



Community-Based Snow Leopard Monitoring through Mobile Technology

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Abstract

The snow leopard (*Panthera uncia*), a flagship species of high-altitude ecosystems, faces critical threats, including human-wildlife conflict driven by livestock depredation. We developed a community-based snow leopard monitoring system in Nepal's Nar and Phu Valley, integrating mobile-based tools for data collection and conflict mitigation. Using the mobile app, local communities documented 483 snow leopard observations (e.g., footprints) between 2023 and 2024. Additionally, we found that the majority of the existing 91 livestock corrals lacked protection from predators. In response, we constructed eight predator-proof corrals to improve livestock protection. A total of 21 herders filed applications to claim livestock loss compensation, demonstrating the utility of our app to facilitate conflict management efforts. The app usage rate has increased over the years, but challenges like

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limited mobile connectivity in remote areas and the need for continuous training and local engagement remain to improve its long term uptake. The findings contribute to strategies aimed at reducing human-snow leopard conflicts while fostering coexistence.

Introduction

The snow leopard (*Panthera uncia*), a flagship species and apex predator, primarily inhabits high-altitude ecosystems across Central and South Asia, extending 12 countries, including Nepal (McCarthy et al., 2023). The species faces several threats, including habitat loss and fragmentation, prey depletion, illegal killing and trade (Li et al., 2020, McCarthy et al., 2023). These pressures intensify conflicts between snow leopards and humans, as livestock depredation by snow leopards often leads to retaliatory killings by local herders (Aryal et al., 2014). Livestock rearing is an important livelihood; thus livestock depredation typically results in substantial economic losses (Suryawanshi et al., 2013).

In Nepal, human-wildlife conflicts (HWC) have increased, placing it among the top nations globally, that are facing significant occurrence of such conflicts (Torres et al., 2018). Several mitigation strategies have been implemented, including community-based conservation programs (Pathaket al., 2024). However, the environment and remoteness in high-altitude regions challenge the implementation of specific measures. Consequently, community-based conservation approaches are a valuable strategy to mitigate HWC between snow leopards and local communities.

Recent technological advancements have integrated modern tools into conservation, with applications such as camera traps increasingly aiding wildlife monitoring and anti-poaching efforts (Arts et al., 2015, O'Connell, 2011). Across

the world, the use of mobile devices and internet access is increasing and expanding into rural and remote areas (Brammer et al., 2016, Pratihast et al., 2012). This development provides a straightforward and practical opportunity to collect data, thereby allowing the use of mobile devices to address conservation issues such as HWCs.

Empowering local communities for implementing conservation activities is essential for establishing sustainable and effective measures. In Nepal, especially within the Annapurna Conservation Area Project (ACAP), mountain communities are actively engaged in snow leopard conservation, addressing livestock depredation and associated threats, such as retaliatory killing (McCarthy et al., 2023). Communities that coexist with the snow leopard, traditionally rely on subsistence farming, livestock herding, Yarsa (*Ophiocordyceps sinensis* - Caterpillar fungus) collection, and, more recently, eco-tourism for their livelihoods.

Seasonal migration patterns and livestock grazing in alpine meadows contribute to the shaping of local ecosystems, which create specific conditions for both habitat competition and food availability for wildlife (Gurung and McVeigh, 2002). The involvement of local communities in data collection can provide a valuable base for implementing targeted conservation measures and strengthen a feeling of autonomy and ownership in the communities.

In this study, we aim to achieve two primary objectives: (1) to co-design a snow leopard monitoring system that is culturally acceptable and feasible for implementation, ensuring it meets the specific needs and capacities of the local community; (2) to develop and implement mobile-based monitoring tools that enable local communities to report snow leopard sightings,

Community-based Monitoring for Snow Leopard Conservation

According to GSLEP, involving local community groups and indigenous societies is critical for conserving snow leopards and their habitat (Sharma et al., 2024). Tools like the Spatial Monitoring and Reporting Tool (SMART), Camera Traps, and Open Data Kit (ODK) support systematic data collection and analysis, but are often too technical for direct use by local communities.

