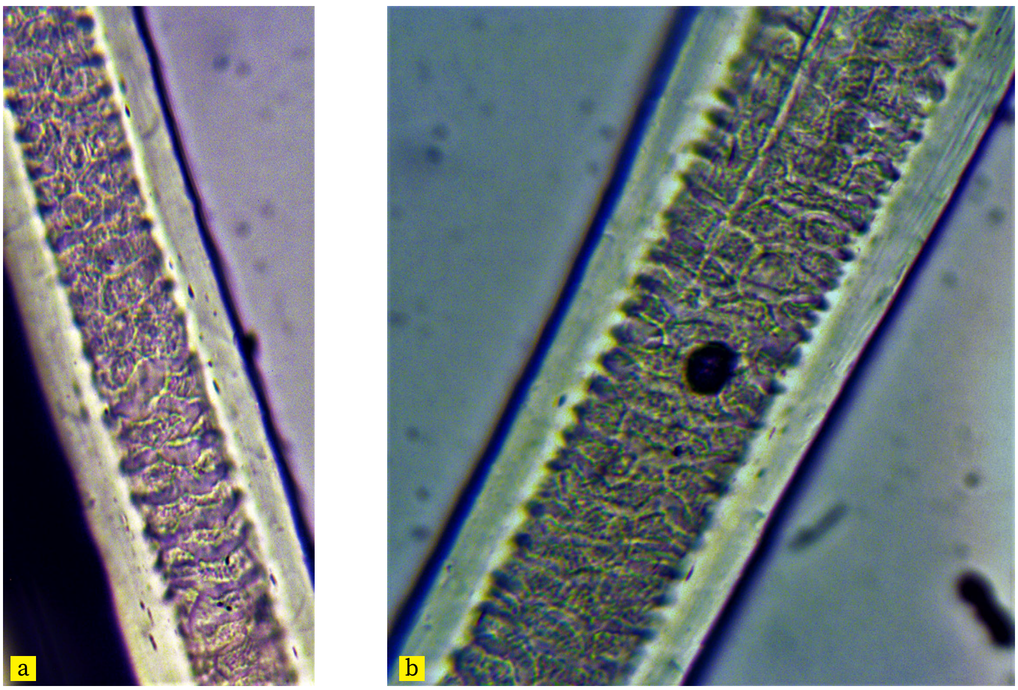

Photo 4 a & b. *Unidentified, possibly of rodent spp.; 400x magnification.*

followed by a rinse with Acetone to remove the dirt. Subsequently, hair, bone, and other materials were separated. The selected hair sample was mounted on a slide using transparent nail polish and gelatine glue to make a cuticular impression (see Chetri et al. 2017 for detailed methods). The impression was later compared with the reference hair sample that was cataloged in a library using a binocular microscope equipped with a camera and photographs were taken. Upon screening hair samples, it was found that the leopard had consumed blue sheep hereafter known as naur (*Pseudois nayaur*, Photo 3). Other small rodents' hair was also observed which remains unidentified (Photo 4). In addition, a few unidentified nails were also recorded in scats (Photo 5). This indicates that the snow leopard had descended from higher elevations as naur are only found at higher elevations above 3000 m in Nepal Himalayas.

Photo 5. *Unidentified claws, possibly of small mammals.*

Discussion

Dispersal is a key demographic process and plays a crucial role in population dynamics, comprised of three key stages: emigration, settlement, and transience, each of which is influence by individual, social, and environmental factors (Morales-González et al. 2021). The dispersal process significantly affects the dynamics and persistence of populations, as well as the distribution and abundance of species, and plays a vital role in shaping the unique spatial and temporal texture of communities and ecosystems (Zimmermann et al. 2005). Dispersal is a common phenomenon among carnivores, including snow leopards, and often occurs when the cubs reach adulthood and leave their mother's territory in search of a permanent home range. The inquisitive naive sub-adult/adult sometimes travels a long distance to find a place for settlement and to establish a permanent home range. Their long excursion trip occasionally ends up in such unexpected places as in the present case. One possible explanation could be due to obstruction from habitat fragmentation and anthropogenic barriers such as highways, fences, and roads which prevented the leopard from returning to its original place. Research indicates that habitat fragmentation poses negative threats to the species during dispersal (Stoner et al. 2013, Johanson et al. 2016). The snow leopard investigation task force report of the government of Nepal highlighted that the existing forest patches connecting KCA to the north and the current location of the snow leopard are highly fragmented. The report also highlighted the possible travel pathways tracing the existing ridgeline at an elevation of 1500 to 2500m. (DNPWC, 2024). Landscape connectivity emerges as a crucial factor facilitating the movement and dispersal of carnivores (Huck et al. 2010, Johanson et al. 2016). In addition, habitat fragmentation and anthropogenic or natural barriers can result in unsuccessful dispersal attempts (de Oliveira et al. 2022). The dispersal distances are shorter in fragmented habitats due to anthropogenic obstacles compared to those in natural and contiguous landscapes (Stoner et al. 2013). The aerial distance from the current location of snow leopard to the nearest mountain protected area, i.e., Kanchenjunga Conservation Area at an elevation range of 2500-3500 m is between 47 to 57.5 km. Research suggests that it is probable for an exploratory snow leopard to travel such distances within 2 to 3 days (Johanson et al. 2024).

We also examined the temperature patterns during the ten days i.e., 15 to 24 January 2024 from the nearest weather stations in Urlabari, Morang, and Taplejung in Kanchenjunga Conservation Area, the likely origin of snow leopards, using data from the weather channel website. The average maximum temperature over these 10 days in Urlabari and Taplejung ranged from 22.1°C to 13.7 °C and the minimum temperature ranged from 9.2°C to 3.4°C respectively (The Weather Company, LLC 2024). The mean difference in maximum and minimum temperature during these periods in Urlabari and Taplejung was found to be only 8.4°C (SD=0.97) and 5.8°C (SD=0.92) respectively. In Taplejung, temperatures in July reach up to 22.5°C (Bhatta et al. 2018). Comparing this with the average temperature in Urlabari, Morang during January (22.1 maximum and 9.2°C minimum), it seems that temperature might not be a limiting factor for the snow leopard's movement in the lowlands of the Tarai during the winter months. However, the implications of such forays in the future possibly increase conflict with humans and other sympatric species like common leopards at lower elevations.

The video footage obtained from CCTV surveillance showed that the leopard was shy and aggressive (see Photo 2). These behavioral observations indicate that the animal was not held in captivity. Analysis of the snow leopard diet indicates that it had consumed naur before appearing in the lowland Tarai. We speculated that if it had been traded or kept as a pet, the diet would have been different. However, our findings as revealed by the hair samples detected in the scats do not support this (Photo 3). We also recorded unidentified rodent spp. hairs and claws in the scats (Photos 4 & 5).

A field observation reveals that the leopard was chased, cornered, and tortured by locals for nearly six hours. It is likely that the snow leopard had descended from a higher elevation as revealed by the naur hair sample in the scat. The naur is the most important diet of snow leopards (Chetri et al. 2017), and are found only at an elevation range of 2500 to 5500 m throughout their distributional range (Harris 2014). It was only due to the collective efforts of the rescue team that the leopard survived. As the leopard was in bad health condition to release it immediately into its natural habitat, therefore, the Government of Nepal decided to keep it for some period under intensive care at NTNC-Central ZOO hospital. This finding has opened an avenue for further research. For example, the snow leopard's long-distance foray into the lowlands is likely a result of a combination of dispersal behavior, exploratory tendencies, resource availability, genetic factors, environmental pressures, and seasonal movements. Therefore, assessing how the interplay between these factors influences snow leopard's dispersal and movement will likely be an important ecological research question. Immediate intervention is necessary to initiate biological research focusing on the north-south corridor linking the Kanchenjunga Conservation Area with low-land forest and protected areas. Understanding landscape features, habitat patches and maintaining connectivity from lowlands to highlands will be crucial in minimizing such incidents and facilitating the movement of snow leopards and other important species.

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Conflict of Interest

No known conflicts of interests.

References

Bhatta, S., Dhamala, M. K., Aryal, P. C., Chauhan, R. and Dawadi, B. 2018. Climate variability and associated response of Larix griffithii in Kanchenjunga conservation area of Nepal. Applied Ecology and Environmental Sciences, 6(1): 23-30. http://dx.doi.org/10.12691/aees-6-1-4

Bohrer, G., Nathan, R. and Volis, S. 2005. Effects of long-distance dispersal for metapopulation survival and genetic structure at ecological time and spatial scales. Journal of Ecology 93:1029–1040. https://doi.org/10.1111/j.1365-2745.2005.01048.x

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

Clobert, J., Le Galliard, J-F., Cote, J., Meylan, S. and Massot, M. 2009. Informed dispersal, heterogeneity in animal dispersal syndromes and the dynamics of spatially structured populations. Ecology Letters 12: 197–209. https://doi.org/10.1111/j.1461-0248.2008.01267.x

de Oliveira, M. E., Saranholi, B. H., Dirzo, R. and Galetti Jr, P. M. 2022. A review of philopatry and dispersal in felids living in an anthropised world. Mammal Review, 52(2), 208-220. https://doi.org/10.1111/mam.12275

DNPWC. 2024. An investigation and research report on Snow Leopard that was found in Urlabari Rural Municipality 1 (in Nepali). A task force report submitted to the Department of National Park and Wildlife Conservation, Babarmahal, Kathmandu. 19 pp.

Harris, R.B. 2014. Pseudois nayaur. The IUCN Red List of Threatened Species 2014: e.T61513537A64313015. https://dx.doi.org/10.2305/IUCN.UK.2014-3.RLTS.T61513537A64313015.en. Accessed on 25 August 2024.

Huck, M., Jędrzejewski, W., Borowik, T., Miłosz-Cielma, M., Schmidt, K., Jędrzejewska, B., Nowak, S. and Mysłajek, R.W. 2010.Habitat suitability, corridors and dispersal barriers for large carnivores in Poland. Acta Theriologica 55: 177–192. https://doi.org/10.4098/j.at.0001-7051.114.2009.

Jackson, R. and Ahlborn, G. 1989. Snow leopards (*Panthera uncia*) in Nepal: home range and movements. National geographic research, 5(2): 161-175.

Jackson, R. M., Mishra, C., McCarthy, T. M. and Ale, S. B. 2010. Snow leopards: conflict and conservation. The biology and conservation of wild felids, 2: 417-430.

Jnawali, S.R., Baral, H.S., Lee, S., Acharya, K.P., Upadhyay, G.P., Pandey, M., Shrestha, R., Joshi, D., Lamichhane, B.R., Griffiths, J., Khatiwada, A. and Amin, R (compilers) (2011). The status of Nepal mammals: the National Red List Series. Department of National Parks and Wildlife Conservation, Kathmandu, Nepal, 276 pp.

Stander, P. E. 1997. Field age determination of leopards by tooth wear. African Journal of Ecology, 35(2), 156-161.

Johansson, Ö., Rauset, G. R., Samelius, G., McCarthy, T., Andrén, H., Tumursukh, L. and Mishra, C. 2016. Land sharing is essential for snow leopard conservation. Biological Conservation, 203: 1-7.

Johansson, Ö., Ausilio, G., Low, M., Lkhagvajav, P., Weckworth, B. and Sharma, K. 2021. The timing of breeding and independence for snow leopard females and their cubs. Mammalian Biology, 101(2): 173-180.

Johansson, Ö., Alexander, J.S., Lkhagvajav, P., Mishra, C. and Samelius, G. 2024. Natal dispersal and exploratory forays through atypical habitat in the mountain-bound snow leopard. Ecology e4264. https://doi.org/10.1002/ecy.4264

Marucco, F., Pilgrim, K. L., Avanzinelli, E., Schwartz, M. K. and Rossi, L. 2022. Wolf dispersal patterns in the Italian Alps and implications for wildlife diseases spreading. Animals, 12(10), 1260. https://doi.org/10.3390/ani12101260

McCarthy, T.M. 2000. Ecology and conservation of snow leopards, Gobi brown bears, and wild bactrian camels in Mongolia. Ph.D. Dissertation, University of Massachusetts, Amherst, 133.

McCarthy, T. M., Fuller, T. K. and Munkhtsog, B. 2005. Movements and activities of snow leopards in Southwestern Mongolia. Biological Conservation, 124(4), 527-537. https://doi.org/10.1016/j.biocon.2005.03.003

McCarthy, T., Mallon, D., Jackson, R., Zahler, P. and 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. Accessed on 09 February 2024.

MoFSC. 2017. Snow Leopard and Ecosystem Management Plan (2017–2026). Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Schaller, G. B., Junrang, R. and Mingjiang, Q. 1988. Status of the snow leopard Panthera uncia in Qinghai and Gansu Provinces, China. Biological Conservation, 45(3): 179-194.

Snow Leopard Network. 2014. Snow leopard survival strategy. Seattle, Washington, USA, 1-145.

Stoner, D. C., Wolfe, M. L., Mecham, C., Mecham, M. B., Durham, S. L., and Choate, D. M. 2013. Dispersal behaviour of a polygynous carnivore: do cougars Puma concolor follow source-sink predictions?. Wildlife Biology, 19(3): 289-301.

