NON-INVASIVE TECHNIQUES FOR MONITORING SNOW LEOPARD (*PANTHERA UNCIA*) POPULATIONS IN PAKISTAN

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ABSTRACT: A rare and endangered carnivore, the snow leopard (*Panthera uncial*) is frequently regarded as a flagship species for biodiversity conservation and a gauge of ecosystem health. But the main challenge in its monitoring is its relatively low population, huge home space, and isolated habitat. For a better understanding of its existence, this particular study employed non-invasive techniques for collecting data from Khunjerab National Park (KNP) (2010–2011) by sign surveys and camera trapping to assess detection probability (p) and occupancy (ψ)**,** accompanied by camera trap records from Chitral Gol National Park (CGNP) (2009)**.** Sign survey data was analyzed using PRESENCE 2.1 is used to analyze the sign survey data while camera trapping data was analyzed by logistic regression. The detection probability for all fresh signs was 0.646 (SE = 0.041), while for fresh scrapes (less than 7 days), it was 0.600 (SE = 0.100). Overall, the occupancy estimates for scrapes were 0.855 (SE = 0.043), whereas the values for all new signs were 0.849 (SE = 0.100). Snow leopards made up 606 (64%) of the 934 photos taken in KNP, with a trap success rate of 0.051 for every 100 trap nights. Because there was no snow leopards were photographed in CGNP, 25 pictures of other animals yielded a small insufficient 0.00053 success rate out of 100 trap nights. Scent lures successfully drew canid species, but not all predators, according to regression analysis. The results indicate the effectiveness of use of sign surveys along with camera trapping for snow leopard monitoring, although larger sample sizes are required for accurate statistical analysis. Furthermore, lure treatments can improve the identification of carnivores, especially canids, which supports their application in upcoming conservation initiatives.

Key Words: Snow leopard; Non-invasive monitoring; Camera trapping; Occupancy modeling

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INTRODUCTION

Known as the "ghost of the mountains," the snow leopard (*Panthera uncia*) is a significant predator in high-altitude environments in Central and South Asia [1]. It maintains the balance of fragile alpine ecosystems and regulates the population dynamics of herbivores such as ibex (*Capra ibex sibirica*) and blue sheep (*Pseudois nayaur*) [2]. Snow Leopard has the title of umbrella and flagship species, which means that protecting it indirectly helps entire ecosystems, including other species that share its habitat [3]. Despite its significance, snow leopard populations are declining due to multiple anthropogenic threats, pointing towards urgent conservation and monitoring efforts [4].

The IUCN Red List listed the snow leopard as endangered from 1972 to 2016. However, in 2017, it was reassessed as vulnerable [5], [6]. Approximately 3,500 and 7,350 individuals are thought to exist there worldwide, dispersed over 12 nations, including China, India, Pakistan, Nepal, Bhutan, Afghanistan, Mongolia, Russia, and the Central Asian states [7]. This enormous cat can be found in Pakistan's Karakoram, Himalayan, and Hindu Kush mountain ranges, namely in the provinces of Gilgit-Baltistan, Khyber Pakhtunkhwa, and Azad Jammu & Kashmir [8]. About 100 and 400 snow leopards are thought to reside in Pakistan; their primary habitats are likely to be in Khunjerab National Park (KNP), Chitral Gol National Park (CGNP), Deosai National Park, and Central Karakoram National Park [9]. However, there is a dire need to develop effective and consistent monitoring tools for precise population estimation.

Leopards are now facing several threats, such as habitat loss from infrastructure development and overgrazing, a declining prey base as a consequence of unregulated hunting and livestock competition, retaliatory killings by hunters in response to livestock predation, illegal hunting for the wildlife trade, and change-driven habitat changes that affect both the species and its prey [10]. Direct sightings of snow leopards are extremely uncommon, especially in their core habitats, because of their elusive behavior and cryptic appearance, which make them infamously challenging to research [11]. Traditional monitoring approaches, including live trapping and radio-collaring, are frequently utilized, but they present substantial ethical, logistical, and economical issues. These invasive approaches can stress and injure caught animals, necessitate skilled people, and incur substantial operational expenses, making them impractical in remote, high-altitude locations [12]. Given these challenges, cost-effective and non-invasive techniques are essential for studying snow leopard populations across their range.