This study developed a community-based monitoring system inspired by SMART principles and tailored for practical application in Nar and Phu villages. Seven-member snow leopard conservation committees were formed and trained. One member from each committee was assigned to monitoring activities. The committees also engaged in awareness campaigns, human-wildlife conflict mitigation, and constructing predator-proof corrals. A pre-workshop survey assessed local socio-economic conditions and identified the key challenges: unclear leopard movements and the need to locate vulnerable corrals and grazing areas. To address these, three data collection forms were designed, ensuring comprehensive data to guide conservation and conflict mitigation efforts. The data collection started in May 2023, and is still ongoing in March 2025. The data used in this report were collected between May 2023 and December 2024 and the Snow leopard observation was aggregated into Summer (May-October) and Winter (November-April) to account for changes in Snow Leopard behavior that is influenced by seasonality and environmental factors like snow cover (Johansson et al., 2022, Zaman et al., 2024).

1. **Snow Leopard Survey Form:** This form helps to systematically record evidence of snow leopard presence, such as direct

sightings, scat, hair, scratches, or prey remains, after the Snow Leopard Information Management System (SLIMS) technique (Jackson and Hunter, 1996). Monitoring these signs is essential to understanding snow leopard distribution and behavior, which is crucial for planning targeted conservation efforts and ensuring coexistence with local communities.

2. **Livestock Registration Form:** By registering all livestock as a baseline, this form creates a robust dataset to compare against reported depredation incidents. Such data is critical for implementing fair compensation schemes, fostering community trust, and incentivizing tolerance towards snow leopards.
3. **Livestock Depredation Form:** This form provides detailed records of predation incidents, including the number and type of livestock lost. Accurate depredation data is essential for assessing the scale of human-wildlife conflict, guiding preventive measures (e.g., predator-proof enclosures), and supporting farmers in claiming compensation effectively.

These forms were designed using the Open Data Kit (ODK) system and deployed on Android-smartphones using methods adapted from Pratihast et al (2012). Data collected on these devices can be stored offline and transferred to servers via GPRS, Wi-Fi, or USB when connectivity is available. A database management system was developed to ensure proper storage and accessibility of the acquired data. Additional tools, such as QGIS mapping software, were used to analyze spatial data and map snow leopard habitats and movement patterns.

In 2023, a co-design workshop was conducted with community leaders and conservation experts to finalize data requirements and select an appropriate mobile data collection app. The ODK