The Weather Company, LLC. 2024. The Weather Channel (https://weather.com/en-IN/weather/monthly/l/86c6ed4ff75b47bccb9f7f2085e40c934f28d214c61dd3c3aa8531990ea8cd59)

Zimmermann, F., Breitenmoser-Würsten, C. and Breitenmoser, U. 2005. Natal dispersal of Eurasian lynx (Lynx lynx) in Switzerland. Journal of Zoology, 267(4), 381-395. https://doi.org/10.1017/S0952836905007545

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Estimating Snow Leopard Population in Lapchi Valley, Gaurishankar Conservation Area, Nepal

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Abstract

Accurate estimations of species abundance are crucial for effectively conserving endangered species. Estimating the population of snow leopards, a cryptic species living in remote and harsh habitats, based on camera trap photos is not easy but can still be useful for baseline estimations. In this study, we used camera traps to estimate the number of snow leopards in Lapchi Valley in Gaurishankar Conservation Area (GCA), Nepal. The study area spanned roughly 280 square kilometers, and for 25 months, we used 26 camera traps (CTs) strategically placed in 16 locations based on potential snow leopard activity. CTs captured a total of 39 snow leopard events. Seven peer observers independently and jointly identified six adults and two sub-adults using fur coloration, spot patterns and unique differences including one individual with an eye abnormality. Two individuals were accompanied by cubs, one of which was later observed with abdominal injuries. We observed seasonal variations in snow leopard activity, with higher occurrences in cold season and absence from May to October. The study area's high snow leopard density and seasonal concentration highlight the importance of Lapchi Valley as a crucial habitat for conservation. In addition, Lapchi Valley connects directly to the Tibetan plateau, so there is a potential for transboundary movement. This research contributes valuable insights for snow leopard conservation strategies, considering the species' elusive nature and the challenges in accurate population estimation.

Introduction

The snow leopard (*Panthera uncia*), known as "Ghost of the mountains" is a flagship apex predator distributed across 12 different countries of the Central and South Asian mountains including Nepal (Ale et al. 2016, Ghoshal 2017). It is categorized as Vulnerable on the IUCN Red List (McCarthy et al. 2017) and is a protected species under Nepal's National Parks and Wildlife Conservation Act 1973. In Nepal, snow leopards range across the northern frontier, described/recorded from all mountainous protected areas of Nepal: Annapurna Conservation Area (Oli et al. 1993, Hanson 2022), Api Nampa Conservation Area (Khanal et al. 2020), Kangchenjunga Conservation (Karmacharya et al. 2011, Thapa et al. 2013), Manaslu Conservation Area (Shrestha et al. 2018, Chetri et al. 2019), Makalu Barun National Park, Dhorpatan Hunting Reserve (DNPWC 2017), Langtang National Park (Chalise & Kyes. 2003), Sagarmatha National Park (Ale et al. 2007, Lovari et al. 2009) but the snow leopard at Sagarmatha National park is assumed as only dispersing individuals presently (Lovari & Mishra 2024), Shey Phoksundo National Park Area (Jackson 1996, Thapa 2006, Devkota et al. 2013) and Gaurishankar Conservation Area (Koju et al. 2021, Pandey et al. 2021, Koju et al. 2023, Koju et al. 2024) as well as outside the protected areas of Nepal (Ale & Karky 2002, Hanson et al. 2019, Hanson 2022).

Snow leopard conservation is a priority in Nepal, and accurate estimations of species abundance are crucial for the effective management and conservation of endangered species (Johansson et al. 2020). When genetic analyses are not available, camera trapping is the most widely used data collection method for estimating abundance of snow leopards (Choo et al. 2020). Individual identification of snow leopards from camera trap images for population and abundance estimation is not an easy task, however, and the accuracy of this method is limited by human observer errors from misclassifying individuals (Alexander et al. 2020, Johansson et al. 2020, Bohnett et al. 2023). Three tools are primarily used to estimate the population from individual identification of snow leopard:

1. Using experts and non-experts to identify individuals based on visual observation
2. Using capture recapture modelling and
3. AI based visual matcher software (Wegge et al. 2012, Alexander et al. 2020, Johansson et al. 2020, Suryawanshi et al. 2021, Blount et al. 2022, Bohnett et al. 2023).

According to an estimation based on sign surveys, approximately 301–400 snow leopards reside throughout the distributional range within Nepal (DNPWC 2017). Recently, a total of 90 individuals from Shey – Phoksundo National Park (SPNP 2023) and 34 individuals from Annapurna – Manaslu complex have been estimated using spatial capture-recapture method (Chetri et al. 2019). However, studies based on strong scientific methodologies that estimate the abundance of snow leopards are still scarce in most areas of Nepal. Although photographic evidence of snow leopard presence in Lapchi Valley has only recently been confirmed at GCA (Koju et al. 2021), GCA is potentially very important for snow leopard conservation because it lies between Langtang and Sagarmatha National Parks in Nepal and adjacent to the Qomolongma Protected Area in China. To better understand the importance of GCA, it is essential to explore the number of snow leopard individuals that use it. The study aimed to estimate the number of snow leopards and their seasonal movement based on photos and videos, recorded from 2018 to 2023 using camera traps at Lapchi Valley of Gaurishankar Conservation Area.

Methods

Study area

Lapchi Valley, Gaurishankar Conservation Area's (GCA) lies between 86°10'32.53" and 86°29'9.45"E and 28°20'13.19" and 28°21'54.55"N. It is a renowned Tibetan Buddhist pilgrimage site situated at the base of the LapchiKhang mountain range. The "ChöraGephel Ling," the main monastery in Lapchi, is surrounded by caves, used as meditation sites by the renowned 11th century poet and saint Jetsun Milarepa. As a result, it is a very important site for Tibetan Buddhism. It is confined to the east, west, and north by China (Koju et al. 2020). It ranges from 968 to 7,181 meters above sea level and features various habitats, from sub-tropical to nival (Figure 1). The valley has 16 major vegetation types and is home to a wide range

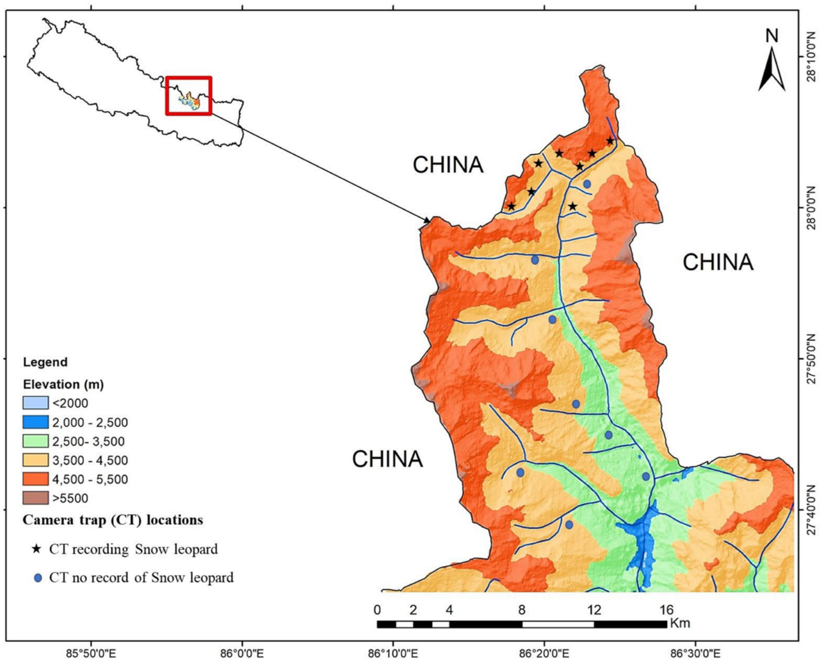

Figure 1: *Map showing Camera trap locations and where snow leopards were recorded in the study area*

of flora and fauna, including 235 bird species, 77 mammal species, 16 fish species, 22 reptilian species, and 10 amphibian species. The GCA is important for snow leopards and other wildlife as it connects habitats from the Tibetan Plateau to the north, Langtang National Park to the west, and Sagarmatha National Park to the east (Awasthi & Singh 2015, Koju et al. 2021, Pandey et al. 2021, Chetri et al. 2022). Livestock rearing is the major source of income for people of Lapchi, and they follow nomadic pastoral practices of seasonal movements of their livestock. Lumnang is their winter retreat area and take livestock to the high valleys in Lapchi and the Tibetan region during the warm period.

Methodology

Camera trapping

In this study, we installed 26 Bushnell Trophy Camera Traps (CTs) (Model #119537C), set in hybrid mode to take both photographs and videos simultaneously for 25 months in two phases: 1) from 22 October 2018 to 16 May 2019, and 2) from 19 October 2021 to 15 March 2023. Due to the challenges of conducting field research in remote mountainous regions, we deployed 26 camera traps at 16 locations close to potential scats and scrapes of leopards and its prey species, 30-40 cm above the ground depending on the slope of the land (Li et al. 2018, Wangdi et al. 2019). We selected these locations ensuring a fair representation of different habitats in the study area. All the camera locations were placed maintaining a minimum of 2 km distance from each other except for four camera traps, which were placed on either side of the river between the forest habitat and the alpine area of Lapchi Valley. The camera traps were set to function over 24 hours with the one-second trigger time between the events and were able to record images at night using infrared LEDs. The CTs were visited at interval of three months during the study period to undertake data recovery and replacing the batteries in order to maintain data integrity and camera functioning. Unfortunately, eight camera traps were lost in different locations which were replaced in the same location during consecutive visits.

Data management and analysis

Images of the same species taken at least 30 minutes apart were considered independent occurrences to analyze the data from the camera traps. Successive photos of distinct individuals, whether of the same or different species, as well as non-consecutive images of the same species at a particular place, were supposed independent events (Carbone et al. 2001). Images that were blank or could not be recognized were removed from the study. The study period was divided into cold and warm months, as delineated by Koju et al. (2023) and Koju et al. (2024). The warm season, defined as the period when yaks and horses graze in the highland pastures of Lapchi Valley, spans from April 16 to November 15. Conversely, the cold period, characterized by the migration of yaks and horses to lower elevation pastures, extends from November 16 to April 15. For the seasonal and monthly events analysis of snow leopards, data from a complete year (March 2022 to February 2023, N=35) were utilized, following the methodology outlined by Koju et al. (2024). The seasonal and monthly events were statistically analyzed using Karl Pearson's Chi-Square Tests.

Identification using observers and peer observation

Identification of individual snow leopards was carried out in two steps: independent and joint identification. For independent identification, we invited seven peer observers with good experience on camera trapping of snow leopards and dedicated to snow leopard conservation, as well as associated with NGOs or universities. All peer observers received the photos and videos of the snow leopards, with a request to identify the individuals following PAWS guidelines. Four experts, jointly revised the analysis and the concurrent conclusion was used as the result following Bayandonoi et al. (2021) and Bohnett et al. (2023). Distinctive spot patterns on the flanks, legs, back, and tail of each snow leopard were used to distinguish individual snow leopards. The utilization of burst photography and video footage maximized the capture of snow leopards from diverse perspectives and body angles. Instances involving single-flank encounters, unclear images, distant subjects, limited body parts in the images, or situations where spot patterns could not be conclusively identified and compared with other instances were categorized as 'Unidentifiable'. Such encounters were excluded from the final analysis (Bayandonoi et al. 2021).

Results

Population estimation

Throughout the study period, our camera traps captured a total of 39 snow leopard events across eight distinct locations (Figure 1) within an area of approximately 60 km^2. The lowest elevation for a snow leopard record was 3535 m asl and the highest level was 4628 m asl (at highest elevation, where CT was installed in this study). The experts' evaluation confirmed the presence of a minimum of 6 individuals (Figure 5, Table 1), including one with an abnormality in its left eye (SL1 [Figure 2]). SL1 was spotted in two locations, CAM1 (winter) and CAM 56 (summer). Two snow leopards, SL4 and SL5, were accompanied by at least one cub each in November and December (Figure 3 [A, B]). Moreover, a juvenile with abdominal injuries (Figure 4) was spotted on March 13, 2023 at CAM 55. The cause and effect of injuries was not known.

