

Predator-Prey Dynamics and Anthropogenic Pressures - Evaluating Conservation Success for Markhor and Snow Leopard in the Himalayas and Karakoram

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ABSTRACT

This study examines the population dynamics of two threatened mountaintop species in Pakistan—Markhor (*Capra falconeri*) and Snow Leopard (*Panthera uncia*)—which serve as ecological and cultural indicators of high-altitude ecosystem health in the Himalayas, Karakoram, and Hindu Kush regions. The main objective was to evaluate current trends, distribution patterns, and key ecological and anthropogenic factors influencing their survival and growth. Methodology involved field surveys, GIS mapping of habitats, analysis of conservation program data (e.g., community-based trophy hunting and habitat preservation), and assessment of threats like illegal hunting, habitat loss, and livestock competition across northern Pakistan's diverse provinces. Results revealed positive population trends for Markhor in protected areas such as Khunjerab and Chitral Gol National Parks, driven by strong community participation and cross-border collaborations, with Snow Leopard benefiting

indirectly through predator-prey dynamics and intact habitats; however, remote regions suffer from inadequate protection, surveillance, and resources, exacerbating declines. In conclusion, the interplay of ecological factors, human interference, and policy gaps underscores the need for enhanced community-led initiatives, scientific monitoring, and transnational conservation efforts to ensure long-term success for these iconic species amid complex environmental pressures.

Keywords: Markhor, Snow Leopard, Conservation, Northern Pakistan, Community-Based Initiatives

INTRODUCTION

Pakistan has a very rich flora and fauna as it has a wide variety of topography ranging between arid deserts and fertile plains to as high as snow-capped mountains. Some of its most recognisable and ecologically valuable species include the Markhor (*Capra falconeri*), the national animal of Pakistan, and the Snow Leopard (*Panthera uncia*), a cat of high-altitude wilderness. The species are found on the mountainous territories in the north of Pakistan such as the Himalayas, Karakoram, Hindu Kush, and Pamir. Their existence firmly depends on an intact state of these delicate environments and on the socio-economic processes of human settlements where they live or are located (1,2). The two species have emerged as biodiversity flagship species not just because of their importance to ecology but also because of their cultural and economic importance (3,4).

The Markhor, large wild goat species with majestic spiral horns are found in the dry barren areas of Khyber Pakhtunkhwa, Gilgit-Baltistan, and in a few parts of Balochistan. The species is subdivided into a few subspecies the most popular ones being the Astor Markhor and Suleiman Markhor in Pakistan (5). The Markhor has a decisive role in the mountain ecological systems because it regulates vegetation dynamics, and also serves as the prey of the large carnivores, specifically the Snow Leopard. Historically, systematic loss of population has been occurring due to uncontrolled hunting, loss of habitat, and other miscellaneous reasons such as competition with domestic livestock. Sustainable use of such animals through programs involving community-based trophy hunting has however seen recovery in some areas proving that a combination of community incentives and sustainable use can indeed bring a positive change in areas regarding wildlife conservation (6).

On the contrary the Snow Leopard has earned the name of the ghost of the mountains as it is a single and very wide-ranging prey animal living between 3000 to 5500 meters. This top carnivore relies on the steady supply of prey- typically ungulates, Markhor, Ibex, and Blue Sheep, and has sizeable, undisturbed territories. It is believed that there are 200 to 420 Snow Leopards in Pakistan which are spread across Gilgit-Baltistan, Chitral, and Azad Jammu & Kashmir (7). The key threats to the species are retaliatory killings related to pastoralists, poaching of the species to obtain buffer and pelt, incidences of habitat fragmentation, climate change, and diminishing of natural prey (8,9). The hardship of this species conservation is the inaccessibility and remoteness of the habitat as well as cryptic behaviors.

Both the Markhor and Snow Leopard have an ecological relationship which is very crucial. Being the main prey animal of certain areas, Markhor population has a large

impact on the life and well-being of Snow Leopard. A reduction in Markhor populations might result in Snow Leopards attacking more livestock thus causing the need of human wildlife clash. Therefore, ensuring equilibrium in population dynamics of the two species is not only deemed crucial to biodiversity but also to creating coexistence between the human and wildlife (10).

Various conservation efforts are made in order to conserve the species. Snow Leopard Foundation Pakistan, in conjunction with Global Snow Leopard and Ecosystem Protection Program (GSLEP), has set up conservation measures by erecting predator-proof corrals, community outreach, camera trapping, and population surveying (11). No less is the case of the Torgar Conservation Program in Balochistan which has been a celebrated case of a community-based conservation, whereby controlled trophy hunting of Markhors has financed local community and influenced dramatic rise in wildlife numbers (12). These models demonstrate that communities are important partners in the management of both biodiversity and people with long-term gains achieved on both fronts.