Non-invasive monitoring techniques have emerged as viable alternatives for studying snow leopards without involving humans [13]. Sign surveys include searching for indirect evidence of snow leopard presence, such as scrapes, scats, scent sprays, pugmarks, and claw markings [12]. A widely utilized technique that allows for the photographic recording of individual snow leopards and aids in identification based on their unique pelage patterns is camera trapping [14]. Researchers has estimated population trends and habitat use by employing occupancy models based on sign surveys and camera trap data [15]. Scent lures that emit olfactory attractants have been utilized to improve carnivore detection rates. However, its efficiency for felids such as snow leopards is equivocal and requires further study [16]. Improving these strategies is essential for snow leopard conservation since new studies show that combining many non-invasive techniques yields the most accurate population assessments [17].

This study aims to evaluate the effectiveness of non-invasive methods, like as camera traps and sign surveys, for tracking snow leopard populations in Pakistan. The paper also looks at snow leopard detection probabilities and occupancy rates in Khunjerab National Park (KNP) and Chitral Gol National Park. Another objective of this study is to examine the function of smell lures in improving the rate of discovery and their possible use in future snow leopard surveillance campaigns. The findings will help to improve non-invasive monitoring approaches, eventually assisting in future conservation strategies and controlling population growth for snow leopards in Pakistan.

METHODOLOGY

Study Area: The sites of the study were two national parks in northern Pakistan that serve as important habitats for snow leopards.

Khunjerab National Park (KNP): As shown in the figure 1, KNP is located in Gilgit-Baltistan and spans 5,031 km² with altitudes ranging from 3,200 to 6,000 meters. It is distinguished by rocky peaks, glacier countryside, and alpine plants. In addition to ungulates like Marco Polo sheep (*Ovis ammon polii*) and Himalayan ibex (*Capra ibex sibirica*), KNP is home to a variety of carnivore species, including red foxes (*Vulpes vulpes*), brown bears (*Ursus arctos*), and snow leopards [18]

Chitral Gol National Park (CGNP): CGNP is 77.5 km² huge and extends in elevation from 1,450 to 4,979 meters. It is situated in the Hindu Kush mountain range, as depicted in figure 2. It has temperate forests, alpine meadows, and steep slopes, with prominent inhabitants, which include golden jackals (*Canis aureus*) and markhors (*Capra falconeri*) [8].

Since these two locations are distant from each other as shown in figure 3 as well as there is very little human habitation and severe winters, both parks are perfect for the conservation of snow leopards.

Techniques

Sign Surveys: Sign surveys were undertaken in the KNP in November and December 2010. The park was divided into 50 grids, each spanning 10 x 10 km. Survey crews carefully traveled 100-meter segments within 15 selected grids, concentrating on terrain characteristics that were likely to include snow leopard signals, such as ridgelines, saddles, and valley bottoms. Signs like scrapes, scats, and smell sprays were documented, alongside information about habitat features and elevation as shown in figure 4. Signs less than 7 days old were chosen for investigation to ensure dependability.

Camera Trapping: Camera trapping was done in CGNP in October and November 2009 and in KNP from December 2010 to January 2011. In order to capture both sides of passing animals, ten camera stations were erected across KNP. Each station had paired cameras (Reconyx digital and CamTrekker analog varieties). Scent lures containing fish oil and gland-based attractants were used at some locations to investigate their impact on detection possibilities. The cameras were programmed to operate constantly for 30 days, with frequent inspections to assure operation. In CGNP, 20 camera stations were set up using similar techniques.

Data Analysis: The detection probabilities (P) and occupancy rates (Ψ) were computed using single-season occupancy models in PRESENCE 2.1 software [19]. Logistic regression was used to determine the effect of ambient factors and lure treatments on detection rates [20].