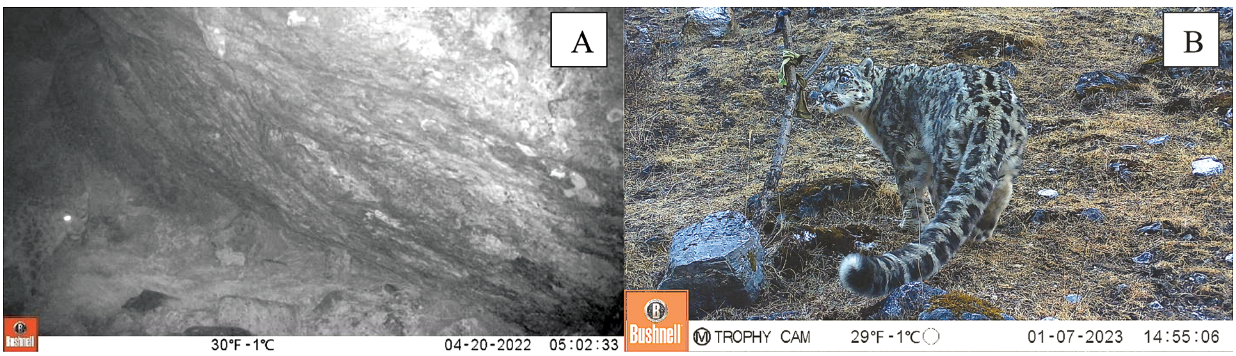

Figure 2: *A snow leopard with injury in left eye at Lapchi Vally: recorded on April 20, 2022 (A) at CAM 56 and on Jan 7, 2023 at CAM1 (B)*

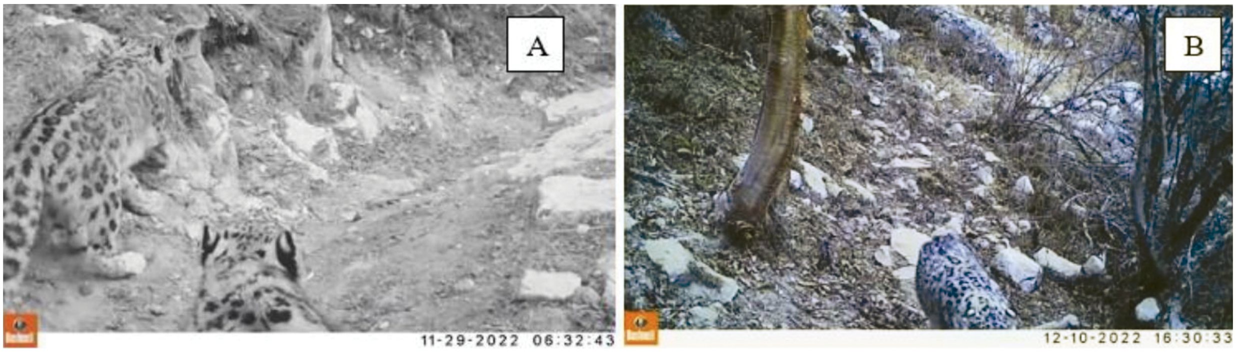

Figure 3: *A pair of female snow leopard with respective cubs: Recorded on November 29, 2022 at CAM 6 (A) and December 10, 2022 at CAM 55 (B)*

Figure 4: *A snow leopard (cub) with deep cut in abdomen as external injuries, recorded on March 13, 2023 at CAM 55.*

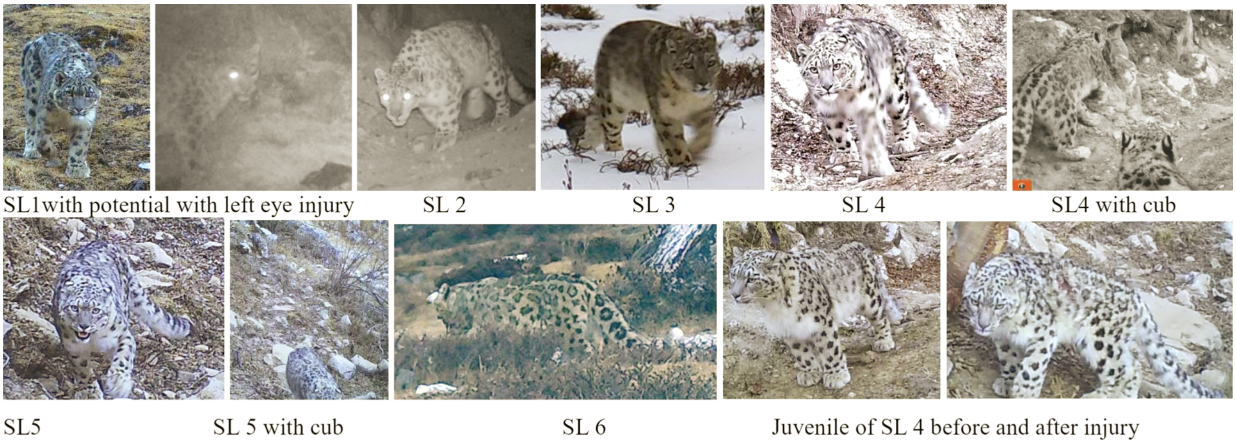

Figure 5: *The visual peer observation from experts confirmed possibility of 6-8 snow leopard individuals*

Table 1: *Snow leopards recorded in cameras and individual identification by peer and group identification*

CAM name	GPS coordinate Latitude	Longitude	Detection number cold	warm	Total	Snow leopard identification (frequency and recorded date) SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	unknown
CAM1	28.10060	86.13891	3	0	3	1 1/7/2023		1 1/22/2023				1 1/21/2023
CAM3	28.10754	86.14855	11	1	12			4 3/25/2022 11/10/2022 11/30/2022 1/22/2023	1 2/8/2023			6 11/11/2018 4/3/2019 11/28/2021 12/1/2022 12/28/2021 2/25/2022 12/10/2022
CAM5	28.12950	86.19231	5	0	5		1 1/20/2023			1 1/20/2023	1 1/22/2023	2 1/14/2023, 2/11/2023
CAM6	28.11988	86.17811	8	1	9		6 11/29/2022 12/18/2022 1/4/2023 2/8/2023 2/12/2023 3/1/2023			1 4/21/2022	1 2/5/2023	1 2/17/2023
CAM9	28.11666	86.17382	2	1	3				1 12/18/2022		1	2 4/21/2022, 12/18/2022
CAM10	28.09368	86.1673	1	0	1							1 1/5/2023
CAM55	28.12359	86.15702	2	0	2				1 12/10/2022		1 13/13/2023	
CAM56	28.12798	86.15861	2	2	4	1 4/20/2022		1 12/9/2022				2 4/20/2022, 12/18/2022
Total number of records			34	5	39	2	6	7	1	2	3	11

Temporal records of snow leopard

From March 2022 to February 2023, a total of 35 snow leopard detections were recorded. The majority of these records occurred in the cold months (88.51%, n=31), with the highest frequency in January (10 events across six camera traps), followed by December (eight events across five camera traps), and February (seven events across three camera traps) (Figure 6). In warm season, only four detections were recorded in April. There were fewer records in November and March, and no records were recorded from May to October (Figure 6). A chi-square test indicated significant seasonal ($p = 0.0005$, $\chi^2 = 20.83$, $df = 1$) and monthly ($p = 0.0001$, $\chi^2 = 50.64$, $df = 11$) variations in snow leopard visits to Lapchi Valley.

Discussion

Our study showed the importance of Lapchi Valley, GCA for snow leopards with at least six adults and two sub-adult individuals consistently identified by expert observers. This support the reliability of manual identification based on camera trap images. While manual identification of individual identification of snow leopards, using the unique fur pattern such as rosettes, remains the most widely used and trusted approach (Jackson et al. 2006, Sharma et al. 2014, Alexander et al. 2016). It is not without challenges, particularly the potential for inaccuracies. To mitigate this, identification by multiple expert observers provides a more robust method, as it reduces individual observer bias and enhances the accuracy of the result.

With a study area of nearly 280 square kilometers being used by at least six snow leopards (2.14 per 100 square kilometers), yielding a population density comparable to estimates from other regions in Nepal. For instance, in Api Nampa Conservation Area Snow leopard density was estimated 3-4.5 individuals per 100 km^2 (Khanal et al. 2020), 34 individuals in 4393 square kilometers in north-central Nepal (Chetri et al. 2019), 1.5

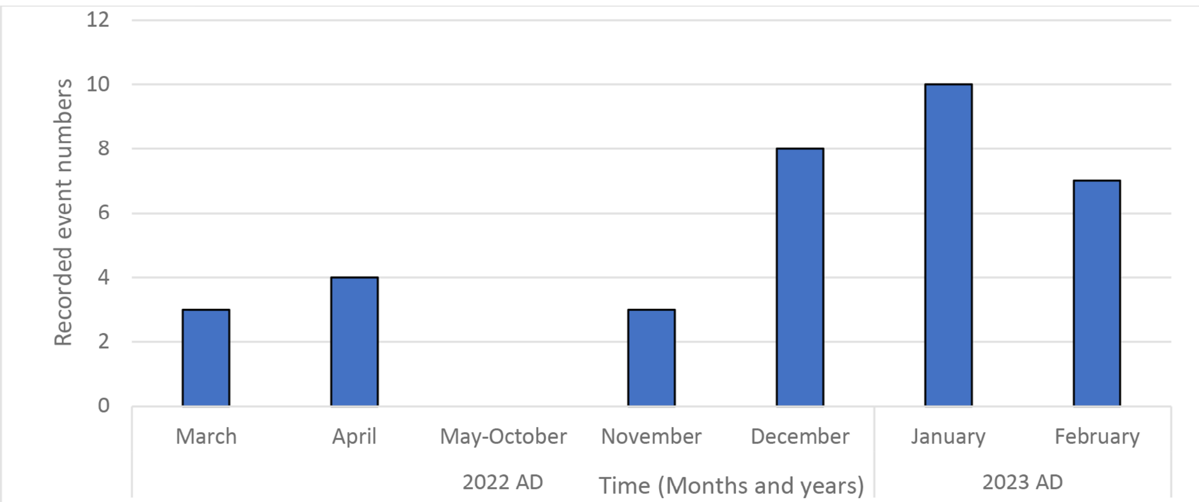

Figure 6: *Annual (March 2022-February 2023) record of snow leopards recorded in camera traps during study period*

per 100 km^2 in Manaslu Conservation Area (Shrestha 2021, Neupane 2024), and 2.21/100 km^2 in Shey Phoksundo National Park (DNPWC & DoFSC 2024). Chetri et al. (2019) has mentioned, however, that higher snow leopard densities can be biased from small sampling areas, and Jackson & Ahlborn (1989) have reported home range overlapping in snow leopards and that certain areas can be used by more than one snow leopard. Lapchi valley is not only a direct transit route to Qomolangma National Nature Reserve in the Tibetan plateau but also between Langtang and Sagarmatha national parks in Nepal, so the valley might be an important link among these habitats. In the future, it is necessary for large scale systematic monitoring of snow leopards to clarify snow leopard ranging and density not only in GCA, but also in collaboration with similar monitoring of snow leopard habitat in adjacent protected areas.

Local studies have reported that livestock comprises the majority of the snow leopard diet during summer in Nepal (Shrestha et al. 2018, Koju et al. 2023), and a recent study from Shey Phoksundo National Park has shown that livestock density may limit the abundance of snow leopards (Khanal et al. 2020). Snow leopards have been assumed to follow the winter and summer migratory movements of their primary prey species from high to low elevations and low to high elevations respectively (Snow Leopard Network 2014). The lower number of snow leopard images during the warm period (May to October) coincides with the movement of livestock to higher pastures and might support the seasonal movement of snow leopard out of Lapchi valley, but this too needs confirmation from a more extensive camera trap survey. For example, our highest camera trap was located at 4628 m asl, and perhaps in the future we need to sample more at this altitude and higher. Furthermore, the period from May to October was aligned with the seasonal migration of villagers' livestock to upper alpine pastures. During this time, many villagers relocate their livestock to grazing areas near or across the China border (Koju 2023), where the installation of camera traps is not feasible. This migration pattern likely contributes to the absence of snow leopard records during these months. It is suggested that while the Lapchi Valley provides some summer grazing grounds, they may not be sufficient to support all the livestock. This insufficiency prompts the need for cross-border grazing, which may also be a traditional practice and area for grazing.

The snow leopard's frequent presence, concentrated cold months activity (Koju et al. 2024), and their absence during May to October in Lapchi Valley, suggests the seasonal preferences for cold season as in Sagarmatha National Park (Lovari et al. 2013), and in Mongolia (Johansson et al. 2022). But the importance of the narrow Lapchi valley is that a minimum of six individuals using the habitat. The area around the Lapchi Monastery was used by all snow leopards that visited Lapchi Valley. Consequently, conserving the habitat in Lapchi Valley becomes vital for snow leopard conservation, as these animals may utilize territories extending across China's political boundary and Nepal. Additionally, this research findings suggest the need of a vigorous survey over large landscape and trans-boundary research initiatives for snow leopard conservation.

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References

Ale, S., Shah, K. B. and Jackson, R. M. 2016. Snow leopard status and conservation: Regional reviews and updates South Asia: Nepal. Snow Leopards Biodiversity of the World: Conservation from Genes to Landscape, Elsevier.

Ale, S. B. and Karky, B. S. 2002. Observations on conservation of snow leopards in Nepal. Contributed Papers to the Snow Leopard Survival Strategy Summit: 3.

Ale, S. B., Yonzon, P. and Thapa, K. 2007. Recovery of snow leopard Uncia uncia in Sagarmatha (Mount Everest) National Park, Nepal. Oryx 41(1):89-92. https://doi.org/10.1017/S0030605307001585.

Alexander, J. S., Johansson, O., Sharma, K., Durbach, I. and Borchers, D.2020. Snow leopard identification good practices.

Alexander, J. S., Zhang, C., Shi, K. and Riordan, P. 2016. A granular view of a snow leopard population using camera traps in Central China. Biological Conservation 197:27-31. https://doi.org/10.1016/j.biocon.2016.02.023.

Awasthi, B. and Singh, N. B. 2015. Status of Human-Wildlife Conflict and Assessment of Crop Damage by Wild Animals in Gaurishankar Conservation Area, Nepal. Journal of Institute of Science and Technology 20:107-111. https://doi.org/10.3126/jist.v20i1.13918.

Bayandonoi, G., Lkhagvajav, P., Alexander, J., Durbach, I., Borchers, D., Munkhtsog, B., Munkhtogtokh, O., Chimeddorj, B., Sergelen, E. and Koustubh, S. 2021. Nationwide snow leopard population assessment of Mongolia-key findings. Ulaanbaatar. Mongolia.

Blount, D., Bohnett, E., Holmberg, J., Parham, J., Faryabi, S. P., Johansson, Ö., An, L., Ahmad, B., Khan, W. and Ostrowski, S. 2022. Comparison of two individual identification algorithms for snow leopards after automated detection bioRxiv:2022.2001. 2020.477059. https://doi.org/10.1101/2022.01.20.477059.

Bohnett, E., Faryabi, S. P., Lewison, R., An, L., Bian, X., Rajabi, A. M., Jahed, N., Rooyesh, H., Mills,E. and Ramos, S. 2023. Human expertise combined with artificial intelligence improves performance of snow leopard camera trap studies. Global Ecology and Conservation 41:e02350. https://doi.org/10.1016/j.gecco.2022.e02350.