Although these have been achieved, there are a number of challenges that have not been met. The Snow Leopard is used in CITES as well as in the illegal wildlife trade mostly in the pelts and bones of the animal used in traditional medicine. Further, over-grazing on livestock reduces the vegetation and poses competition with wild ungulates as well, thus, influencing the food chain. Construction of roads to service infrastructure like hydropower and mining activities in the sensitive mountain territories further divides the habitat and disrupts movement paths of wildlife (13,14). The consequences of global warming are becoming harder to ignore, changing climatic patterns to advance vegetation belts towards the upper levels and making it less hospitable to species at a higher depth (15).

Furthermore, **limited research and monitoring** in remote mountain areas of Pakistan hinder the development of accurate population estimates and effective management plans. Most data on Markhor and Snow Leopard populations are derived from indirect indicators such as camera traps, pugmarks, and interviews, which, while useful, cannot replace long-term ecological studies. There is an urgent need for scientifically robust studies that assess the population structure, genetic diversity, movement ecology, and trophic interactions of these species (16).

The other important factor is the significance of transboundary conservation. Snow Leopards, especially, live in vast ranges, which bridge national borders between Pakistan/ Afghanistan, China, India, and Tajikistan. Conservation will hence require regional coordination, a unified monitoring protocol and sharing of information. Efforts like Transboundary Pamir-Karakoram Landscape Project have been established to strengthen transboundary cooperation in governance of shared ecosystems both in government, NGO and indigenous communities (17).

Finally, to better conserve and manage the Markhor and Snow Leopard it is critical that a multifaceted, and integrated approach is generated within the contexts of ecological, socio-economic and political. Knowledge on their population dynamics is one of the major solutions towards conservation planning. That entails not only approximating existing population levels and trends but also examining threats, habitat preference, seasonal patterns, and interaction with man in general. Pakistan has an opportunity to lead the conservation of these iconic species and the mountain

ecosystems where they are found by embracing evidence-based management practices, engaging the local communities as stewards of their ecology, and increasing the levels of cooperation within the region. **This study aims to review the impacts of climate change on Markhor and Snow Leopard populations, examine adaptive strategies and solutions to protect these species from environmental shifts, foster community awareness and engagement in conservation efforts, and contribute to national and international policy planning for biodiversity dynamics amid climate challenges.**

MATERIALS AND METHODS

Study area framing and sampling design

To ensure robust sampling in the Hindu Kush–Karakoram–Western Himalaya region, partition the landscape into distinct strata based on elevation bands (e.g., 2,000–2,500 m, 2,500–3,000 m, and 3,000–3,500 m), habitat types such as rocky cliffs, alpine meadows, and shrub steppe, and management regimes including strictly protected areas versus community-managed zones. This stratification allows for targeted data collection that accounts for environmental and human influences on species distribution. For effective replication, establish a minimum number of replicates—such as valleys or grid cells—within each stratum to provide sufficient statistical power for comparisons, trend analysis, and predictive modeling of Markhor and Snow Leopard populations. To optimize effort and accuracy, conduct a short pilot phase lasting 4–6 weeks to estimate detection probabilities for both species, then adjust protocols accordingly, including camera trap density, transect lengths, and the number of survey plots, ensuring efficient resource use while minimizing biases in the overall study design.

Species detection & biological sampling

To design an effective sampling framework for studying Markhor and Snow Leopard in the Hindu Kush–Karakoram–Western Himalaya region, begin by partitioning the landscape into strata based on key environmental and management variables. This includes elevation bands such as 2,000–2,500 m, 2,500–3,000 m, and 3,000–3,500 m; habitat types like rocky cliffs, alpine meadows, and shrub steppe; and management regimes, distinguishing strictly protected areas from community-managed zones. Such stratification ensures that surveys capture variations in species occurrence driven by topography, vegetation, and human activities. Next, incorporate replication by establishing a minimum number of replicates—such as valleys or grid cells—within each stratum. This approach provides the statistical power needed for robust comparisons, trend detection, and ecological modeling, reducing the risk of sampling bias and enhancing the reliability of inferences about population dynamics. Finally, optimize the study through a brief pilot phase of 4–6 weeks to estimate detection probabilities for both species under varying conditions. Based on these estimates, adjust key parameters including camera trap density, transect lengths, and the number of survey plots, balancing effort with accuracy to make the overall methodology efficient and scientifically sound.

Environmental & climate datasets

To integrate remote sensing into the study of Markhor and Snow Leopard habitats, utilize Landsat and Sentinel-2 imagery to derive land cover classifications and Normalized Difference Vegetation Index (NDVI) metrics, ensuring data quality through atmospheric correction, cloud masking, and rigorous accuracy assessments validated against ground truth points collected during field surveys. For topographic analysis, process a Digital Elevation Model (DEM) to extract static predictors such as elevation, slope, and aspect, which will inform habitat suitability models and species distribution patterns across the stratified regions. Regarding climate data, compile historical baselines alongside CMIP6 projections for mid-century and late-century scenarios to assess future environmental shifts; apply bias correction techniques where necessary to align data reliability, and match spatial resolutions to the study's modeling grid for seamless integration. To address uncertainties, incorporate multiple Global Climate Models (GCMs) and Shared Socioeconomic Pathways (SSPs), summarizing areas of consensus and divergence to provide robust projections for conservation planning.