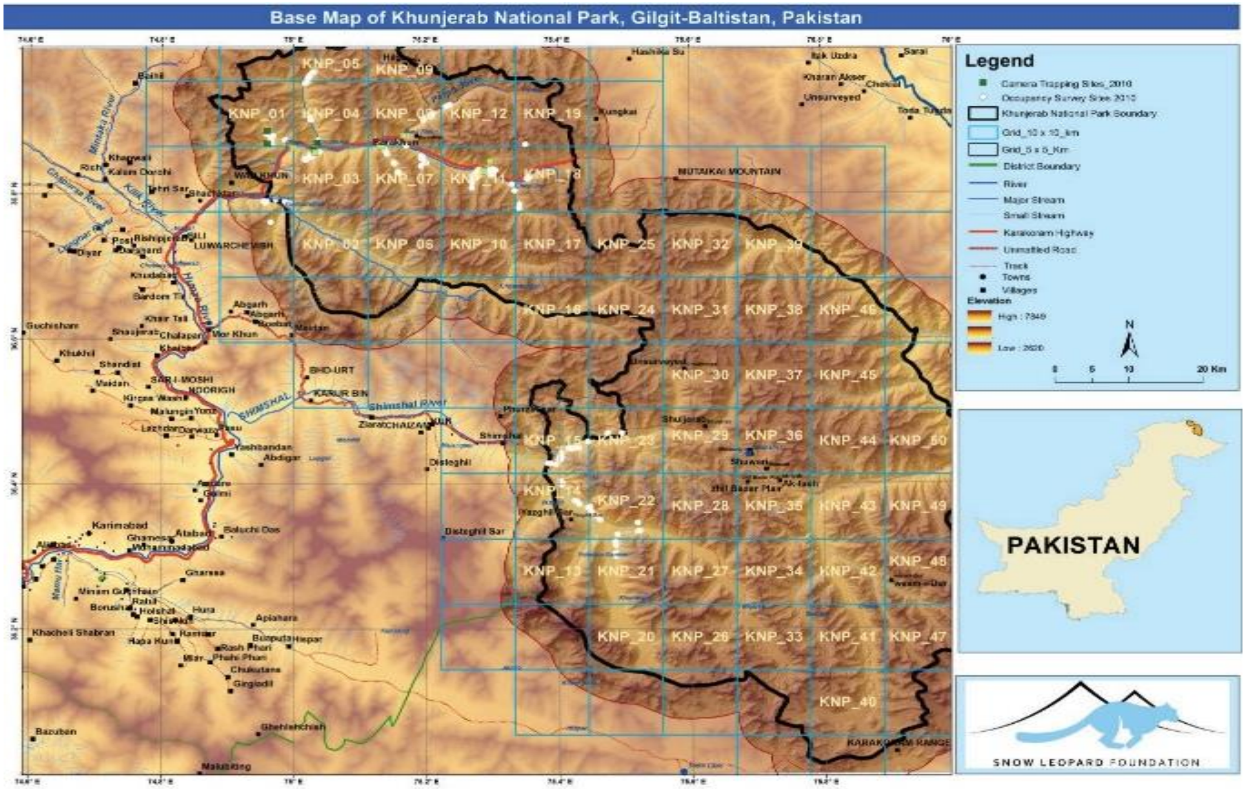

Figure 1: Site of camera trapping locations for snow leopard monitoring, sign surveys, and study sites (shown by green boxes and white dots, respectively) in Khunjerab National Park, Gilgit Baltistan, Pakistan, 2010–2011