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J., Griffiths, M., Holden, J., Kawanishi, K. and Kinnaird, M. 2001. The use of photographic rates to estimate densities of tigers and other cryptic mammals. Animal Conservation forum, https://doi.org/10.1017/S1367943001001081, Cambridge University Press.

Chalise, M. K. and Kyes., R. C.2003. Snow leopard investigation in Langtang: An editorial. NAHSON Bulletin. Kathamandu, NEBORS. 12: 1.

Chetri, M., Odden, M., Devineau, O. and Wegge, P. 2019. Patterns of livestock depredation by snow leopards and other large carnivores in the Central Himalayas, Nepal. Global Ecology and Conservation 17:e00536. https://doi.org/10.1016/j.gecco.2019.e00536.

Chetri, M., Odden, M., Sharma, K., Flagstad, Ø. and Wegge, P. 2019. Estimating snow leopard density using fecal DNA in a large landscape in north-central Nepal. Global Ecology and Conservation 17:e00548. https://doi.org/10.1016/j.gecco.2019.e00548.

Chetri, M., Regmi, P. R., Dahal, T. P. and Thami, S. 2022. A checklist of mammals of Gaurishankar Conservation Area, Nepal. Nepalese Journal of Zoology 6(S1):56-62. https://doi.org/10.3126/njz.v6iS1.50533.

Choo, Y. R., Kudavidanage, E. P., Amarasinghe, T. R., Nimalrathna, T., Chua, M. A. and Webb, E. L. 2020. Best practices for reporting individual identification using camera trap photographs. Global Ecology and Conservation 24:e01294. https://doi.org/10.1016/j.gecco.2020.e01294.

Devkota, B. P., Silwal, T. and Kolejka, J. 2013. Prey density and diet of snow leopard (Uncia uncia) in Shey Phoksundo National Park, Nepal. Applied Ecology and Environmental Sciences 1(4):55-60. https://doi.org/10.12691/aees-1-4-4.

DNPWC 2017. Snow Leopard Conservation Action Plan (2017-2021). Department of National Parks and Wildlife Conservation, Kathmandu, Nepal.

DNPWC and DoFSC 2024. Snow Leopard Conservation Action Plan for Nepal (2024-2030). Kathmandu, Nepal., Department of National Parks and Wildlife Conservation and Department of Forests and Soil Conservation. p 78.

Ghoshal, A. 2017. Determinants of occurrence of snow leopards and its prey species in the Indian Greater and Trans Himalaya. Rajkot: Wildlife Science department, Saurashtra University.

Hanson, J. H. 2022. Household Conflicts with Snow Leopard Conservation and Impacts from Snow Leopards in the Everest and Annapurna Regions of Nepal. Environmental Management 70(1):105-116. https://doi.org/10.1007/s00267-022-01653-4.

Hanson, J. H., Schutgens, M. and Leader-Williams, N. 2019. What factors best explain attitudes to snow leopards in the Nepal Himalayas? Plos one 14(10):e0223565. https://doi.org/10.1371/journal.pone.0223565.

Jackson, R. and Ahlborn, G. 1989. Snow leopards (Panthera uncia) in Nepal: home range and movements. National geographic research 5(2):161-175.

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

Jackson, R. M., Roe, J. D., Wangchuk, R. and Hunter, D. O. 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. Wildlife Society Bulletin 34(3):772-781. https://doi.org/10.2193/0091-7648(2006)34[772:ESLPAU]2.0.CO;2.

Johansson, Ö., Mishra, C., Chapron, G., Samelius, G., Lkhagvajav, P., McCarthy, T. and Low, M. 2022. Seasonal variation in daily activity patterns of snow leopards and their prey. Scientific reports 12(1):21681. https://doi.org/10.1038/s41598-022-26358-w.

Johansson, Ö., Samelius, G., Wikberg, E., Chapron, G., Mishra, C. and Low, M. 2020. Identification errors in camera-trap studies result in systematic population overestimation. Scientific reports 10(1):6393. https://doi.org/10.1038/s41598-020-63367-z.

Karmacharya, D. B., Thapa, K., Shrestha, R., Dhakal, M. and Janecka, J. E. 2011. Noninvasive genetic population survey of snow leopards (Panthera uncia) in Kangchenjunga conservation area, Shey Phoksundo National Park and surrounding buffer zones of Nepal. BMC research notes 4(1):1-9. https://doi.org/10.1186/1756-0500-4-516.

Khanal, G., Mishra, C. and Ramesh Suryawanshi, K. 2020. Relative influence of wild prey and livestock abundance on carnivore-caused livestock predation. Ecology and Evolution 10(20):11787-11797.

Khanal, G., Poudyal, L. P., Devkota, B. P., Ranabhat, R. and Wegge, P. 2020. Status and conservation of the snow leopard Panthera uncia in Api Nampa Conservation Area, Nepal. Oryx 54(3):421-428. https://doi.org/10.1017/S0030605318000145.

Koju, N. P.2023. The ecological bridge of the mountains. Kantipur Daily. Kathmandu, Nepal, Kantipur Publications Ltd.

Koju, N. P., Bashyal, B., Pandey, B. P., Shah, S. N., Thami, S. and Bleisch, W. V. 2021. First camera-trap record of the snow leopard Panthera uncia in Gaurishankar Conservation Area, Nepal. Oryx 55(2):173-176. https://doi.org/10.1017/S003060532000006X.

Koju, N. P., Bashyal, B., Pandey, B. P., Thami, S., Dhamala, M. K. and Shah, S. N. 2020. New record on Asiatic Golden Cat Catopuma temminckii Vigors & Horsfield, 1827 (Mammalia: Carnivora: Felidae): photographic evidence of its westernmost distribution in Gaurishankar Conservation Area, Nepal. Journal of Threatened Taxa 12(2):15256-15261. https://doi.org/https://doi.org/10.11609/jott.5227.12.2.15256-15261.

Koju, N. P., Buzzard, P., Shrestha, A., Sharma, S., Kai, H., Li, J., Kyes, R. C., Chen, C. and Beisch, W. V. 2024. Habitat Overlap and Interspecific Competition between Snow Leopards and Leopards in the Central Himalaya of Nepal. Global Ecology and Conservation:e02953. https://doi.org/10.1016/j.gecco.2024.e02953.

Koju, N. P., Gosai, K. R., Bashyal, B., Byanju, R., Shrestha, A., Buzzard, P., Beisch, W. B. and Khanal, L. 2023. Seasonal Prey Abundance and Food Plasticity of the Vulnerable Snow Leopard (Panthera uncia) in the Lapchi Valley, Nepal Himalayas. Animals 13(20):3182. https://doi.org/10.3390/ani13203182.

Li, X., Bleisch, W. V. and Jiang, X. 2018. Unveiling a wildlife haven: occupancy and activity patterns of mammals at a Tibetan sacred mountain. European Journal of Wildlife Research 64(5):53. https://doi.org/10.1007/s10344-018-1213-y.

Lovari, S., Boesi, R., Minder, I., Mucci, N., Randi, E., Dematteis, A. and Ale, S. 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. https://doi.org/10.1111/j.1469-1795.2009.00285.x.

Lovari, S., Minder, I., Ferretti, F., Mucci, N., Randi, E. and Pellizzi, B. 2013. Common and snow leopards share prey, but not habitats: competition avoidance by large predators? Journal of Zoology 291(2):127-135. https://doi.org/10.1111/jzo.12053.

Lovari, S. and Mishra, C. 2024. Living on the edge: depletion of wild prey and survival of the snow leopard. In: D. Mallon and T. Maccarthy (Eds) Snow leopards. Nikki P. Levy Academic Press is an imprint of Elsevier, 125 London Wall, London EC2Y 5AS, United Kingdom.

McCarthy, T., Mallon, D., Jackson, R., Zahler, P. and McCarthy, K.2017. Panthera uncia. The IUCN red list of threatened species 2017: e. T22732A50664030.

Neupane, S.2024. Study reveals critical status of snow leopards in Nepal's Manaslu Conservation Area. Onlinekhabar. Kathmandu, Nepal, Onlinekhabar Pvt. Ltd.

Oli, M., Taylor, I. and Rogers, D. M. 1993. Diet of the snow leopard (*Panthera uncia*) in the Annapurna Conservation Area, Nepal. Journal of Zoology 231(3):365-370. https://doi.org/10.1111/j.1469-7998.1993.tb01924.x.

Pandey, B. P., Thami, S., Shrestha, R., Subedi, N., Chalise, M. K. and Ale, S. B. 2021. Snow leopards and prey in Rolwaling Valley, Gaurishankar Conservation Area, Nepal. Catnews 74:14-19.

Sharma, K., Bayrakcismith, R., Tumursukh, L., Johansson, O., Sevger, P., McCarthy, T. and 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. https://doi.org/10.1371/journal.pone.0101319.

Shrestha, B. 2021. Implication of snow leopard distribution, population dynamics and landscape genetics, and prey preference for its conservation in Nepal. PhD, Univerzita Karlova, Přírodovědecká fakulta, Ústřední knihovna, Czech.

Shrestha, B., Aihartza, J. and Kindlmann, P. 2018. Diet and prey selection by snow leopards in the Nepalese Himalayas. Plos one 13(12):e0206310. https://doi.org/10.1371/journal.pone.0206310.

Snow Leopard Network 2014. Snow leopard survival strategy. Seattle, Washington, USA:1-145.

SPNP 2023. Population Assessment of Shey - Phoksundo National Park's Snow Leopard and Prey. Shey - Phoksundo National Park, Dolpa, Nepal. Pp:65.

Suryawanshi, K., Reddy, A., Sharma, M., Khanyari, M., Bijoor, A., Rathore, D., Jaggi, H., Khara, A., Malgaonkar, A. and Ghoshal, A. 2021. Estimating snow leopard and prey populations at large spatial scales. Ecological Solutions and Evidence 2(4):e12115. https://doi.org/10.1002/2688-8319.12115.

Thapa, K. 2006. Study on status and distribution of the snow leopard and blue sheep including people interactions, Kanchanjungha Conservation Area and Shey Phoksundo National Park. Report submitted to WWF Nepal.

Thapa, K., Pradhan, N. M. B., Barker, J., Dhakal, M., Bhandari, A. R., Gurung, G. S., Rai, D. P., Gokarna, Thapa, J., Shrestha, S. and Singh, G. R. 2013. High elevation record of a leopard cat in the Kangchenjunga Conservation Area, Nepal. Catnews (58):26-27.

Wangdi, T., Tobgay, S., Dorjee, K., Dorji, K. and 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. https://doi.org/10.1016/j.gecco.2018.e00466.

Wegge, P., Shrestha, R. and 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. https://doi.org/doi.org/10.2981/11-049.

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Reflections from a snow leopard eco-camp program in Mongolia

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Abstract

Environmental education can efficiently engage individuals in addressing environmental challenges and promote collaboration among stakeholders. The aim of this paper was to understand how children participating in eco-camps perceived nature and the environment. Additionally, we aim to share our experiences from eight years of eco-camp activities conducted for sixth-grade students (aged 12-13 years) in the Gobi region of southern Mongolia. The program utilized active learning in snow leopard habitats. We used creative expressions, specifically write-ups such as poems, to capture the children's perceptions and feelings about nature. The findings revealed that the children participating in the program conveyed a sense of awe for nature and awareness of ecosystem services. Feedback from parents

and teachers indicated that the program was effective at creating positive changes in the children's behavior. While short-term outcomes were evident, further investigation into the long-term sustainability of these changes are needed.

Introduction

Environmental education can effectively inform and engage people to address environmental challenges and promote collaboration among stakeholders (Kruse, 2004, Ardoin, 2020). It involves developing attitudes, values, awareness, knowledge, and skills that prepare people for informed environmental action (Birdsall, 2010, Monroe, 2016). Children are a crucial audience as they often develop long-lasting attitudes towards nature and the environment early on (Dobson, 2007, Niederdeppe, 2021). Outdoor activities have been shown to enhance children's learning and understanding of nature and the environment (Robinson, 2001). Educational programs for children can support conservation and environmental engagement by increasing knowledge and attitudes towards the environment and endangered species (Grúňová, 2017; Frame, 2021).

Since 2014, the Snow Leopard Conservation Foundation and its partners have implemented an education program for children in the Tost Mountains of southern Mongolia to promote community-based conservation efforts by educating children about local wildlife. The purpose of this paper is to understand how the participating children perceived nature and the environment. Additionally, we also share our experiences from eight years of eco-camp activities in the Gobi region of southern Mongolia.

Methods

Eco-camp program description

The eco-camp program aims to promote a sense of pride in the local environment and ownership of environmental actions. We believe that this sense of pride and ownership will spread throughout the wider community through interactions with friends and family members. The five-day eco-camps are for children in grade six (aged 12-13 years) and are held during the summer months. The program emphasizes active learning in snow leopard habitats and focuses on raising awareness about the local biodiversity and environment through nature-based lectures and exploring the natural environment (Figure 2). Most activities take place outdoors and include interactive learning, games and knowledge sharing (see Appendix 1 for detail). Each year, we invite 40 children from the district center to participate in the eco-camps, although the program was suspended for two years (2020-2021) during the COVID-19 pandemic. We also invite two teachers from the district center each year to join the program.