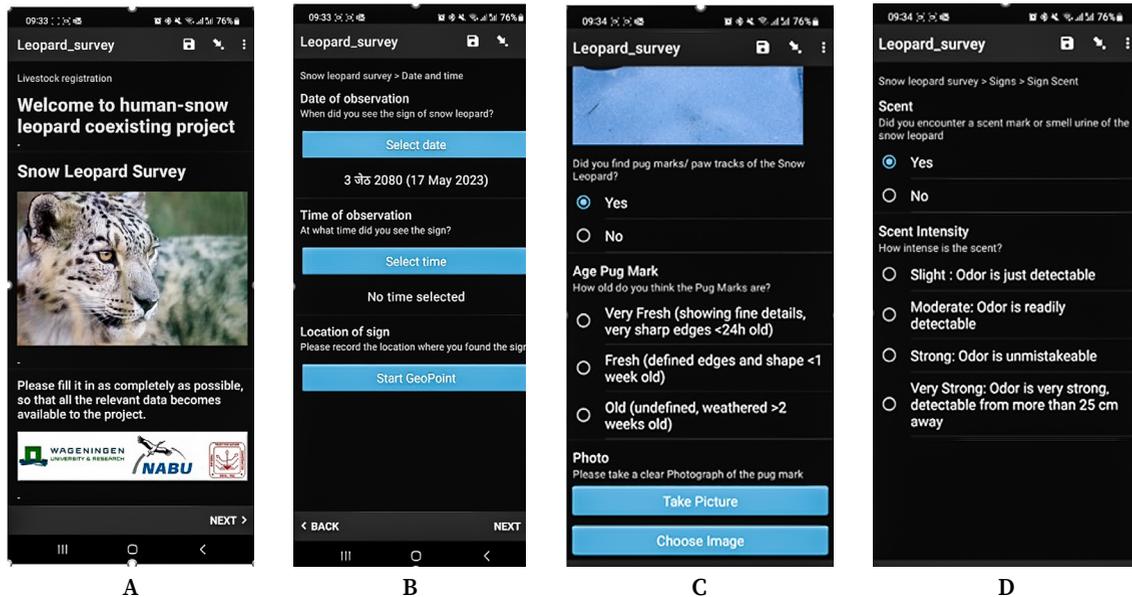


Figure 2. Screen capture of mobile data collection using Open Data Kit (ODK) Collect. A) welcome screen and start of the survey, B) basic data records like location date and time, C) selection screen of choices for pugmark detected and D) conditional selection of Scent is recorded.

collect app was customized to meet local needs, including translation into the local language, icon-based navigation, and selection features to minimize typing (Figure 2). The app allows data collection offline and automatically transfers the data to the server once an internet connection is available. After the workshop, six training sessions, focusing on app usage, were held for local communities. Additionally, a recorded video manual was provided on each mobile device, enabling users to conduct refresher training as needed over time. These sessions empowered participants to independently collect and report data, fostering a sense of ownership and confidence in using the monitoring system.

To further support the implementation and acceptance of the technology, we conducted ongoing training sessions throughout the project. These sessions covered the use of monitoring tools, data collection techniques, and basic troubleshooting for smartphones. The goal was to

share knowledge and equip community members with the skills needed to actively manage and participate in snow leopard conservation efforts.

Results

Initially, the questionnaires were designed based on key indicators to assess the community's technical capacity for adopting the technology. Data was collected using household surveys, interviews with commune leaders, and discussions with conservation officials. In total, 58 individuals participated in this process. We found that the digital literacy in the communities was high, with 100% of community members owning mobile phones, 74.5% of people use internet regularly, of which 58.8% use social media.

Following this, a monitoring design workshop was conducted with the participation of 61 community members (29 from Phu Valley and 32 from Nar Village). They helped to design the application by determining the most important

features tailored to their needs and gained deeper understanding of the App use in the field. In practice, around 30 people from the communities actively use one of the three co-created forms. Among them 3 people using the Snow leopard survey (trained, knowledgeable staff) and the corral survey.

An ODK Central server was set up to store all data submitted by the local community, see Figure 3 for the server interface. The data, along with attached photographs, was downloaded as a CSV file and analyzed further using Excel and QGIS software.

Snow-leopard observation

Between May 2023 and December 2024, the local community actively monitored snow leopards, focusing on proxy- or indirect evidence of their presence. This included signs such as scrapes, scats, scent markings, urination spots, claw marks, and pugmark. During this period, approximately 483 observations were recorded. See Table 1 for the data summary, Figure 4 for location of observations and Figure 5 for photos of records.