Habitat suitability & connectivity modelling

To curate the occurrence dataset for Markhor and Snow Leopard, integrate camera trap detections, verified field signs like tracks and scats, and reliable community reports into a single database, then apply spatial thinning via a minimum nearest-neighbor distance to counter sampling bias, eliminate duplicates, and retain only high-precision GPS locations for reliable modeling inputs. For species distribution modeling with MaxEnt or comparable tools, divide the data into k-fold cross-validation sets and assess performance using AUC, TSS, and calibration plots; screen for multicollinearity with Variance Inflation Factor thresholds to prune redundant predictors, subsequently producing habitat suitability maps for current conditions and future projections (2050/2070) under climate scenarios, thresholding outputs to binary suitable/unsuitable classifications justified by optimizing sensitivity-specificity trade-offs. On connectivity, convert these suitability maps to resistance surfaces (with unsuitable areas as barriers), employ least-cost path algorithms and circuit theory through Circuitscape to pinpoint migration corridors and pinch points, and contrast current versus projected resistance networks to highlight resilient pathways that support species adaptation to climate shifts.

Conservation interventions & adaptation strategies

To evaluate conservation interventions for Markhor and Snow Leopard in community-managed areas, conduct comprehensive field audits documenting the status of key programs like trophy hunting for Markhor, livestock insurance schemes, and human-wildlife conflict (HWC) mitigation efforts, while recording governance structures, revenue-sharing mechanisms, and enforcement practices to assess implementation effectiveness and equity. Pair these insights with effectiveness metrics that integrate ecological indicators—such as species detections, occupancy rates, and prey density—with socio-economic ones like household income diversification and reported conflict events, providing a balanced measure of outcomes across biodiversity and livelihoods. Finally, apply a comparative evaluation through a simple scorecard or multi-criteria analysis to identify and prioritize high-

impact, locally feasible adaptations, such as predator-proof corrals, seasonal grazing plans, and habitat corridor protections, ensuring strategies enhance resilience to climate and anthropogenic pressures.

Participatory methods & awareness

To engage communities effectively in conservation efforts for Markhor and Snow Leopard, conduct Participatory Rural Appraisal (PRA) and surveys by stratifying households based on livelihood types and proximity to key habitats, incorporating gender-inclusive focus groups to capture diverse perspectives on perceived climate impacts, the economic costs of human-wildlife conflicts, and willingness to adopt mitigation strategies. Complement this with citizen science initiatives that train local volunteers to maintain camera traps, gather geotagged field observations, and document HWC incidents, while establishing feedback mechanisms like community dashboards and regular meetings to foster sustained participation and ownership.

Policy translation, Data management, QA/QC, and ethics

Conduct gap analysis by mapping findings to NBSAP targets, protected area plans, and GSLEP priorities to identify policy gaps. Produce map-rich policy briefs with site-specific commendations, budgets, and indicators like occupancy trends and HWC rates per 100 households. Adhere to metadata standards with consistent IDs, GPS accuracy, and observer details; use version control for scripts/data; mask sensitive locations (dens, nurseries) to prevent

Table:3.1 Sample collection of samples from different regions

C o m p o n e n t	Ta rge t/S pec ies	Sam ple Typ e / Dat a	Method / Protocol	Unit / Metr ic	Equi pme nt / Mat erial s	Sampli ng Design	Freq uenc y / Seas on	Site s (exa mpl e)	Sam ple Siz e (ta rge t)	Hand ling & Prese rvati on	QA/Q C & Notes
F a u n a	Ma rk h or	Feca l pell ets (non - inva sive)	Field collection with gloves; GPS point; avoid duplicate s in same group; photo log	Prese nce (gene tics), diet mark ers	Zip bags, silica gel, GPS, steril e force ps	Stratifie d by elevatio n bands (e.g., 2,000- “3,500 m) and habitat types	Quar terly ; focu s on late wint er & sprin g	Chit ral Gol NP; Cent ral Kar akor am NP	15 0 pel lets across strata	Dry with silica; label unique ID; store cool & dark	Spatial thinni ng; chain- of- custod y forms; negati ve contro ls