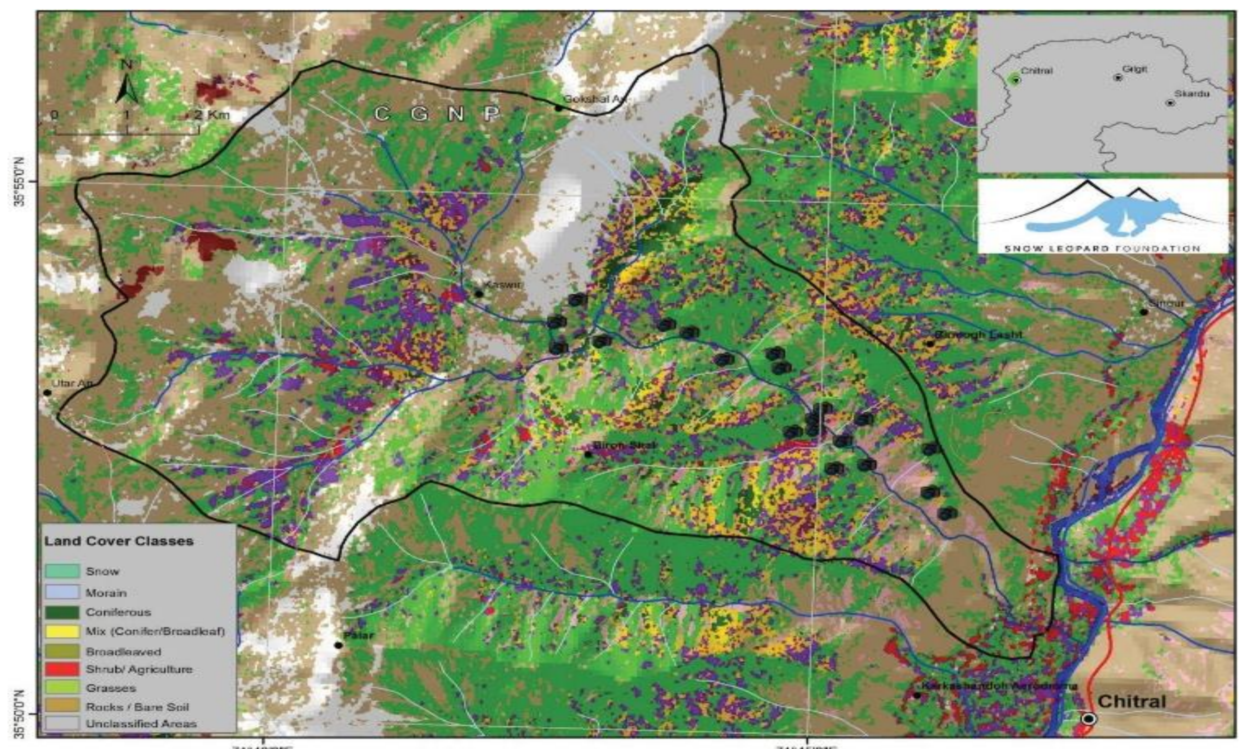

Figure 2: Tracking points of camera trapping (black dots) for snow leopard in Chitral Gol National Park (CGNP) in 2009.

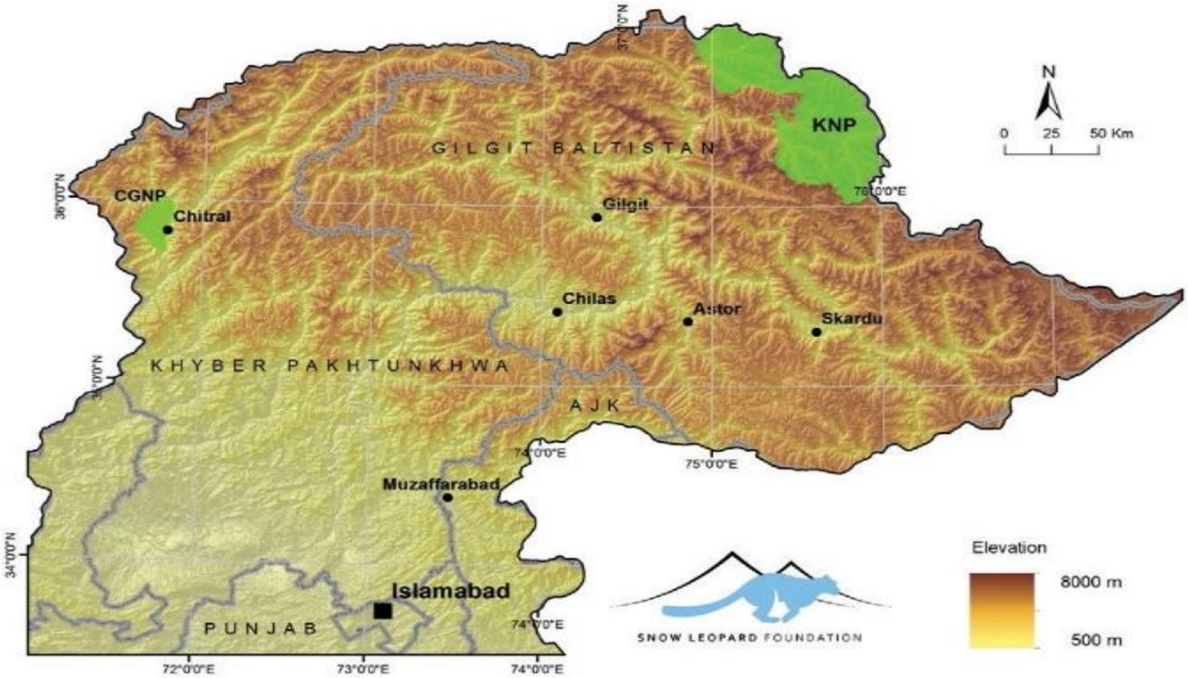

Figure 3*:* Location of KNP and CGNP research area sites, indicating their separation from one another.

Figure 4: Sign of snow leopard marking behavior found in 2009 and 2010 surveys conducted in CGNP and KNP.

RESULTS

Carnivore Species in KNP: At Khunjerab National Park (KNP), sign surveys confirmed the presence of snow leopards, brown bears, red foxes, and Indian wolves. Among these species, snow leopard signs were the most prevalent; 145, or 73% of all marks, were scrapes, and 28 or 14% were scats (Figure 5). 198 snow leopards' scats, pugmarks, scrapes, and odor sprays were recorded. There found evidence of snow leopard presence at 130 out of 151 survey stations, and these markers were spread across 14 of the 15 survey cells. The grid cell with the highest number of indications (20) was KNP_01 (Dhee), suggesting that snow leopard activity was substantial there. Additionally, this study gives evidences of the presence of endangered ungulate species, especially Marco Polo sheep and blue sheep in the park.