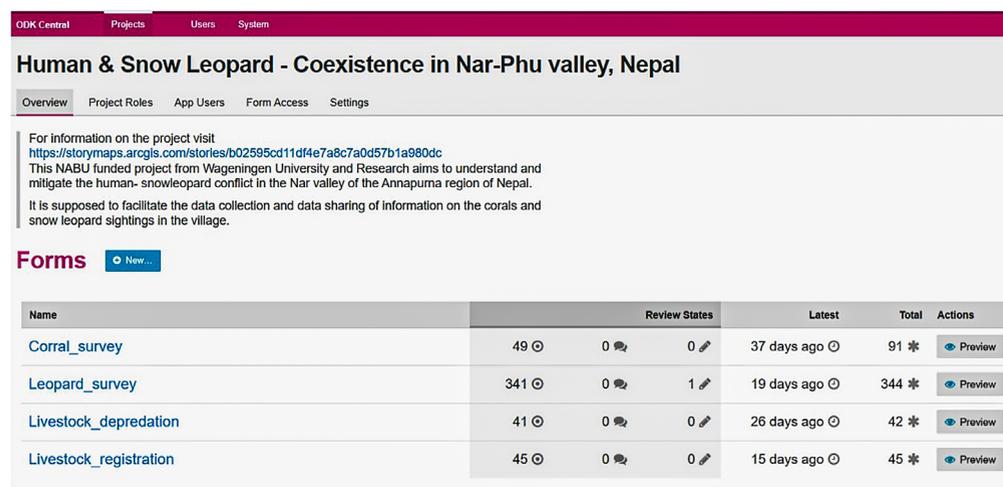


Figure 3. Screen capture of the categorized mobile data as hosted on the ODK central server. The Server hosts the project “Human & Snow Leopard - Coexistence in Nar-Phu valley, Nepal”, it has a description and contains four different data collection forms that are connected to the ODK collect mobile App. It shows the total number of submissions and the latest day of submission.

Table 1 Summary of observations collected by citizen scientists from local communities and field specialists with the Snow Leopard survey ODK form. Showing the number of different signs collected in summer and winter 2023 to 2024

Year	Snow leopard observation							
	Number of different sign of Snow Leopard							
	Date	Scrape	Scat	Pug mark	Scent Mark	Claw mark	Urine mark	Total
2023	Summer	42	22	11	1	6	0	82
	Winter	24	9	8	4	7	2	54
2024	Summer	79	54	33	4	25	1	196
	Winter	55	19	30	11	29	7	151

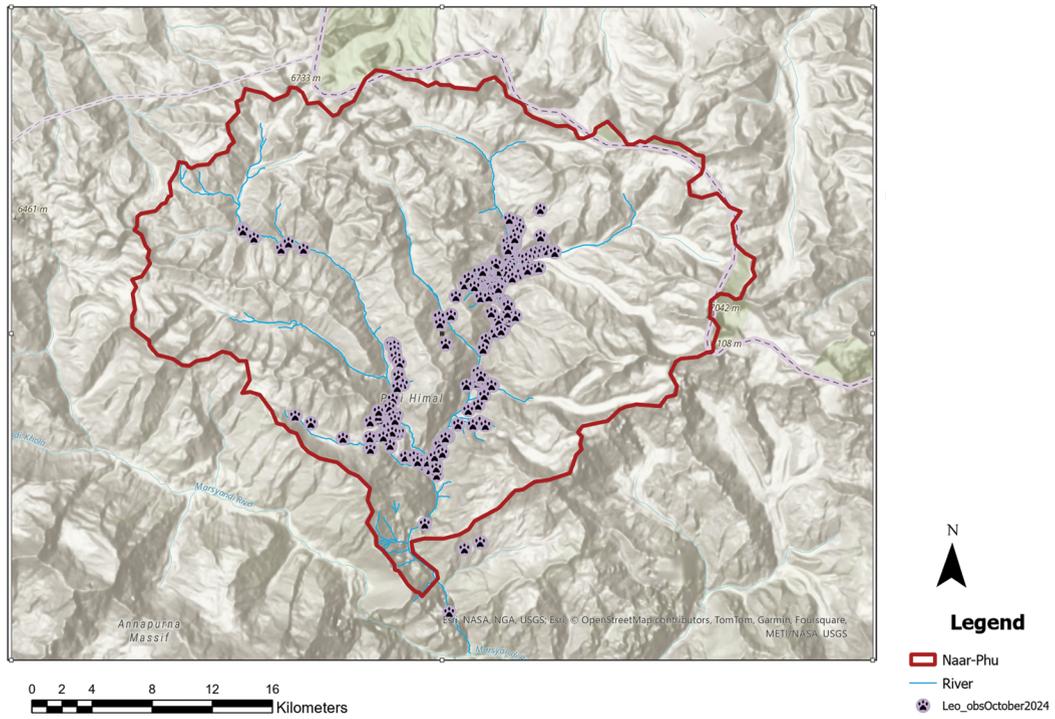


Figure 4. Map showing above mentioned Snow-leopard observation collected by citizen scientists from local communities within the Nar-Phu valley in 2023-2024



Figure 5. Ground photo showing examples of collected snow leopard evidence (A) Scat, (B) Scrape mark and (C) Pug mark in snow?