We invited children from the Gurvantes district center in the South Gobi province (aimag) of southern Mongolia (See Figure 1; Table 1). In 2014 and 2017, we also invited children from Bayangobi and Sevrei district centers. Of these three districts, Gurvantes is the largest, with a population of 4,840 inhabitants in 2022 based on local government statistics. In comparison, Bayangobi and Sevrei had populations of 2,753 and 2,010 inhabitants, respectively, in 2022 based on local government statistics. Each district center has one public school with a student population ranging from about 800 to 1,000 students aged 6 to 18 years.

Figure 1. *Location of the Tost Mountains in southern Mongolia where the eco-camps are held. Also shown on the map are the three districts from which the participants at the eco-camps came from, the extent of the Tost-Tosonbumba Nature Reserve, and the capital Ulaanbaatar.*

Figure 2. *Nature based activity in snow leopard habitat in the Tost Mountains focusing on raising awareness about the local biodiversity and environment through exploratory learning.*

Table 1. *Participant profile in the snow leopard Eco-camps in 2014-2022.*

District	Gurvantes		Bayangobi		Sevrei		Total	
Year	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**	**Boys**
2014	12	8	8	12	0	0	21	19
2015	20	20	0	0	0	0	20	20
2016	21	19	0	0	0	0	21	19
2017	10	10	0	0	9	11	22	18
2018	19	22	0	0	0	0	19	22
2019	23	17	0	0	0	0	23	17
2022	24	18	0	0	0	0	24	18
Total	**129**	**114**	**8**	**12**	**9**	**11**	**150**	**133**

The five-day eco-camp takes place in the Tost-Tosonbumba Nature Reserve, where the Snow Leopard Conservation Foundation and the Snow Leopard Trust have had a research station since 2008. This nature reserve is an extension of the Gobi-Altai mountain range, known for its rugged terrain, desert steppe, and semi-desert grasslands. It contains diverse wildlife populations, including snow leopards (*Panthera uncia*), wolves (*Canis lupus*), Eurasian lynx (*Lynx lynx*), ibex (*Capra Sibirica*), argali sheep (*Ovis ammon*), bearded vultures (*Gypaetus barbatus*), golden eagles (*Aquila chrysaetos*), and black vultures (*Aegypius monachus*) (Sharma, 2014).

Program monitoring and assessment

To assess the efficiency and effectiveness of the eco-camps, the Snow Leopard Conservation Foundation has monitored eco-camp activities since 2014, focusing on input, process, and output indicators. These indicators include children's gender and background (herder children vs other background), as well as the number and types of activities conducted at the camp. In addition, the school administration provides us with the number of grade six students in Gurvantes, Bayangobi, and Sevrei.

In 2022, we asked the children to express their interactions and emotions towards nature in any creative form they felt comfortable with, such as short write-ups (including poems), videos, drawings, or other mediums. This exercise encouraged children to articulate their feelings and connections with nature. Write-ups were the most common method used by the children to convey their thoughts. The program coordinator then evaluated their interactions and emotions towards nature in the write-ups shared with us, noting that not all children wished to share their work. In total, we analyzed 10 write-ups. Before using the children's write-ups, we received written consent from their parents to do so. The evaluation used deductive coding to capture references to nature, ecosystem services, and associated emotions (see Table 2 for definitions

Table 2. *Definition of the below mentioned ecosystem services and other terms are from Millennium Ecosystem Assessment (2005), IPBES IAS Assessment (2022) and Damasio (2004). We defined ecosystem services as the benefits people obtain from nature and the environment following the Millennium Ecosystem Assessment (2005).*

Terms	Definitions
Natural elements	**Natural elements are elements that have been produced by nature, without the intervention of humans.**
Wildlife	The native fauna of a region.
Human elements	The human element is a generic term to describe what makes humans behave the way they do and the consequences that result from these behaviors.
Feeling	The capacity or ability to experience physical sensations (such as pain, touch, or temperature) that is mediated chiefly by end organs and sensory receptors in the skin.
Emotions	Emotions are unconscious mental reactions (such as anger or fear) that are typically accompanied by physiological and behavioral changes in the body.
Aesthetic value	The positive value that an object or event possesses when appreciated or experienced aesthetically.
Ecosystem services	**Ecosystem services are the benefits people obtain from nature and the environment.**
Cultural services	Cultural services are non-material benefits provided by nature and the environment.
Regulating services	Regulating services are benefits obtained from the regulation of ecosystem processes.
Provisioning services	Provisioning services are products obtained from nature and the environment.

of the natural elements and ecosystem services used). Expressions and feelings could fall into more than one of these categories. To examine the children's connection and appreciation of nature as expressed in the write-ups, we used the Atlas.ti analysis tool (Hwang. 2008) to count how frequently children referred to a set of predefined natural elements and ecosystem services in their poems. The write-ups were translated into English (before they were entered into Atlas.ti). The translations were made by the first author who is fluent in Mongolian and English.

The decision to use creative expressions was influenced by feedback from previous eco-camp sessions (i.e. before 2022) where the participants indicated they felt more comfortable expressing their thoughts and feelings about nature through creative means rather than responding to a fixed questionnaire.

In 2022 we also requested feedback from parents and teachers on what the children had learned and how the program could be improved. For parents, this was done through informal conversations and through written feedback where 6 parents provided feedback through conversations and 5 parents by written feedback. Four of the teachers who participated in the eco-camp sent written feedback.

Results

Eco-camp participation and reach

A total of 283 children attended the eco-camps in Tost from 2014 to 2019 and again in 2022 to 2023 (See Table 1). Among them, 158 participants (56%) were herder children, while the remaining 125 (44%) were non-herder children living in the district centers. On average, 53% of the participants were girls and 47% were boys. The eco-camp included children from Gurvantes district throughout all eight years. In 2014, the eco-camp also included 20 children from Bayangobi, and in 2017, it included 20 children from Sevrei district. The number of sixth-grade students from Gurvantes ranged from 279 to 420 between 2014 to 2022, with participation rate varying from 6% in 2017 to 15% in 2022 among all children of that age group in Gurvantes. The participation rate of sixth-grade students from Bayangobi was 8% in 2014, while the participation rate of sixth-grade students from Sevrei was 6% in 2017. Thirteen teachers from Gurvantes, one teacher from Sevrei, and one teacher from Bayangobi participated in the eco-camps between 2014 to 2022. One teacher from Gurvantes participated in two eco-camps.

Interactions and emotions towards nature as expressed in write-ups

Local natural elements were mentioned in all 10 write-ups and a total of 42 times. The predominant focus was on environmental elements (mentioned 22 times), and included air, water, river, wind and others. Wildlife (mentioned 16 times), with references to birds, flies, bumble bees, lizards, was the second-most cited natural elements. Human elements were referenced twice, specifically related to motorbike sounds and recalling the teacher's remarks about the interconnectedness of nature. Plants were also mentioned twice. Overall, the write-ups expressed admiration for the beauty of the natural surroundings and its diverse elements a total of 22 times.

Ecosystem services were mentioned 37 times: cultural services were referenced 14 times, regulating services 12 times, and provisioning services 11 times. In terms of cultural services, the children expressed aesthetic values and their appreciation for the natural environment through quotes such as:

> *"Birdsong sounds like an opera. The earth, soil, wind, and water here are truly wonderful, having aesthetic value from nature."*
> (Boy from Gurvantes district, 2022)

Regulating services were highlighted through quotes such as:

> *"We need to save the atmosphere from greenhouse gasses and fossil fuels which pollutes the sky"*
> (Girl from Gurvantes district, 2022)

Provisioning services were exemplified by references to water and pasture, as seen in the following quote:

> *"Water is worth more than human life. The wind, for instance, is like some magnum opus. This vale of gales is an earthbound ocean"*
> (Boy from Gurvantes district, 2022)

The children also recognized the interconnectedness of animals with the natural world, with phrases such as:

> *"Realizing that animals are related to all things"*
> (Boy from Gurvantes district, 2022)

The children expressed their feelings and emotions towards nature and the environment a total of 19 times in their write-ups. We categorized these expressions into five different emotions. Comfort was the most commonly expressed emotion, mentioned six times, highlighting the positive experience of spending time in nature. This sentiment was captured in quotes such as:

> *"Perhaps the lull of nature exists in a peaceful stature"*
> (Girl from Gurvantes district, 2022)

> *"The environment has such a beautiful sound"*
> (Girl from Gurvantes district, 2022)

Curiosity and wonder were also prominent emotions expressed five times in the write-ups. The children marveled at the wonders of nature with lines such as:

> *"Winds blow as I sit back, soon abated but returning, is the gust redoubling?"*
> (Girl from Gurvantes district, 2022)

> *"Never seen such an enchanting sight, wouldn't have known such a secret"*
> (Girl from Gurvantes district, 2022)

The children also showed a deep curiosity, as seen in the quote:

> *"It's voice is meshed ubiquity and snatches my inner curiosity. To wonder about this creation."*
> (Girl from Gurvantes district, 2022)

Feedback from parents and teachers

In 2022, six parents provided feedback through conversations and five submitted written feedback (a total of eleven parents provided feedback). Four teachers who participated over the years in the eco-camp program also sent written feedback. Feedback from participants' families was consistently positive, comprising both written and verbal expressions of satisfaction. Specifically, parents noted positive changes in the children's behavior, such as a heightened awareness of environmental conservation and a more thoughtful approach to living sustainably and protecting the natural environment. In the feedback received from 100% of parents, a common theme emerged: parents expressed pride in their children's learning experiences during the program and happiness about their participation in the eco-camps. One parent shared a specific instance:

> *"I was pleasantly surprised. Normally, when a spider crawls around my house, we instinctively kill it and get rid of it. This time, I was about to do the same, but my daughter promptly stopped me, saying, 'We can relocate the animal without harming it.' She then went on to explain the significance of the spider in the environment. Her initiative and articulate explanation truly impressed me, and I couldn't be prouder of my daughter."*
> (quote from a 40-year-old mother)

Another parent shared the following feed-back:

> *"After the eco-camps experience my daughter taught us some lessons for our family. She said that we needed to reduce consumption of plastic bags and plastic bottles. Initially, I did not bother much. But she started pressuring us to not buy plastic bags when we went shopping and to not buy small bottles of plastic water and drinks. She started to be concerned about the garbage we produced as a family and we started being more careful and reducing the amount we produced"*
> (quote from a 35-year-old father).

All four teachers reported positive experiences and expressed their willingness to share their insights with other educators. They were also eager to integrate similar outdoor experiences into their classroom curriculum. Some teachers were pleasantly surprised by the heightened level of engagement and enthusiasm displayed by children that had participated in the eco-camps when exposed to experiential learning outdoors. They shared how they thought the outdoor experiences proved effective in expanding the children's knowledge and broadening their overall experiences.

Discussion

Public engagement and environmental education have proven effective in promoting awareness of environmental challenges and support for conservation (Kruse. 2004, Ardoin. 2020). Our work focused on children participating in eco-camps in the Tost Mountains, revealing a notable connection and appreciation for nature and the environment. Following the eco camps, there was an increase in knowledge and appreciation for nature as expressed by teachers and parents, a positive outcome that aligns with the effectiveness of using write-ups and poems as a tool for examining this connection (Nosek. 2009, Dai. 2022).

The children's admiration for the natural surroundings and their appreciation of eco-system services, showcased a deep understanding. Some children referred to regulatory ecosystem services and the interconnectedness of different ecosystem components. The strong appreciation and connection to nature among the children mirror findings from other parts of the world, underscoring the importance of engaging children early on for the establishment of lasting connections with nature (Dobson, 2007; Witt, 2013; Niederdeppe, 2021).

Feedback from teachers and families corroborated the positive impact of the eco-camps, indicating an increased knowledge and appreciation for nature and the environment among participating children, similar to the findings in other environmental education programs (Ardoin. 2020). Notably, the awareness of nature and the environment among the children extended to their families and friends through subsequent discussions, highlighting the spillover effects that have been observed also in other environmental programs (Whitehouse. 2014, Chimed. 2023). However, it is crucial to acknowledge that our follow-up was conducted shortly after the eco-camp experience, leaving the long-term and permanent changes uncertain. In addition, we were not able to interview all parents of the attending children. Understanding the lasting outcomes of eco-camps and their contribution to conservation over extended periods requires further investigation (Stern. 2008, Collado. 2013).

Our team ensured a balanced gender ratio among the children attending the eco-camp, with 53% girls and 47% boys. Other research in snow leopard landscapes have highlighted how women or girls can have negative preconceptions about wildlife (Suryawanshi. 2014, Alexander. 2023, Chimed. 2023). This underscores the importance of gender-inclusive environmental engagement. Additionally, half of the eco-camp attendees were herder children, emphasizing the significance of connecting with this group as they share landscapes with snow leopards (Dickman, 2013, Mijiddorj, 2018).

We have successfully operated the eco-camp in Gurvantes since 2014, focusing on areas with ongoing snow leopard conservation activities. In some years, 15% of children aged 12 to 13 attended the eco-camp, representing a relatively large proportion of the age group from one district. However, the geographical coverage of the eco-camps is limited to Gurvantes and neighboring districts. Gurvantes was selected for the eco-camps because it is a hotspot for snow leopard conservation and community engagements (Young, 2021). Before expanding eco-camps into larger areas, we recommend strengthening the existing program. To enhance the impact of our efforts, we suggest supporting an eco-club within the school itself to help the children to remain active throughout the year. Additionally, providing teachers with resources and training to offer classes on mountain and steppe ecology year-round could further strengthen the existing program before expanding into larger areas.