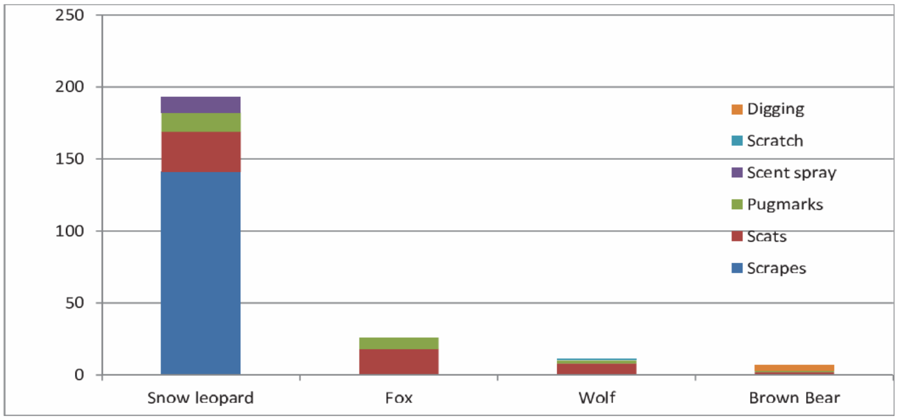

Figure 5: Occupancy sign survey results of detection frequency in Khunjerab National Park, November-December 2010.

Patterns of Habitat and Detection: Various topographic features are associated with the number of detected snow leopard signs. The majority of scrapes were located in valley terrain, indicating a preference for that topography (Figure 6). The kind of vegetation also had an impact on snow leopard distribution, with scrub vegetation being the most commonly associated environment. The 52 indicators of snow leopards found in scrub regions show a strong correlation between habitat preferences and vegetation type (Figure 7). Snow leopards are prevalent over the vast altitudinal range of KNP, as evidenced by signs of them at elevations ranging from 3101 to 4499 meters.

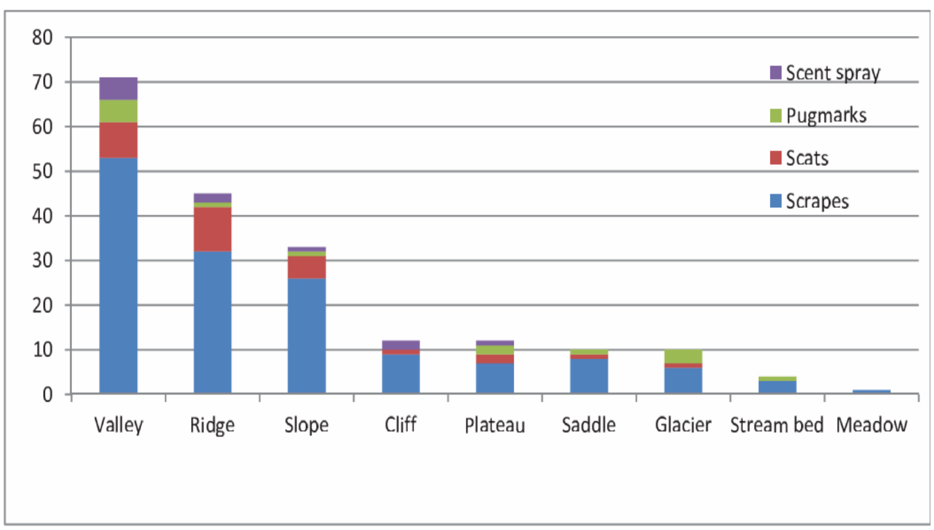

Figure 6: Relative frequency of snow leopard signs with respect to different topographic regions at KNP, (November and December 2010)