Corrals

The use of corrals varies across villages. A total of 91 corrals were recorded during the survey. Phu village had the highest number of corrals (45 corrals), while Nar village recorded almost the same amount (46 corrals). The most common type is the open corral, which restricts animals from roaming but provides

no protection from predators. In response to community consultations, eight predator-proof corrals were constructed during this period to enhance livestock protection. The map in Figure 6 illustrates the distribution of all corrals, including predator-proof corrals, across the study area (Figure 7).

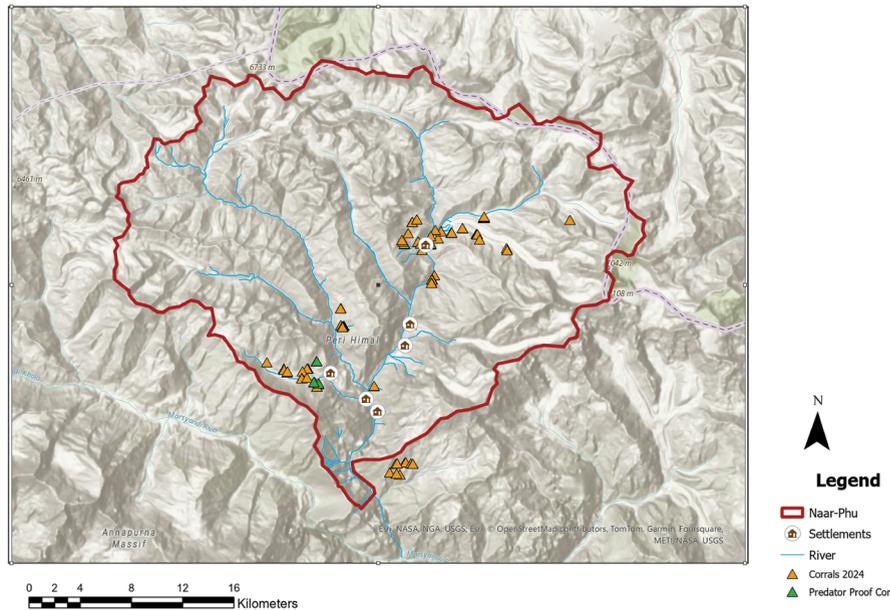


Figure 6. Map of corrals around collected with the ODK app within the study area. The orange triangles indicate the locations of traditional corrals and green triangles indicate the location of newly built predator proof corrals.



(A)



(B)

Figure 7. Photo showing a typical Open corral (A) and a newly built predator-proof corral (B)

The species typically housed in the corrals is the Yak, the most valuable and common domesticated animal in the area. Despite their value, yaks are most often housed in open, roofless corrals. They are only kept in newly built, enclosed, predator-proof corrals on rare occasions.

Livestock depredation

A total of 59 livestock depredation incidents were recorded, including 46 animals killed and 13 injured. Twenty-three people from both communities (Nar and Phu) used the App to submit depredation incidents, mostly in late summer (end October) 2024. In 2023, local herders used the app to report the two depredation incidents involving two yaks, and app usage increased

in 2024. A total of 22 yak-kill incidents were reported via app in 2024 (Figure 8). The map (Figure 9) highlights the locations of these conflicts. Seasonal distribution shows that 44 depredation incidents occurred in summer, and 2 in winter. The lower number of conflicts reported in winter is attributed to livestock being kept indoors during this season, reducing their exposure to predators. A total financial loss was indicated in 2023 of NRP 92000,- (around 647 Euro) per household and in 2024 of NRP 1145000,- (around 8063 Euro) per household, which is about 14% (2023) and 175% (2024) the mean income of a household in Gandaki province (National Statistics Office, 2023).