In summary, our work shows that children attending the eco-camps have a strong appreciation for their environment in the Gobi. However, long-term monitoring of connectedness and appreciation for nature and the environment is important for understanding how eco-camps may result in more permanent and sustained conservation engagements. Our eco-camps reached between 5 and 15% of grade six students in Gurvantes which we hope will help to foster greater awareness and future conservation engagements. Here positive views towards nature and the environment during and following the eco-camps are particularly encouraging. However, further studies are needed to examine for more permanent and long-term impacts of eco-camps and their contribution to conservation.

References

ATLAS.ti Scientific Software Development GmbH (2023) ATLAS.ti Mac (Version 23.2.1) [Computer program]. Available at: https://atlasti.com (Downloaded: 27 July 2023).

Alexander, J. S., Murali, R., Mijiddorj, T. N., Agvaantseren, B., Lhamo, C., Sharma, D., ... & Young, J. C. (2023). Applying a gender lens to biodiversity conservation in High Asia. Frontiers in Conservation Science, 4, 1006052.A

Ardoin, N. M., Bowers, A. W. and Gaillard, E. (2020) "Environmental education outcomes for conservation: A systematic review," *Biological conservation*, 241(108224), p. 108224. doi: 10.1016/j.biocon.2019.108224.

Aryal, A., Brunton, D., Ji, W., Barraclough, R. K., & Raubenheimer, D. (2014). Human–carnivore conflict: ecological and economical sustainability of predation on livestock by snow leopard and other carnivores in the Himalaya. Sustainability Science, 9, 321-329.

Birdsall, S. (2010) “Empowering students to act: Learning about, through and from the nature of action,” *Australian journal of environmental education*, 26, pp. 65–84. doi: 10.1017/s0814062600000835.

Collado, S., Staats, H. and Corraliza, J. A. (2013) “Experiencing nature in children’s summer camps: Affective, cognitive and behavioural consequences,” Journal of environmental psychology, 33, pp. 37–44. doi: 10.1016/j.jenvp.2012.08.002.

Cronin, C. and Hawthorne, C. (2019) “‘Poetry in motion’ a place in the classroom: Using poetry to develop writing confidence and reflective skills,” *Nurse education today*, 76, pp. 73–77. doi: 10.1016/j.nedt.2019.01.026.

Chimed, O., Lkhagvasuren, D., Alexander, J. S., Barclay, D., Bayasgalan, N., Lkhagvajav, P., ... & Samelius, G. (2023). Delivery of educational material increased awareness of the elusive Pallas’s cat in Southern Mongolia. *Applied Environmental Education & Communication*, *22*(1), 1-12.

Dai, P., Zhang, S., Gong, Y., Yang, Y., & Hou, H. (2022). Assessing the inspirational value of cultural ecosystem services based on the Chinese poetry. Acta Ecologica Sinica, 42(5), 467-475.

Damasio, A. R. (2004). “Emotions and feelings. In Feelings and emotions” The Amsterdam symposium (Vol. 5, pp. 49-57). Cambridge: Cambridge University Press.

Dickman, A., Marchini, S. and Manfredo, M. (2013) “The human dimension in addressing conflict with large carnivores,” *Key Topics in Conservation Biology 2*. Wiley, pp. 110–126. doi: 10.1002/9781118520178.ch7.

Dobson, A. (2007) “Environmental citizenship: towards sustainable development,” *Sustainable development*, 15(5), pp. 276–285. doi: 10.1002/sd.344.

Frame, J. R., Good, B., Slinger, P., Smith, M. P., Butler, B., & Marancik, D. (2021). Measuring of the effects of a sea turtle conservation education program on children’s knowledge and attitudes in Grenada West Indies. Ocean & Coastal Management, 211, 105752.

Grúňová, M., Brandlová, K., Svitálek, J., & Hejcmanová, P. (2017). Environmental education supports conservation action by increasing the immediate and long-term environmental knowledge of children in West Africa. Applied Environmental Education & Communication, 16(1), 3-16.

Hwang, S. (2008) “Utilizing qualitative data analysis software: A review of Atlas.Ti,” *Social science computer review*, 26(4), pp. 519–527. doi: 10.1177/0894439307312485.

Islar, M., Balvanera, P., Kelemen, E., Pascaul, U., Subramanian, S. M., Nakangu, B., Porter-Bolland, L. (2022). Methodological Assessment Report on the Diverse Values and Valuation of Nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.: Chapter 6: Policy options and capacity development to operationalize the inclusion of diverse values of nature in decision-making.

Kling, K. J. and Hopkins, M. E. (2015) “Are we making the grade? Practices and reported efficacy measures of primate conservation education programs,” *American journal of primatology*, 77(4), pp. 434–448. doi: 10.1002/ajp.22359.

Kruse, C. K. and Card, J. A. (2004) “Effects of a conservation education camp program on campers’ self-reported knowledge, attitude, and behavior,” *The journal of environmental education*, 35(4), pp. 33–45. doi: 10.3200/joee.35.4.33-45.

Levick, W. R. (2010) “Observer rating of memory in children: A review,” Brain impairment: a multi-disciplinary journal of the Australian Society for the Study of Brain Impairment, 11(2), pp. 144–151. doi: 10.1375/brim.11.2.144.

Monroe, M. C. and Krasny, M. E. (2016) *Across the spectrum: Resources for environmental educators*. North American Association for Environmental Education.

Mijiddorj, T. N., Alexander, J. S., Samelius, G., Badola, R., Rawat, G. S., & Dutta, S. (2018). Corrigendum to: Livestock depredation by large carnivores in the South Gobi, Mongolia. Wildlife Research, 45(4), 381-381.

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: Wetlands and water synthesis. World Resources Institute, Washington, DC.

Niederdeppe, J., Winett, L. B., Xu, Y., Fowler, E. F., & Gollust, S. E. (2021). Evidence-based message strategies to increase public support for state investment in early childhood education: results from a longitudinal panel experiment. The Milbank Quarterly, 99(4), 1088-1131.

Nosek, A. (2009). “Poems for children as a means of conveying knowledge about the region”, In Nuevas perspectivas para la difusión y organización del conocimiento: actas del congreso (pp. 211-215). edUPV, Editorial Universitat Politècnica de València.

Prokop, P., Usak, M., & Erdogan, M. (2011). Good predators in bad stories: Crosscultural comparison of children’s attitudes towards wolves. Journal of Baltic Science Education, 10(4), 229-242.

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.

Stern, M. J., Powell, R. B. and Ardoin, N. M. (2008) "What difference does it make? Assessing outcomes from participation in a residential environmental education program," The journal of environmental education, 39(4), pp. 31–43. doi: 10.3200/joee.39.4.31-43.

Skyggebjerg, A. K. (2018) "Poetic constructions of nature: The Forest in recent visual poetry for children," in *Ecocritical Perspectives on Children's Texts and Cultures*. Cham: Springer International Publishing, pp. 141–155.

Suryawanshi, K. R., Bhatia, S., Bhatnagar, Y. V., Redpath, S., & Mishra, C. (2014). Multiscale factors affecting human attitudes toward snow leopards and wolves. Conservation Biology, 28(6), 1657-1666.

Witt, Annick Hedlund-de (2013) "Pathways to environmental responsibility: A qualitative exploration of the spiritual dimension of nature experience," *Journal for the Study of Religion Nature and Culture*, 7(2), pp. 154–186. doi: 10.1558/jsrnc.v7i2.154.

Vaughan, C., Gack, J., Solorazano, H., & Ray, R. (2003). The effect of environmental education on schoolchildren, their parents, and community members: A study of intergenerational and intercommunity learning. The Journal of Environmental Education, 34(3), 12-21.

Young, J. C., Alexander, J. S., Bijoor, A., Sharma, D., Dutta, A., Agvaantseren, B., ... & Mishra, C. (2021). Community-based conservation for the sustainable management of conservation conflicts: Learning from practitioners. Sustainability, 13(14), 7557.

Appendix 1: Example Agenda for General Five Day Eco-Camps Curriculum

DAY 1

1. **Introductory Session:** Start with joyful games to break the ice and foster a friendly atmosphere.
2. **Exploring the Local Environment:** Discuss the types of wildlife and plants in the area, emphasizing how people benefit from their surroundings.
3. **Enhancing the Sense of Touch:** Connect with nature through tactile experiences. By touching natural objects, children will sharpen their sense of touch and gain a deeper understanding of nature's intriguing aspects.
4. **Understanding Vulnerable and Threatened Species:** Engage in group discussions about vulnerable wildlife and plants to help children comprehend the reasons behind their threats.
5. **Three-Stone Game – Stone Painting:** Encourage creativity as children paint stones, transforming them into unique pieces of art.

DAY 2

1. **Wildlife Signature:** Visit the main habitat valley of snow leopards to observe direct and indirect signs of wildlife.
2. **Reflection on Snow Leopard Life:** After the trail visit, discuss the "Snow Leopard Cub" book to reflect on the life, biology, and ecology of snow leopards.
3. **Snow Leopard and Prey Animal Game:** Help children understand the food chain and the importance of carnivores in nature through interactive play.
4. **Research Insights:** Show slides illustrating how researchers conduct studies on snow leopards.

DAY 3

1. **Sighting Sense – Drawing Session:** Encourage children to find and use as many natural colours as possible in their drawings, enhancing their awareness of nature.
2. **Biodiversity Game:** Ask kids to name their favourite animals, then discuss each animal's role in the ecosystem.
3. **Adaptation Discussion:** Explain how plants and animals develop special structures and behaviours to adapt to their environment for survival, providing examples from wildlife.
4. **Taste Exploration:** Engage children's sense of taste by sampling natural items (e.g., plants, water) to strengthen their connection with nature.
5. **Garbage Talk:** Discuss the impact of garbage on the environment, focusing on decomposition times and the dangers of toxic waste.

DAY 4

1. **Sense of Smell:** Explore various natural scents, particularly from mountain plants, to deepen understanding of plant characteristics.
2. **Water Conservation Session:** Investigate daily water usage in households to promote water conservation awareness.
3. **Pasture Changes Discussion:** Examine changes in local pastures, exploring reasons for these changes and their consequences.
4. **Listening to Nature – Silent Session:** Enhance hearing skills by encouraging children to listen attentively to their environment and document their feelings.
5. **What If I Were a Plant or Animal?:** Have children write letters advocating for proper treatment of wildlife.

DAY 5

1. **My Contribution to Conservation:** Summarize what has been learned throughout the week, allowing children to express their thoughts on wildlife conservation and write down their commitments to protect nature.
2. **Conflict Role Play – Coexisting or Conflicting?:** Brainstorm solutions for living harmoniously with wildlife while protecting livestock in natural habitats.
3. **Poster Session:** Form groups to create posters illustrating key takeaways from the project.
4. **Creative Reflection:** Ask children to write a poem about their connection with nature, aiming to capture their impressions and feelings toward the natural world.

Extra Notes:

This agenda summarizes main activities while allowing flexibility for new exercises based on weather and timing. The focus is on maintaining high-quality themes and effective debriefing sessions. Most activities will be conducted outdoors whenever possible, complemented by fun games related to environmental themes and conservation efforts.

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First Photographic Evidence of Pallas's Cat (*Otocolobus manul*) from Himachal Pradesh, India

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Abstract

While the study of carnivore ecology has made significant progress, our knowledge of small cats remains limited. For some species, their distribution remains largely unknown. We report the first photographic evidence of the Pallas's cat in Himachal Pradesh, India. Of the 56 camera traps placed for snow leopard population estimation across Kinnaur region between March-May 2024, we recorded Pallas's cat at three camera trap sites with 19 images from three instances during morning hours. These captures were at an elevation of 3900–4100 meters in rocky habitats largely dominated by boulders and cliffs. Sympatric carnivores captured were snow leopard (*Panthera uncia*), red fox (*Vulpes vulpes*), stone marten (*Martes foina*) and free-ranging dogs. This discovery not only extends the known

distribution of Pallas's cat but also underscores the urgent need for focused conservation research and action in this region, especially given the presence of free-ranging dogs. This can be achieved through coordinated, landscape level and trans-boundary efforts.

Main Text

Small carnivores (mammals of order Carnivora weighing <16 kg) play significant roles in determining the structure and function of an ecosystem through top-down effects on herbivores, long-distance seed dispersal, pest control and nutrient cycling (Do Linh San et al., 2022; Marneweck et al., 2021). Even though there is increasing evidence of them being excellent sentinel species (Marneweck et al., 2022), we have a paucity of information about them (Bandyopadhyay et al., 2024; Marneweck et al., 2021). India is home to 15 species of wild cats (60% of the global felid diversity), of which 11 are small carnivores (Jackson, 1997). Alarmingly though, a majority of them show a declining trend (Bandyopadhyay et al., 2024).

The Pallas's cat (*Otocolobus manul*), like many small carnivores, faces significant threats from habitat fragmentation and increasing feral species, making focused research on its distribution and status critical for conservation planning. Also known as manul, the Pallas's cat is a small cat species documented from 13 countries and is listed as Least Concern on the IUCN Red List (Ross et al., 2020). However, its distribution is fragmented, spanning from the Middle East Asian region to montane grasslands and shrublands of Northern and Central Asia and some parts of South Asia (Aghili et al., 2008; Anile et al., 2021; Barashkova et al., 2007; Belousova, 1993; Jutzeler et al., 2010). Despite its wide range of occurrence, it is a habitat and prey specialist (Ross et al., 2010, 2020) with its prey populations also prone to land-use change and climate change (Lanz et al., 2019; Ma et al., 2021). In India, this elusive and rare small cat has been reported from several locations in Ladakh (Mahar et al., 2017; Maheshwari et al., 2023; Mallon, 1991), and occasional sightings from Sikkim (Chanchani, 2008; Menon, 2014; Prater & Society, 1990) and a camera trap record from Uttarakhand (Pal et al., 2019) (Figure 1 (a)). Owing to its limited observations resulting from rough terrain and cryptic nature, knowledge about this species is sparse, especially in South Asia (Dhendup et al., 2019; Mahar et al., 2017). This lack of comparable and accurate data across its range acts as an impediment in formulating and implementing effective conservation plans for the species (Lanz et al., 2019; Ross et al., 2019).