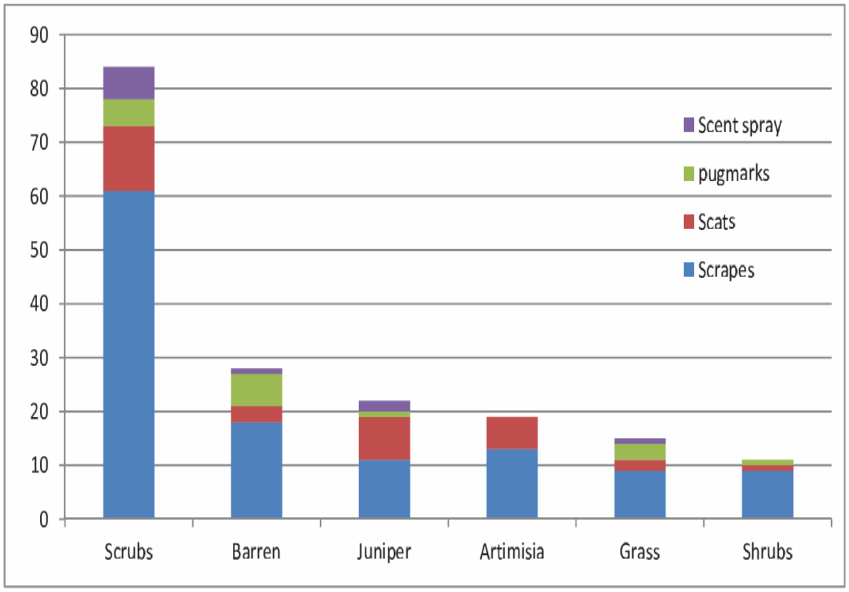

Figure 7: Relative frequency of snow leopard signs with respect to different vegetation habitat at KNP, (November and December 2010).

Modeling Occupancy and Detection Probability: Occupancy models were used to evaluate the likelihood of snow leopard discovery based on new scrapes and other types of signs. Snow leopards had an estimated detection probability of 0.600 (SE 0.100) based just on new scrapes, while the estimate for all combined fresh indicators was 0.646 (SE 0.041). When all the scraps and fresh indicators (sprays, scent, scants and pugmarks) were analyzed, the snow leopard occupancy probability (Ψ) in KNP was 0.855 (SE 0.043) and 0.849 (SE 0.100) respectively. A separate set of models was examined for all combined signs (less than 7 days old), and 16 occupancy models were evaluated using new scrape signs (less than 7 days old) (Table 1).

Table 1: PRESENCE 2.0 software was used in KNP (2010) to evaluate the impact of several site variables (such as ridge, valley, and area) on snow leopard occupancy (Psi) and detection probability (P) using a variety of models ran utilizing all snow leopard fresh signs (<7 days).

Model	AIC	ΔAIC
"psi(.),p(ridge)"	145.74	0.00
"psi(area),p(ridge)"	147.74	2.00
"psi(ridge),p(area)"	161.21	15.47
"psi(.),p(area)"	169.84	24.10
"psi(area),p(area)"	169.97	24.23
"psi(ridge),p(.)"	178.77	33.03
"psi(area),p(.)"	187.50	41.76

The best-performing models demonstrated that ridge and area had a significant impact on occupancy estimates and detection probabilities. When models were run using only new scrapes, "Ψ(.), p(ridge)" was the top-ranked model (AIC = 156.99) (Table 2). The model's parameter estimate for the ridge variable was -7.105 (SE 1.1989), suggesting that ridges considerably decreased the probability of discovering snow leopard scrapes in these areas. Once again, the detection probability was significantly impacted negatively by this model.

Table 2: PRESENCE 2.0 software was used in KNP (2010) to quantify the impact of several site variables (such as ridge and area) on snow leopard occupancy (Psi) and detection probability (P) using a variety of models ran utilizing all snow leopard fresh scrapes (<7 days).

Model	AIC	ΔAIC
"psi(.),p(ridge)"	156.99	0.00
"psi(area),p(ridge)"	165.11	8.12
"psi(.),p(area)"	175.45	18.46
"psi(area),p(area)"	180.29	23.30
"psi(ridge),p(area)"	185.29	28.30
"psi(.),p(.)"	193.67	36.68
"psi(area), p(.)"	196.16	39.17

Camera Trapping

Khunjerab National Park: Over the course of 31 days, from December 4, 2010, to January 3, 2011, camera trapping was carried out in KNP. During the trial, a total of six digital cameras took 934 pictures while operating correctly. 879 photos were examined after three human images and fifty-two empty frames were eliminated. Snow leopards were the most commonly photographed species among these, accounting for 606 photos (64%) of the total. 215 photos (23%), wolves (11 photos), hares (29 photos), pikas (5 photos), Himalayan stone martens (2 photos), ibex (49 photos), and birds (17 photos) were the next most common animals (Figure 8). For all species, the average camera trap success rate was determined to be 0.051 per 100 trap nights.