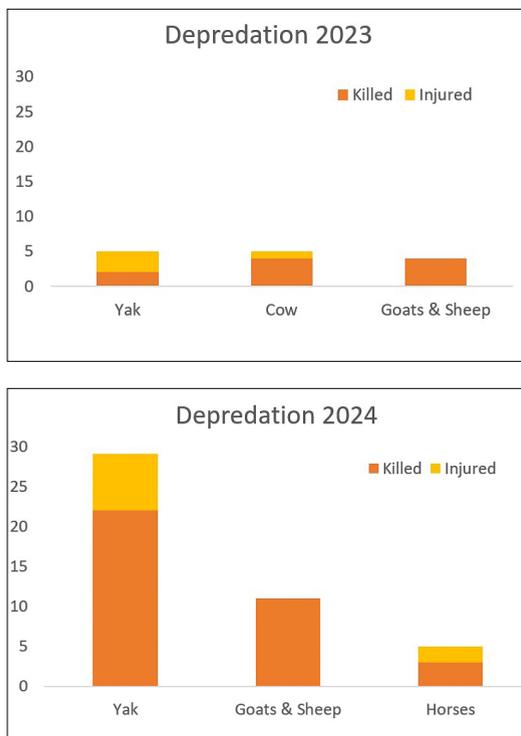
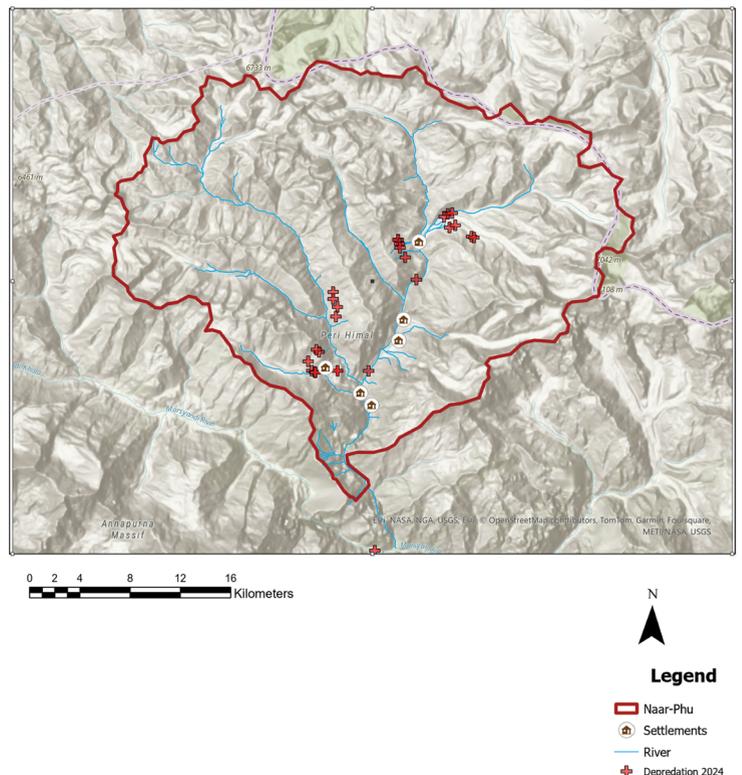


Figure 8. Overview of depredation incidents recorded by livestock farmers via the app. It shows the yearly total number animals attacked

Figure 9. Map of recorded depredation incidents in the study area relative to the settlements



Discussion

Integrating mobile technology and local knowledge in Snow Leopard conservation

Prior studies to monitor and conserve snow leopards, utilized methods such as camera-trapping and non-invasive eDNA sampling (O’Connell, 2011, Lama et al., 2018, Hellström et al., 2023). Most of these technologies are implemented by experts and face operational challenges. In contrast, our community-based monitoring approach demonstrates the potential of integrating mobile technology with local knowledge and practices. By adopting SMART principles and designing practical, locally relevant solutions, we developed a monitoring system tailored to the unique challenges of the communities in Nar and Phu villages.