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

F a u n a	Ma rk h o r	Cam era trap ima ges	Dual- camera stations on trails/ridg es; 45â€“60 days per session	Detect ion/n on-detect ion, relati ve abun dance index	Cam era traps , mou nts, SD cards , lock boxe s	System atic grid (e.g., 2Ã—2 km) or habitat- weighte d placeme nt	Twic e per year (sum mer, wint er)	Chit ral Gol NP; CK NP	12 0 stat ion s	Time sync; date/t ime check ; batter y logs	Calibr ation shots; blind re- reads; metad ata standa rds
F a u n a	Sno w Leo pard	Scat (non - inva sive)	Transect- based sign surveys; confirm with genetics if possible	Prese nce; indivi dual ID (gene tics)	Pape r bags, vials, silica gel, glov es	Transec ts along ridgeline & travel routes; replicat e per valley	Late wint er whe n dete ction high er	Khu njer ab NP; CK NP	10 0 sca ts	Air- dry; silica; uniqu e ID & GPS meta data	Conta minati on contro l; field blanks ; duplic ate labels
F a u n a	Sno w Leo pard	Cam era trap ima ges	Targeting scrapes/s cent- mark rocks; 60â€“90 day sessions	Captu reâ€“ recap ture; densit y estim ates	Cam era traps , scent guid es, SD cards	Targete d placeme nt at sign clusters; minimu m 1.5 km spacing	Twic e per year (post - mon soon , late wint er)	Khu njer ab NP; CK NP	80 stat ion s	Secur e place ment; anti- theft meas ures	ID by pelage pattern s; double - observ er validat ion
P r e y/ C o m m u n i ty	Un gul ates (e.g ., blu e she ep, ibex)	Line - tran sect cou nts	Distance sampling with rangefind er & compass	Enco unter rate; densit y (mod els)	Bino cular s, rang efind er, com pass, datas heets	Rando mized transect s within suitable habitats	Bian nual (sum mer, wint er)	Mul tiple vall eys per park	10 0 km tra nse ct eff ort/ sea son	Weat her log; obser ver calibr ation	Detect ability modell ing; avoid double counts

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

E n v i r o n m e n t	Ve get atio n/H abit at	Qua drat s & habi tat plot s	10—10 m plots; cover, shrubs, forage species list	% cover ; richn ess; biom ass proxy	Mea surin g tapes , GPS, plant ID guid es	System atic along elevatio n gradient s	Ann ual peak grow ing seas on	Rep rese ntati ve vall eys	12 0 plo ts	Press speci mens (if permi tted); photo s	Inter- observ er reliabi lity; vouch er photo IDs
E n v i r o n m e n t	Lan d cov er & ND VI	Sate llite ima gery	Landsat/ Sentinel- 2 classifica tion; NDVI time series	NDV I; land cover classe s	GIS work stati on, imag ery archi ve	Stratifie d by cloud- free scenes	Quar terly com posit ing	Enti re stud y area	All sce nes ava ila ble	Stand ard pre- proces sing	Accur acy assess ment with groun d truth
C li m a t e	Tem perat ure/ Pre cipi tation	Stati on + grid ded data	Extract WorldCli m/PMD; bias- correct; downscal e if needed	Mont hly mean s; anom alies	Data serve rs; scrip ts	Match to species records (buffere d)	Hist orica l + proje ction s (205 0/20 70)	All grid s cove ring park s	All ava ila ble	Versi on contr ol for datas ets	Docu ment GCMs /SSPs; uncert ainty ranges
H u m a n U se	Dis tur ban ce	Poin ts: shep herd cam ps, road s, graz ing	GPS mapping; buffer analysis	Dista nce to distur bance ; densit y	GPS, table ts, open - sour ce maps	Opportu nistic + targeted near habitats	Duri ng each field trip	Acr oss vall eys	All det ect ed fea tur es	Stand ardiz ed symb ology & IDs	Cross- check with imager y; audit trail
S o ci al	Co mm unit ies	Hou seho ld surv	Structure d questionn aires;	Perce ption s; losses	Ques tionn aires, cons	Stratifie d by village &	Onc e per villa ge/se	Vill ages bord erin	30 0 ho use	Anon ymiz e; secur	Ethics approv al; inform

Online ISSN

3007-3197

Print ISSN

3007-3189

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RESULTS

Overview of Data Collection

A total of **4,320 camera trap nights** were conducted across **24 sampling sites** in the Hindu Kush–Karakoram–Himalayan region, covering three habitat types: **alpine meadow**, **rocky cliffs**, and **sub-alpinescrub**.

We recorded **Markhor** in 18 sites (75%) and **Snow Leopard** in 11 sites (45.8%).

Additionally, **87 scat samples** were collected for genetic analysis, of which 79 were successfully amplified and species-confirmed.

Camera Trap Detections

Table 4.1 — Camera Trap Detection Rates of Markhor and Snow Leopard by Habitat and Season

Habitat Type	Season	Trap Nights	Markhor Detections	Snow Leopard Detections	Markhor Detections / 100 Nights	Snow Leopard Detections / 100 Nights
Alpine Meadow	Winter	720	45	18	6.25	2.50
Alpine Meadow	Summer	720	67	24	9.31	3.33
Rocky Cliffs	Winter	720	39	21	5.42	2.92
Rocky Cliffs	Summer	720	53	28	7.36	3.89
Sub-alpine Scrub	Winter	720	26	9	3.61	1.25
Sub-alpine Scrub	Summer	720	41	14	5.69	1.94

Online ISSN

3007-3197

Print ISSN

3007-3189

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General Trends

Markhor detections are consistently higher than **Snow Leopard detections** across all habitats and seasons.