During the study, 14 analog cameras were also employed, but only four of them were active for a short time and could only capture a limited number of images. These included one image of sheep, four images of red foxes, and three images of ibex. The extraordinarily cold temperatures at KNP, which might reach -12°C at times, making non-digital cameras unworkable. The unpredictable operations of non-digital camera effected the success rate negatively. Interestingly, a mother snow leopard was filmed playing with her two pups at an elevation of 3410 meters in the Karchnai Valley (Figure 9).

Central Gojal National Park: In Central Gojal National Park (CGNP), 20 analog cameras were deployed for camera trapping in October 2009. Of the 25 photographs shot, no snow leopards were spotted. Two markhor, one hare, one bird, ten golden jackals, nine red foxes, one leopard cat, and an unknown carnivore were among the animals photographed. All of the cameras operated for an average of 23 days. At 0.00053 per 100 trap nights, CGNP's overall camera trap success rate was significantly lower than KNP's.

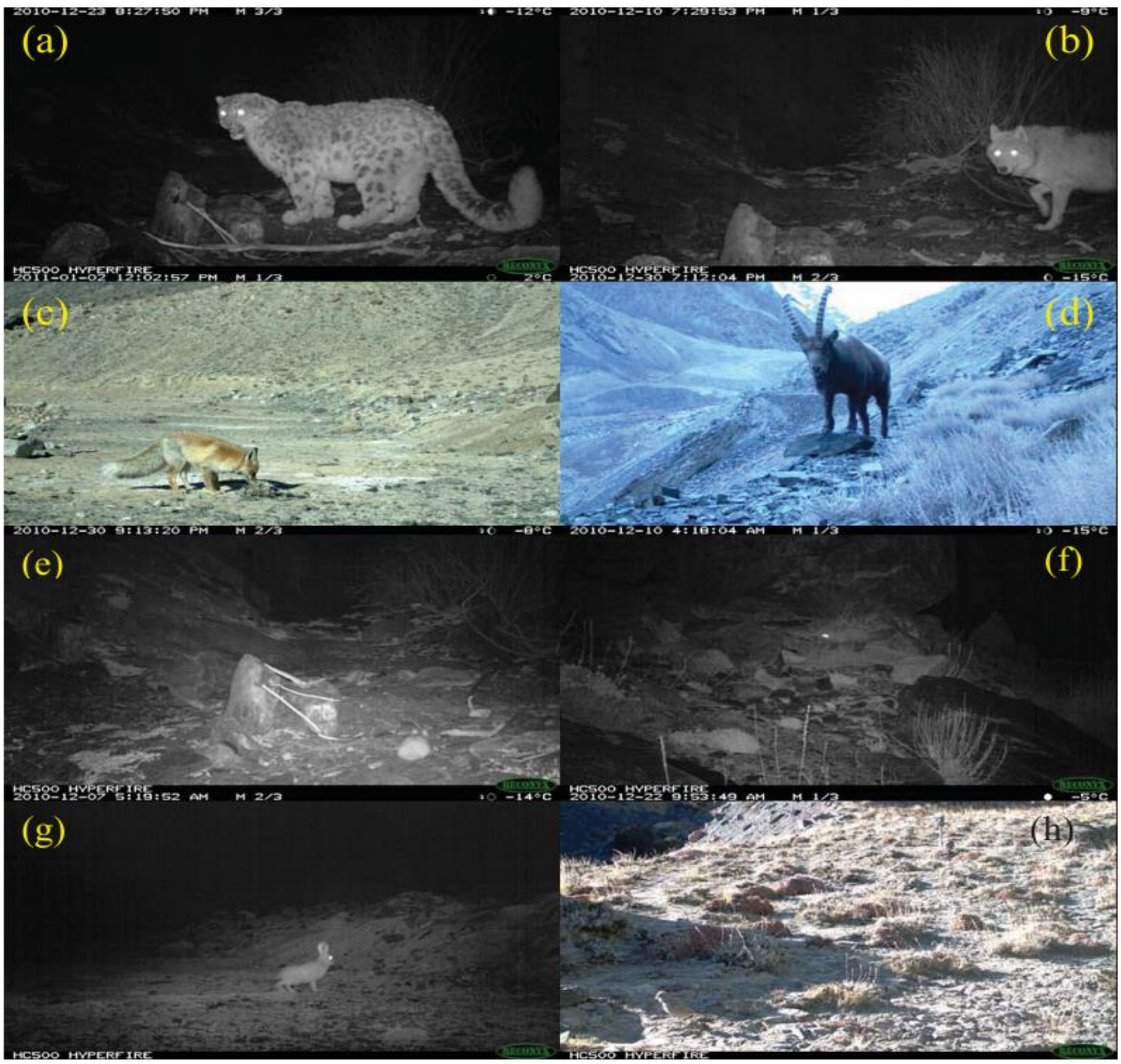

Figure 8: Animals captured by camera in KNP 2010 represented as (a): a snow leopard, (b): wolf, (c): red fox, (d): ibex, (e): pica, (f): stone marmo, (g): hare, (h): bird

Figure 9: A female leopard with two cubs in KNP (Karchnai Valley 2010).