The results from the snow leopard survey form indicate seasonal variation in the detection of indirect signs. Scrapes, scats and pug marks were recorded more frequently during the summer, while scent marks, claw marks and urine marks were detected more often during winter (Table 1). This distinction could be explained by the difference in detection probability for different signs in different seasons (e.g., snow cover in winter and high vegetation cover in summer). Snow leopards, communicate commonly via indirect marking behavior, so the increased recordings of these types of signs during the winter could reflect an increase in marking behavior due to the reproductive communication of snow leopards during this period (Jackson and Hunter, 1996, Jackson, 2015) . In addition, a higher total number of signs were recorded in 2024 compared to 2023 (Table 1). This increase likely reflects the growing acceptance and usage of the app among local communities driven by

the implementation of targeted measures and conducted workshops, rather than a change in the local snow leopard population or distribution.

A notable increase in depredation incidents was recorded using the depredation form in 2024 compared to 2023 (Figure 8). However, based on the available data and the short comparison timeframe, it cannot be determined whether this increase reflects a genuine rise in snow leopard attacks on livestock or is a result of more widespread use of the apps following the workshops. In addition, the establishment of the snow leopard conservation committees in Nar and Phu during the monitoring period has simplified the process for the affected herders to receive actual compensation payments, which potentially has further encouraged the reporting of livestock depredation through the app. In 2023, three farmers used the app to submit a depredation claim, while in 2024, more than 15 farmers used the same form. This suggests that the app is increasingly accepted as a viable tool to mitigate HWCs.

The mobile application ODK Collect is publicly available through the Google Play Store and is compatible with Android devices. Upon installation, users can access the relevant data collection forms by entering an access code or scanning a QR code. The ODK system is highly adaptable, allowing mobile forms to be developed using Microsoft Excel, which facilitates the implementation and customization of comparable compensation schemes or other community-based data collection systems across diverse geographic regions, target species, or thematic areas. However, the acquisition, maintenance and upkeep of the ODK server requires technical knowledge or is connected to costs if choosing for ODK Cloud, the fully-managed and supported

option of ODK server (<https://docs.getodk.org/central-install/>).

Building a mobile application, for a certain demographic that lives very remotely can be challenging and needs careful consideration for the needs of the target group, as well as trial runs and error handling in close communication with the target user group. Ideally, the target user group should have the possibility to actively contribute in the design of the app or the form. However, due to the remoteness and language barriers this process can be slow and weaknesses in the App design are possibly not addressed or addressed very late during rare and costly field visits. This can lead to data not being recorded or false records. This also applies to the interpretation of questions asked in the forms. In one incident, a farmer recorded a total livestock loss of 1. Further elaboration note in the form indicated that 20 yaks below age 3 and 15 yaks above age 3 had been killed. Thanks to the supporting images of the official forms and the depredation incident, the correct number could be determined with certainty. Nevertheless, this revealed a weakness in the form that needs to be understood and addressed.

This error also shows that it is crucial to find the balance between necessary detailed information and unnecessary complexity of an app. As complexity and interpretability of options increase, the probability of errors also rises well. We recommend using terminology, categories, and choices that the target user group is already familiar with, and avoiding open questions as much as possible.

Capacity building and awareness were pivotal to the success of our approach. Training sessions provided community members with the technical skills to use smartphones to collect

data accurately and manage reports effectively. This built confidence in the committees, making them active contributors to conservation rather than passive participants. Awareness campaigns complemented this effort by engaging the community in sharing an understanding of the ecological importance of snow leopards and the benefits of coexistence. By addressing misconceptions and emphasizing the value of snow leopard conservation to local livelihoods, these initiatives helped reduce resistance to conservation measures. The dual focus on capacity building and awareness ensured that the monitoring system was both technically viable and socially accepted.