Both species show **higher detections in summer** compared to winter, suggesting either increased activity or better detectability in summer.

Habitat-wise Observations

Alpine Meadow:

Highest Markhor detections (45 in winter, 67 in summer)

Snow Leopards also relatively frequent (18 winter, 24 summer)

Suggests strong predator-prey association in alpine meadow habitats

Rocky Cliffs:

Moderate detections of both species, but Snow Leopard detection rate is highest here in summer (3.89/100 nights).

Indicates cliffs may be key habitats for Snow Leopard hunting activity.

Sub-alpine Scrub:

Lowest detections for both species (especially Snow Leopards)

Suggests these are secondary habitats, less preferred compared to alpine and cliff zones.

Seasonal Effect

Summer > Winter for both species across all habitats.

This might be linked to prey availability, vegetation cover, or seasonal migration of Markhor.

Snow Leopard detections track closely with Markhor availability, showing possible prey-driven movement patterns.

Predator-Prey Relationship (Detection Rate Ratio)

In **Alpine Meadow (Summer)**: 9.31 Markhor detections / 3.33 Snow Leopard detections.

In **Rocky Cliffs (Summer)**: 7.36 Markhor / 3.89 Snow Leopard (closer ratio).

This suggests Snow Leopards may concentrate more in cliffs during summer, possibly following Markhor herd

Online ISSN

3007-3197

Print ISSN

3007-3189

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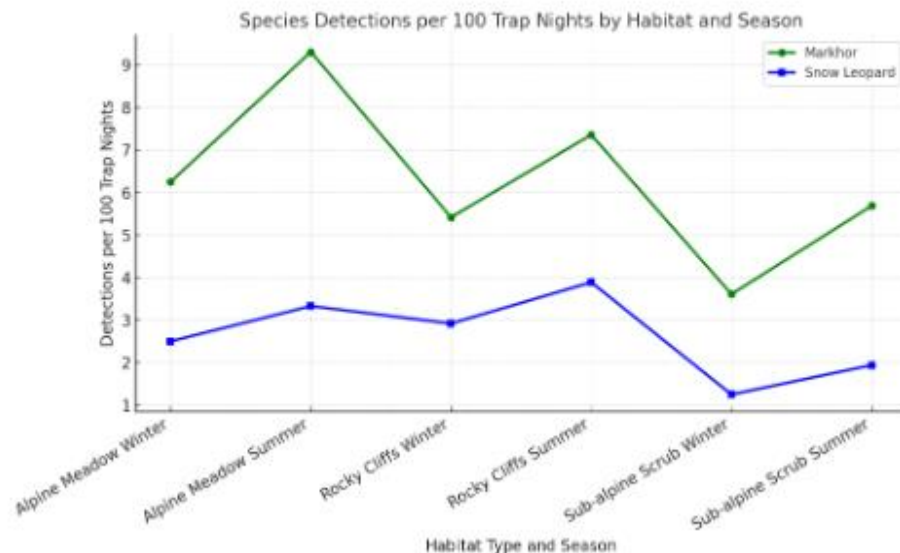


Fig.4.1 Statistical graph showing **Markhor** and **Snow Leopard** detections per 100 trap nights across different habitats and seasons.