Model Selection and Regression Analysis: For the affect assessment of different features of detected carnivores, a statistical logistic model was employed. The statistical significance of the models was evaluated at a significance level of $p < 0.05$. Several models that contained different explanatory parameters, including ungulate detections, survey location, and lure presence, were analyzed. The only statistically significant predictor among these was the inclusion of a lure, which increased the probability of locating carnivores. Figure 10 indicates the beta = 2.351, SE = 1.187, z-value = 1.980, and p = 0.0477.

The research area (KNP vs. CGNP) did not have a statistically significant effect, even though it was a variable in the models with findings are beta = 1.918, SE = 1.278, z-value = 1.501, and p = 0.1332. It was maintained in the final model to account for methodological and regional differences, such as research year, camera type, and ambient conditions. The presence of ungulates had no discernible effect on the identification of carnivores. The best-supported model included ungulate detection, survey location, and lure presence as explanatory variables (Table 3). The model coefficients are shown in Table 4. The location of the survey and the presence of lures were significant at $p < 0.1$, while the presence of ungulates was not.

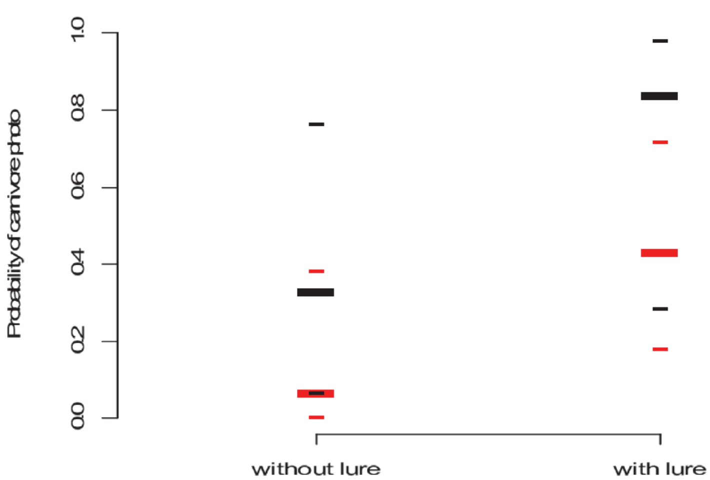

Figure 10: Photo detection probability (lure and without lure) for carnivores in 2009 and 2010. Where every bar indicates different specie (Red color for CGNP and black color for KNP).

Table 3: Logistic regression models for canid species detected while camera trapping in both locations.

Model	Response	AIC	∆AIC
Predators ~ Lure + Survey	Predators detected	30.65	0.00
Lure + Survey	Canid detected	31.47	0.82
Treatment + Survey	Canid detected	31.97	1.32
Lure + Survey + Ungulate detected	Canid detected	32.36	1.71
Lure * Survey	Canid detected	32.46	1.81

Table 4: Coefficients details of the model and the significance.

Coefficients	Estimate	Std. Error	z value	Pr (>|z|)
(Intercept)	-2.578	1.170	-2.203	0.0276 (<0.05)
Lure True	2.342	1.248	1.877	0.0605(<0.1)
Survey KNP	2.772	1.637	1.693	0.0904 (<0.1)
Ungulate Detected True	-1.868	1.898	-0.984	0.3252

Conclusion: This study demonstrates the effectiveness of non-invasive methods for snow leopard monitoring in distant areas, including camera trapping and sign surveys. According to data from Nepal and India, scrapes were the most reliable indicator of snow leopard presence, and sign surveys were reliable. Although camera traps provided crucial photographic evidence and made it possible to identify specific individuals, the CGNP's analog cameras' failure highlights the need for contemporary digital technologies like Reconyx, which functioned well in harsh environments.

Scent lures worked well for dogs but not so well for cats, suggesting that further work needs to be done. The difference in detection rates between KNP and CGNP emphasizes how critical it is to increase survey efforts and improve technique. Future research should employ genetic analysis, optimal lure formulations, and contemporary digital monitoring tools to increase detection accuracy. For effective conservation and the survival of the species, snow leopard monitoring must be done in a thorough, scientific manner.

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