Recognizing sampling bias of community-based data

Community-based data inherently exhibit sampling bias, as data are typically recorded in areas frequented by humans while excluding regions that are less accessible. Consequently, analyses of potential species distributions must account for the limitations of presence-only datasets by incorporating pseudo-absence data to mitigate sampling bias (Barbet-Massin et al., 2012). Integrating remote sensing data with local observation data to develop Species Distribution Models (SDM's), risk- or conflict-models offers accurate regional picture of the species distribution (Pettorelli et al., 2014), and improves our understanding and predicting potential shifts due to change in human use and pressures and climate-induced suitability changes. This approach relies on the ability to characterize local findings and environmental conditions in a broader regional context. Methods, like the QUICKScan spatial participatory tool (Verweij et al., 2018) can integrate outcomes of SDM's with

additional local knowledge and regional spatial data to upscale to regional risk- or conflict areas.

Linking to Broader Conservation Networks

The Global Snow Leopard and Ecosystem Protection Program (GSLEP) provides a valuable platform for scaling these efforts across the snow leopard's range. By integrating mobile-based monitoring systems into the broader conservation strategies of GSLEP, the effectiveness of conservation efforts can improve significantly. Mobile technology can help to track snow leopard populations and identify areas of high human-wildlife conflict, enabling targeted interventions and reducing the need for lethal control measures.

Scaling to other human-wildlife conflict mitigation

While demonstrated in snow leopard monitoring and conflict mitigation, this approach is applicable to other species as well. In Nepal, human-wildlife conflict is a major concern, with elephants, tigers, leopards, and bears causing crop damage, livestock depredation and occasionally human injury or loss of life, which in turn triggers retaliatory killings of wildlife (Baral et al., 2022).

One solution to this challenge is to prevent conflict from occurring through nonlethal interventions such as fencing, livestock corrals, and guard animals (Reidinger Jr and Miller, 2013). Addressing conflicts is crucial, with economic incentives like wildlife tourism revenue sharing or compensation schemes helping mitigate human-wildlife conflict impacts (Dickman and Hazzah, 2016, Loveridge et al., 2010). The Government of Nepal and local NGOs have implemented compensation programs for livestock losses due to tigers, leopards, and bears. In 2018, Nepal

allocated USD 130,000 for compensation, though many argue it remains insufficient to address the widespread conflicts (Lamichhane et al., 2018).

Our research demonstrates how mobile technology can support conservation efforts by enhancing monitoring, enabling timely interventions, and preventing conflict in high-risk areas. First, the increasing number of mobile users worldwide, particularly in rural and underserved regions, makes mobile-based solutions more accessible and effective. Second, most human-wildlife conflicts require key information such as the location, type of conflict, and photographic evidence, all of which can be seamlessly integrated into the system. Third, our system is flexible and can be easily adopted for addressing various human-wildlife conflicts, making it a scalable solution that can be applied to different species or regions with minimal adaptation.

Conclusion

This study developed a community-based snow leopard monitoring system tailored to Nar and Phu villages while integrating SMART principles with mobile data collection via ODK. Conservation committees were established, trained, and actively involved in monitoring activities, including snow leopard presence surveys, livestock registration, and depredation reporting. Evidence showed that technology acceptance and use increased throughout the project and should be maintained and strengthened for lasting effects on communities' livelihoods and snow leopard protection conservation. It is highly adaptable and applicable across many different regions and topics but requires technical knowledge and funds to set up the infrastructure, maintain the server and implement the tailored

data collection app.

Future efforts should prioritize sustainability through robust financial planning, periodic training, and infrastructure development, while exploring expansion to other regions and incorporating advanced tools like camera traps and remote sensing. Securing international partnerships and funding is essential for scaling and sustaining these conservation initiatives.

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Conflict of Interest

The authors declare no conflict of interest.

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