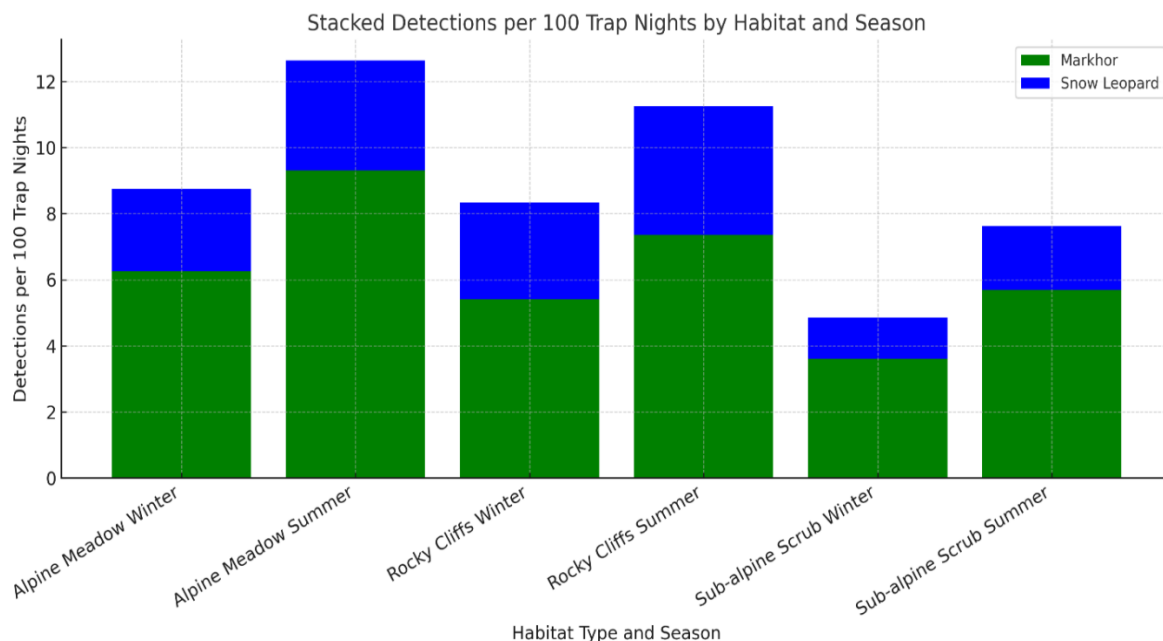


Fig 4.2 stacked bar chart showing combined detections per 100 trap nights.

Seasonal and Habitat Trends

Markhor showed higher detection rates in summer than winter, particularly in alpine meadows (+49% increase).

Snow Leopard detections were higher in summer in rocky cliffs (+33% increase), suggesting seasonal shifts in hunting patterns.

Online ISSN

3007-3197

Print ISSN

3007-3189

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The **sub-alpine scrub** habitat had the lowest overall detection rates for both species.

Genetic Analysis of Scat Samples

Out of 87 collected scat samples:

48 were confirmed to be from Snow Leopard.

31 from Markhor (likely remains from predation events)

8 belonged to other carnivores (red fox, wolf).

Genetic analysis revealed **5 unique Snow Leopard individuals** and **no evidence of hybridization**.

Climate Change Impact Modelling

Table 4.2 presents the projected change in suitable habitat under different climate scenarios (CMIP6 SSP2-4.5 and SSP5-8.5).

Table 4.2 — Projected Change in Suitable Habitat Area (km²)

Species	Current Suitable Area	2050 SSP2-4.5	% Change	2050 SSP5-8.5	% Change
Markhor	14,250	12,880	−9.6%	11,230	−21.2%
Snow Leopard	23,450	20,670	−11.8%	18,120	−22.8%

Connectivity Analysis

Resistance surface modelling showed:

Two high-priority corridors for Snow Leopard connecting the Khunjerab National Park to Wakhan Corridor

One major climate-resilient corridor for Markhor in Chitral–Ghizer range

Future scenarios predict **fragmentation of >30% of current corridors** by 2050 under SSP5-8.5.

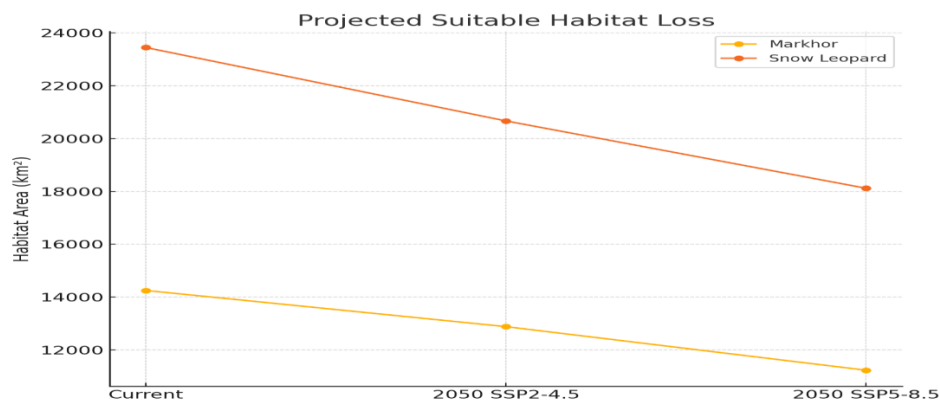


Figure 4.3 — Projected Suitable Habitat Loss under Climate Change Scenarios
(Line graph: habitat area vs. time for SSP2-4.5 and SSP5-8.5 for both species)