Here we report the first photographic evidence of Pallas's cat in the trans-Himalayan region of Hangrang valley, Kinnaur from the state of Himachal Pradesh, India (Figure 1). We obtained this record during a camera trapping survey for snow leopard (*Panthera uncia*) population estimation across the state of Himachal Pradesh, India conducted in partnership with the Himachal Pradesh Forest Department. We had placed 56 cameras for a duration of 60 days, from March 2024 to May 2024, with the aim to estimate snow leopard populations in the Kinnaur region. We deployed cameras in 4 x 4 km grids based on snow leopard signs such as scat, scratch or spray marks in their suitable habitat like ridgelines, cliff bases and overhanging boulders. We recorded the Pallas's cat at three independent camera trap sites in the valley, at elevations ranging from

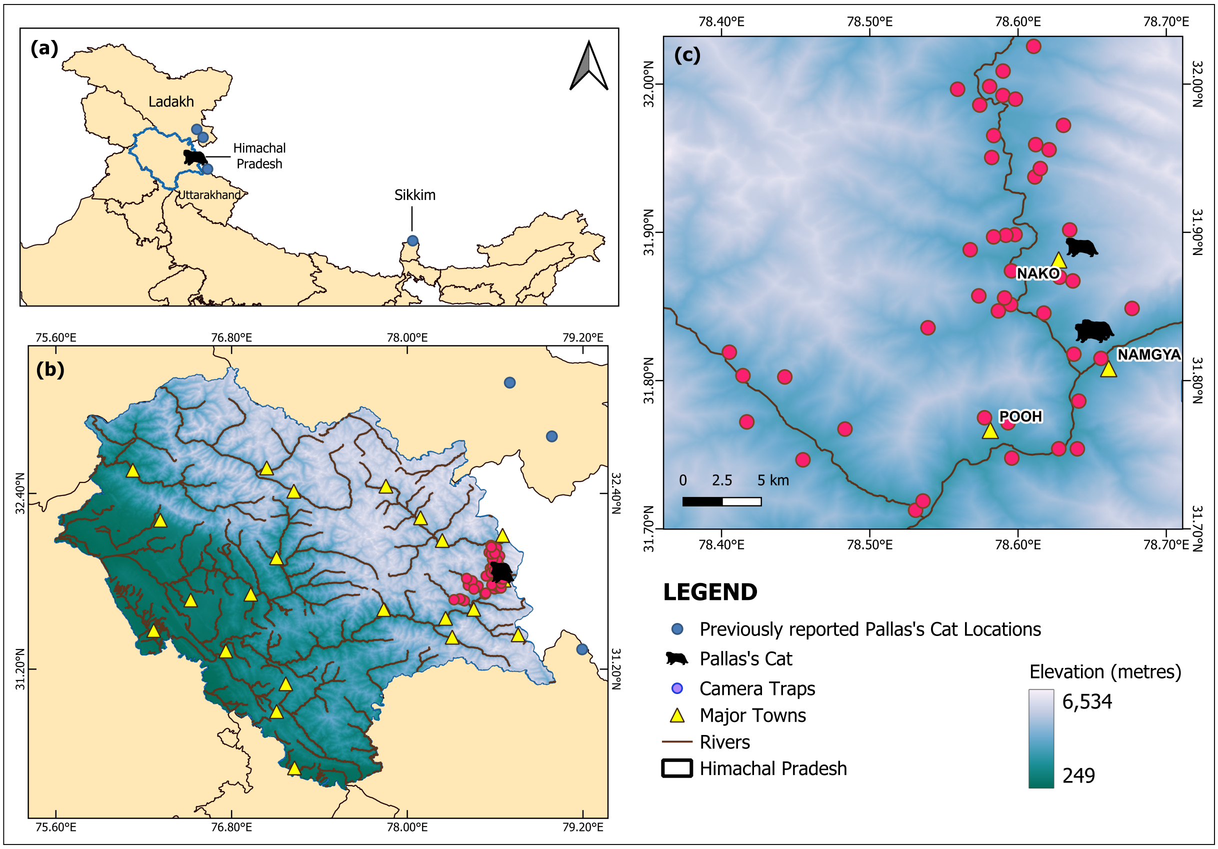

Figure 1. **(a)** *Previously reported Pallas's cat locations in Ladakh, Uttarakhand and Sikkim,* **(b)** *the state of Himachal Pradesh with camera trap locations, and* **(c)** *Hangrang Valley where the Pallas's cat was recorded.*

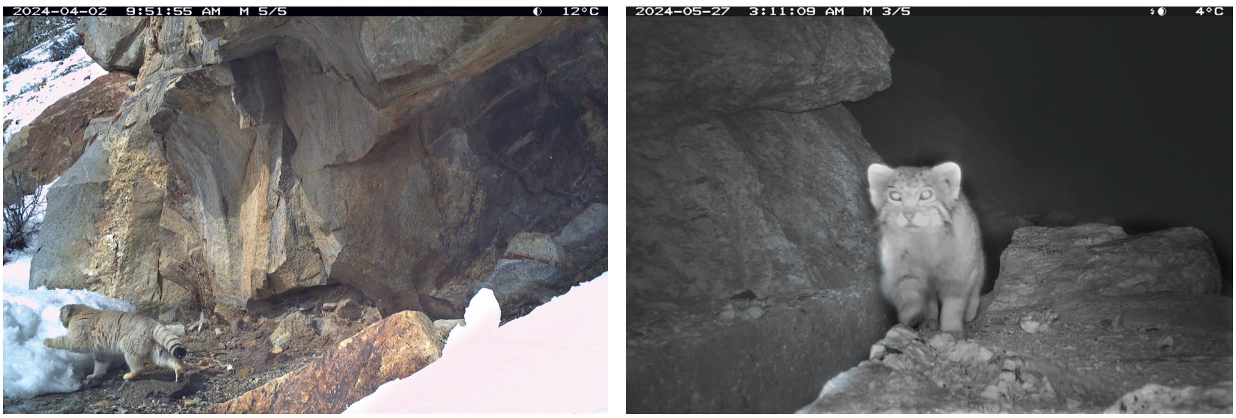

Figure 2. *Pallas's cat captured in Hangrang valley, Upper Kinnaur.*
(Photo credit: Wildlife Wing-Himachal Pradesh Forest Department and Nature Conservation Foundation).

3900–4100 meters above mean sea level. The Pallas's cat was photographed once at each of the three sites, with a total of 19 images, during the early morning hours, specifically between 3 AM and 4 AM and one at 10 AM (Figure 2). They were observed solitary, walking past the camera. Individual identification was not possible given these low number of captures.

Hangrang valley is located in the Kinnaur region adjacent to Spiti. This region of Upper Kinnaur is characterized by a cold and arid environment with annual rainfall of < 50 mm and harsh snow-bound winters (Chawla et al., 2012; Rahimzadeh, 2016) (Figure 3), and rugged mountains with precipitous watersheds flowing into the Sutlej (Rahimzadeh, 2016). The habitat in the surrounding area where we recorded the Pallas's cat was covered with medium-large sized rocky boulders and cliffs, interspersed with patches of meadows (Figure 4). One of the

Figure 3. *The trans-Himalayan landscape from Hangrang valley in Kinnaur.*

Figure 4. *Trans-Himalayan region of Upper Kinnaur where camera traps were placed.*

sites had an Irrigation and Public Health water pipeline source. The vegetation in the area was sparse, dry alpine scrub *Artemisia* spp., *Astragalus* spp., *Eurasia* spp., *Carex* spp.

Other wildlife that we recorded along with the Pallas's cat include snow leopard, red fox (*Vulpes vulpes*), stone marten (*Martes foina*), Himalayan snowcock (*Tetraogallus himalayensis*), chukar (*Alectoris chukar*), and pika (*Ochotona* spp.) (Figure 5). Pikas were captured

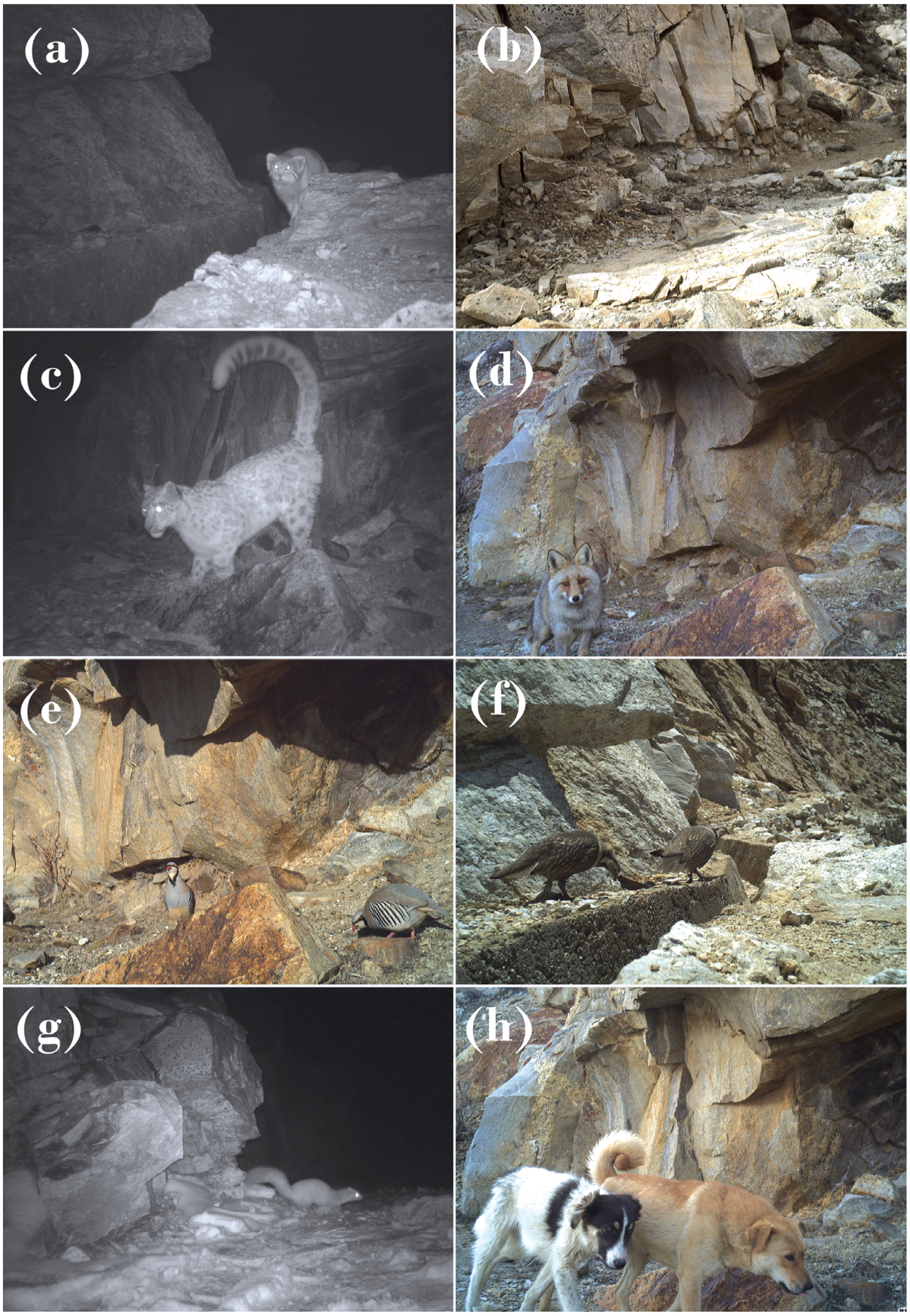

Figure 5. *Pallas's cat and other wildlife that were captured in Hangrang valley* **(a)** *Pallas's cat,* **(b)** *pika,* **(c)** *snow leopard,* **(d)** *red fox,* **(e)** *chukar,* **(f)** *Himalayan snowcock,* **(g)** *stone marten,* **(h)** *free-ranging dogs. (Photo credit: Wildlife Wing-Himachal Pradesh Forest Department and Nature Conservation Foundation).*

on multiple occasions, and the occurrence of Pallas's cat is strongly linked with the presence of its prey (Greenspan & Giordano, 2021). Their probable prey species in this part of their distribution also include chukar, voles (*Alticola* spp.) and Tibetan snowcock (*Tetraogallus tibetanus*) (Dhendup et al., 2019).

The Hangrang valley is situated very close to the international border with Tibet. Research suggests there are many regions possibly inhabited by/suitable for the Pallas's cat, however, they suffer from a lack of survey effort (Greenspan & Giordano, 2021). Models do predict the western Himalayas and the Tibetan plateau as plausible habitats for this species (Greenspan & Giordano, 2021). Earlier, in 2020-21, there have been locally reported sightings shared across social media and older records from the state as well (Negi, 1998). This finding reiterates the need to have Pallas's cat-focused camera trap surveys to better understand its presence.