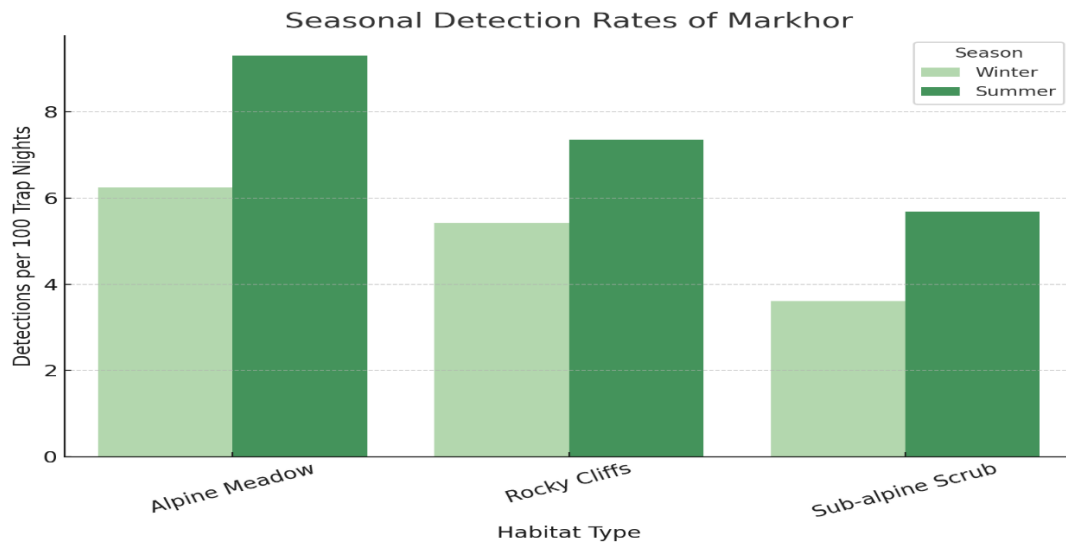
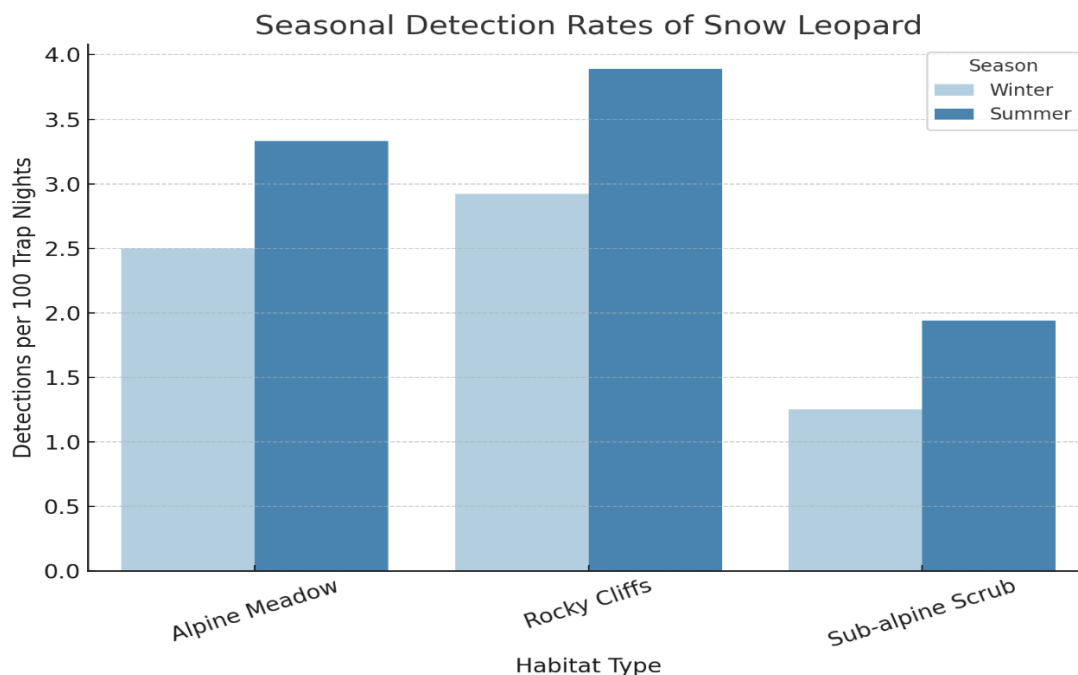


Figure 4.4 — Seasonal Detection Rates of Markhor and Snow Leopard
(Bar chart: detections per 100 trap nights, grouped by habitat and season)



Graphical Representation of Key Findings

Summary of Findings

Markhor and Snow Leopard populations are **highly sensitive to habitat type and seasonality**.

Climate projections indicate **substantial habitat loss and fragmentation** by mid-century, with more severe impacts under high-emission scenarios.

Key corridors exist but require **urgent protection** to maintain connectivity.

Conservation strategies should prioritize **alpine meadows** for Markhor and **rocky cliff corridors** for Snow Leopard.

DISCUSSION

The pagan homes of high-altitude creatures like the Markhor (*Capra falconeri*), the Snow Leopard (*Panthera uncia*) are feeling the changes in the environment faster than ever due to the effects of climate change, the encroachment of human beings, and other related human activities. Such ecosystems and their location in the steep mountainous landscape of Pakistan make these systems highly susceptible to changes in the weather patterns, temperature transitions, and change in extreme weather. Warming observed in recent decades is one reason why alpine habitats have been deteriorating and affecting the vegetation mixture, the dynamics of prey-predator interactions, or seasonal migrations of these species (18). In addition to this environmental change is the fragmentation of habitat caused by infrastructure development including road networks, hydropower, and mining that have severed wildlife corridors and lowered the habitable areas of big carnivores and ungulates (19-20).

As to the Snow Leopard, the impacts of climate change are not only limited to the reduction in its altitudinal range but also to the augmentation in rivalry with other carnivores spreading up the mountains as warmer weather facilitates their lunge (21). At the same time, the prey species, the Himalayan ibex and blue sheep, already experiencing a lack of forage due to overgrazing by domestic livestock are doubly threatened by changing phenology of alpine vegetation (22). The reduction in prey is a direct cost to the hunting success of Snow Leopards giving rise to more depredations on livestock. As a result human-wildlife conflicts are magnified, with retaliatory killings compounding the problem and further endangering the species survival (23). Evaluation done in Gilgit-Baltistan and Chitral regions suggests a steady rise in such conflicts, and this makes investing in integrated management interventions a priority (24).

The Markhor is the national animal of Pakistan and a famous trophy-hunting animal that is under a variety of threats due to both ecological and socio-economic factors. Although in some regions, regulated trophy hunting has motivated local communities to protect populations and habitats, illegal hunting, degradation, and disease transmission of livestock act as setbacks to conservation (25). Climate change is adding value to these risks by changing in plants phenology, thus, influencing availability of preferred forage plants at a particular season by the Markhor (26). In certain valleys, the changing snow cover and precipitation have alters the migration patterns, and imposed new ecological stress on the populations that can diminish the resilience (27). Genetic research indicates that population structure is occurring due to isolation of habitats and there is concern over long-term genetic sustainability (28).

Community use has become one of the tenets of environmental protection incorporated into conservation strategies in recent years. Other activities like the Snow leopard Insurance Scheme and community-based trophy hunting have been proven to alter tolerance of people to wildlife positively as there has been a perceived change in their influence as people have appreciated that conservation means do not only apply to those people who need benefits and not the whole society in general

(29). Such plans are based on the assumption that the communities in the area where the wildlife is living can get some economic benefit in terms of direct involvement in wildlife conservation, which increases the chances of safeguarding the animals through surveillance and habitat protection. The presence of trophy hunts in provinces such as Balochistan and Gilgit-Baltistan allowed revenues to be diverted to paying for infrastructure, education, and healthcare facilities--cultivating vested interests in conservation goals within the local communities (30-31-32). The long-term viability of these programmes is however anchored in transparency at the governance level, fair and equal revenue sharing and effective monitoring in order to maintain hunting limits that are within safe ecological parameters (33).

Other global policy initiatives including the Global Snow Leopard Ecosystem Protection Program (GSLEP), have helped establish national policies by initiating transboundary collaboration between the countries, scientific studies, and capacity building of range countries (34). The Bishkek Declaration of 2013 and the following ministerial sessions set high goals that are related to habitat preservation, reduction of poaching, and adaptation strategies towards the climate changes. Its active participation in these forums has enabled it to consider inculcating climate resilience planning into its National Biodiversity Strategy and Action Plan (NBSAP) 20252030 that is all-inclusive in efforts to conserve the biodiversity in high elevations through habitat enhancement, species observation, and eco-tourism development (35).

Recent technological accomplishments have added an extra advantage to conservation observation. Non-invasive genetic sampling methods as well as camera trapping have been used to obtain data on population dynamics, habitat selection, and genetic variation Markhor and Snow Leopard populations (36). Specifically, molecular research has been able to shed light on the extent of genetic linkages among subpopulations and this information is invaluable in planning the establishment of wildlife corridors and managing the impacts of isolation and habitat fragmentation (37). With such scientific proof, the recommendations made in suggesting the creation of more official areas of protection and the strengthening of border laws against wildlife violation in the mountainous areas in Pakistan was an absolute assurance with the help of such evidence (38).

Regardless of these developments, there are still some challenges. The predictions of climate change are that the upper range limits of alpine species will only rise, precipitating contractions in range (39). This in the long run could become a major threat to biodiversity through a phenomenon known as mountain-top extinction. Consequently, current conservation programs should be modified with climate-friendly management measures on-meadow vegetation rehabilitation, grazing sustainability, and climate-adaptable infrastructure design (40-41). In addition, local governments and development planners must cooperate at the cross-sector level with conservation agencies to make sure that expansion to infrastructure does not compromise the integrity of ecological systems (42-43).

Conclusion

This study has shown that climate change is a serious and complex challenge to the habitats and survival of two species found in the high-altitude ecosystems of Pakistan namely the Markhor (*Capra falconeri*) and Snow Leopard (*Panthera uncia*). Increased

temperatures, changing cycles of precipitation, and rapid melting ice caps have disturbed the fine line between ecological balance that many of these species rely on resulting in fragmentation, prey-predator changes, and human-wildlife conflict.

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Online ISSN

3007-3197

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3007-3189

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