Pallas's cat has been recorded in trade in India in the past five decades (Bandyopadhyay et al., 2024; *CITES Trade Database*, 2022). It is listed in Appendix II of the CITES (CITES, 2022) and Schedule 1 of the Wildlife Protection Amendment Act, 2022 (The Indian Wildlife Protection (Amendment) Act, 2022). Despite this, there are numerous threats that the animal faces. From our camera trap data, we observed free-ranging dogs present at the majority of locations (see Figure 5). They are highly invasive, threatening wildlife through predation, competition, disease transmission, hybridization, inducing chronic stress and fear-induced behavioural changes (Dar et al., 2023; Home et al., 2018). There has been a rise in their number in the trans-Himalayas, and pose significant threat of harming wildlife, especially small cats, and competing for prey (Home et al., 2018; Mahar et al., 2024; Shrivastava, 2023). Moreover, their widespread distribution in the landscape and high exposure rates to pathogens result in serious disease risks to carnivores (Home et al., 2022). In addition to this, the habitat of Pallas's cat is fragmented by heavy military presence and disturbance due to proximity to an international border, and large-scale infrastructure development causing irreversible damage to the ecosystem (Dey & Basu, 2023; Hussain, 2023). Unregulated tourism, military camps and poor waste management attract free-ranging dogs, exacerbating the issue (Dey & Basu, 2023; Geneletti & Dawa, 2009; Mahar et al., 2024). This region is also highly vulnerable to climate change with many irreparable impacts on mountain ecosystems (IPCC, 2023; Krishnan et al., 2019). Increasing human pressures, rapidly changing land-use patterns, dependence on small mammal prey, and erratic seasons can likely endanger the future of the Pallas's cat (Banerjee et al., 2019; Ross et al., 2019).

The Pallas's cat is an indicator species for the mountain steppe ecosystems (Lanz et al., 2019). Hence, holistic conservation measures at a landscape-level are needed for effectively conserving it, its habitat and sympatric species. Reducing and controlling dog populations through better waste management practices, sterilization programs, and responsible dog ownership should be encouraged. Along with these, continuous monitoring and robust population assessments across its vast range are essential to derive efficient conservation measures. Raising awareness about the presence of these species also holds the potential to increase local stewardship for its conservation. More focused studies to understand the distribution and ecology of Pallas's cat are needed to aid in long-term conservation and management. Particular emphasis on its ranging behaviour, habitat use and reproductive success in such landscapes is needed.

This record is a crucial finding, not least because it is one of the first reported sightings from the state, but this could also be a population that is connected to the adjoining Tibetan plateau, further adding to its known global distribution. Potential cross-border connectedness can render the Pallas's cat a species that will need implementation of collaborative transboundary conservation. This will need raising awareness and capacities of key stakeholders which can assist in establishing connectivity across the trans-Himalayan region. Joint monitoring, patrolling and research programs to study the species will help in developing better strategies and action plans based on shared findings. These efforts can be leveraged to support viable populations of the species and safeguarding of its habitat.

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Conflict of Interest

No known conflict of interests.

Literature Cited

Aghili, A., Masoud, R., Murdoch, J. D., & Mallon, D. P. (2008). First record of Pallas's cat in northwest Iran. *Cat News*, *49*, 8–9.

Anile, S., Augugliaro, C., Munkhtsog, B., Dartora, F., Vendramin, A., Bombieri, G., & Nielsen, C. K. (2021). Density and activity patterns of Pallas's cats, Otocolobus manul, in central Mongolia. *Wildlife Research*, *48*(3), 264–272. https://doi.org/10.1071/WR20061

Bandyopadhyay, K., Banerjee, K., Vittoria Mazzamuto, M., Koley, S., Koprowski, J. L., Qureshi, Q., & Jhala, Y. (2024). Review of small cat ecology and status within India. *Mammal Review*, mam.12348. https://doi.org/10.1111/mam.12348

Banerjee, A., Chakraborty, P., & Bandopadhyay, R. (2019). Urgent conservation needs in the Sikkim Himalaya biodiversity hotspot. *Biodiversity*, *20*(2–3), 88–97. https://doi.org/10.1080/14888386.2019.1656547

Barashkova, A., Smelansky, I., Goryunova, S., & Naidenko, S. (2007). Pallas's cat: Investigation for saving (clarifying conservation status in Russia). *Siberian Environmental Center, Novosibirsk, Russia*.

Belousova, A. V. (1993). Small Felidae of Eastern Europe. *Central Asia, and the Far East: Survey of the State of Populations. Lutreola*, *2*, 16–21.

Chanchani, P. (2008). Sighting of a manul or Pallas cat in north Sikkim, India. *Cat News*, *48*, 18–19.

Chawla, A., Kumar, A., Lal, B., Singh, R. D., & Thukral, A. K. (2012). Ecological Characterization of High Altitude Himalayan Landscapes in the Upper Satluj River Watershed, Kinnaur, Himachal Pradesh, India. *Journal of the Indian Society of Remote Sensing*, *40*(3), 519–539. https://doi.org/10.1007/s12524-011-0169-0

CITES Trade Database. (2022). Convention on International Trade in Endangered Species of Wild Fauna and Flora. https://trade.cites.org/

CITES, U. (2022). *Appendices I, II and III*. Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Dar, S. A., Sharief, A., Kumar, V., Singh, H., Joshi, B. D., Bhattacharjee, S., Dutta, R., Dolker, S., Singh, A. P., Singh, V. K., Sidhu, A. K., Thakur, M., & Sharma, L. K. (2023). Free-ranging dogs are seriously threatening Himalayan environment: Delineating the high-risk areas for curbing free-ranging dog infestation in the Trans-Himalayan region. *Environmental Monitoring and Assessment*, *195*(11), 1386. https://doi.org/10.1007/s10661-023-11972-6

Dey, R., & Basu, A. (2023). Military-Induced Threat to The Himalayan Ecosystem: From Defilement to PossibleAmelioration. *Journal of Mountain Research, 18*(1). https://doi.org/10.51220/jmr.v18i1.10

Dhendup, T., Shrestha, B., Mahar, N., Kolipaka, S., Regmi, G. R., & Jackson, R. (2019). Distribution and status of the manul in the Himalayas and China. *Cat News, 13,* 31–36.

Do Linh San, E., Sato, J. J., Belant, J. L., & Somers, M. J. (2022). The World's Small Carnivores. In *Small Carnivores* (pp. 1–38). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118943274.ch1

Geneletti, D., & Dawa, D. (2009). Environmental impact assessment of mountain tourism in developing regions: A study in Ladakh, Indian Himalaya. *Environmental Impact Assessment Review, 29*(4), 229–242. https://doi.org/10.1016/j.eiar.2009.01.003

Greenspan, E., & Giordano, A. J. (2021). A rangewide distribution model for the Pallas's cat (Otocolobus manul): Identifying potential new survey regions for an understudied small cat. *Mammalia, 85*(6), 574–587. https://doi.org/10.1515/mammalia-2020-0094

Home, C., Bhatnagar, Y. V., & Vanak, A. T. (2018). Canine Conundrum: Domestic dogs as an invasive species and their impacts on wildlife in India. *Animal Conservation, 21*(4), 275–282. https://doi.org/10.1111/acv.12389

Home, C., Bijoor, A., Bhatnagar, Y. V., & Vanak, A. T. (2022). Serosurvey of viral pathogens in free-ranging dog populations in the high altitude Trans-Himalayan region. *Journal of Threatened Taxa, 14*(5), Article 5. https://doi.org/10.11609/jott.7203.14.5.21025-21031

Hussain, B. (2023, July 21). India-China Military Buildup Threatens Fragile Himalayan Ecosystems. *Voice of America*. https://www.voanews.com/a/india-china-military-buildup-threatens-fragile-himalayan-ecosystems-/7190915.html

IPCC. (2023). *Summary for Policymakers* (Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 1–34). IPCC. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

Jackson, P. (1997). The status of cats in the wild. *International Zoo Yearbook, 35*(1), 17–27. https://doi.org/10.1111/j.1748-1090.1997.tb01185.x

Jutzeler, E., Xie, Y., & Vogt, K. (2010). The smaller felids of China: Pallas's cat Otocolobus manul. *Cat News Special Issue, 5,* 37–39.

Krishnan, R., Shrestha, A. B., Ren, G., Rajbhandari, R., Saeed, S., Sanjay, J., Syed, Md. A., Vellore, R., Xu, Y., You, Q., & Ren, Y. (2019). Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes. In P. Wester, A. Mishra, A. Mukherji, & A. B. Shrestha (Eds.), *The Hindu Kush Himalaya Assessment* (pp. 57–97). Springer International Publishing. https://doi.org/10.1007/978-3-319-92288-1_3

Lanz, T., Breitenmoser-Wursten, C., Barclay, D., Nygren, E., Samelius, G., & Breitenmoser, U. (2019). Prologue: Why care about Otocolobus manul? *Cat News Special Issue, 13,* 5–8.

Ma, L., Mi, C., Qu, J., Ge, D., Yang, Q., & Wilcove, D. S. (2021). Predicting range shifts of pikas (Mammalia, Ochotonidae) in China under scenarios incorporating land use change, climate change and dispersal limitations. *Diversity and Distributions, 27*(12), 2384–2396. https://doi.org/10.1111/ddi.13408

Mahar, N., Habib, B., & Hussain, S. A. (2024). Do we need to unfriend a few friends? Free-ranging dogs affect wildlife and pastoralists in the Indian Trans-Himalaya. *Animal Conservation, 27*(1), 53–64. https://doi.org/10.1111/acv.12876

Mahar, N., Shrotriya, S., Habib, B., Singh, S., Takpa, J., & Hussain, S. A. (2017). Recent records of Pallas's cat in Changthang Wildlife Sanctuary, Ladakh, India. *Cat News, 65,* 36–37.

Maheshwari, A., Chapman, S., & Bhadula, A. (2023). *Pallas's cat and Tibetan fox standoff in Ladakh, India*. https://www.researchgate.net/profile/Aishwarya_Maheshwari/publication/371638760_Pallas's_cat_and_Tibetan_fox_standoff_in_Ladakh_India/links/648d2def8de7ed28ba30d1c2/Pallass-cat-and-Tibetan-fox-standoff-in-Ladakh-India.pdf

Mallon, D. P. (1991). Status and conservation of large mammals in Ladakh. *Biological Conservation, 56*(1), 101–119. https://doi.org/10.1016/0006-3207(91)90092-N

Marneweck, C. J., Allen, B. L., Butler, A. R., Do Linh San, E., Harris, S. N., Jensen, A. J., Saldo, E. A., Somers, M. J., Titus, K., Muthersbaugh, M., Vanak, A., & Jachowski, D. S. (2022). Middle-out ecology: Small carnivores as sentinels of global change. *Mammal Review, 52*(4), 471–479. https://doi.org/10.1111/mam.12300

Marneweck, C. J., Butler, A. R., Gigliotti, L. C., Harris, S. N., Jensen, A. J., Muthersbaugh, M., Newman, B. A., Saldo, E. A., Shute, K., Titus, K. L., Yu, S. W., & Jachowski, D. S. (2021). Shining the spotlight on small mammalian carnivores: Global status and threats. *Biological Conservation, 255,* 109005. https://doi.org/10.1016/j.biocon.2021.109005

Menon, V. (2014). *Indian Mammals: A Field Guide*. Hachette UK.

Negi, S. S. (1998). *Discovering the Himalaya* (Vol. 1). Indus Publishing. https://books.google.com/books?hl=en&lr=&id=kusLzP8H6TQC&oi=fnd&pg=PA5&dq=Negi+S.+S.+1998.+Discovering+the+Himalaya+(Vol.+1).+Indus+Publishing.&ots=sAfw5Cw-QT&sig=lOedEFO1xz-eEtBfjciupgt8VPc

Pal, R., Bhattacharya, T., & Sathyakumar, S. (2019). First record of Pallas's cat in Uttarakhand, Nelang Valley, Gangotri National Park, India. *Cat News*, *69*, 25.

Prater, S. H., & Society, B. N. H. (1990). *The Book of Indian Animals*. Bombay Natural History Society. https://books.google.co.in/books?id=ic26bwAACAAJ

Rahimzadeh, A. (2016). *Mountain Livelihoods in Transition: Constraints and Opportunities in Kinnaur, Western Himalaya* [PhD Thesis, UC Berkeley]. https://escholarship.org/uc/item/5t29j6n5

Ross, S., Barashkova, A., Dhendup, T., Munkhtsog, B., Smelansky, I., Barklay, D., & Moqanaki, E. (2020). *Otocolobus manul. The IUCN Red List of Threatened Species 2020: E.T15640A180145377*. IUCN. https://www.iucnredlist.org/species/15640/180145377

Ross, S., Moqanaki, E. M., Barashkova, A., Dhendup, T., Smelansky, I., Naidenko, S., Antonevich, A., & Samelius, G. (2019). Past, present and future threats and conservation needs of Pallas's cats. *Cat News Special Issue*, *13*, 46–51.

Ross, S., Munkhtsog, B., & Harris, S. (2010). Dietary composition, plasticity, and prey selection of Pallas's cats. *Journal of Mammalogy*, *91*(4), 811–817. https://doi.org/10.1644/09-MAMM-A-342.1

Shrivastava, S. (2023, November 13). Ladakh's small cats face resource competition, intimidation by free-ranging dogs. *Mongabay-India*. https://india.mongabay.com/2023/11/ladakhs-small-cats-face-resource-competition-intimidation-by-free-ranging-dogs/

The Indian Wildlife Protection (Amendment) Act, Ministry of Environment, Forests and Climate Change, Government of India (2022). http://www.indiaenvironmentportal.org.in/files/file/wildlife%20protection%20amendment%20act%202022.pdf

En route towards Langu river following the only trail into the study area where Rodney Jackson conducted the first telemetry study on snow leopards.

Snow Leopard
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