Journal homepage: http:/www.indianecol.org

Indian Journal of Ecology

DOI: https://doi.org/10.55362/IJECOL/2026/0148
Article Number: 0000

Temporal Patterns of Leopard Predation on Livestock in Hamirpur District, Himachal Pradesh, India

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Received: April 30, 2026 Revision Submitted: June 30, 2026 Accepted: July 01, 2026

ABSTRACT: Livestock depredation by leopards is widely reported across the Indian Himalayan region. This study investigated long-term trends in leopard-induced livestock depredation over 23 years (2001–2023) in Hamirpur District, Himachal Pradesh, a representative Shivalik Himalayan landscape. To our knowledge, this is one of the longest continuous assessments of leopard–livestock conflict in the Shivalik Himalayas. Data were obtained from official Forest Department compensation records and therefore represent reported depredation incidents rather than absolute predation rates. Mann–Kendall trend analysis revealed a significant decline in annual livestock mortality ($Z = -2.01$, $p = 0.045$), although occasional peaks occurred. A total of 1,420 livestock mortalities were recorded, comprising 1,195 (84.15%) small livestock and 225 (15.85%) large livestock. Among 1,079 reported depredation incidents, 744 (68.95%) occurred in animal sheds, 272 (25.21%) in private land/pasture areas, and 63 (5.84%) in forests. Seasonal mortalities were highest during summer (32.46%), followed by monsoon (26.41%), autumn (20.77%), and winter (20.35%). Hamirpur Range accounted for 73.73% of recorded livestock mortalities, followed by Aghar (12.96%), Barsar (8.31%), Nadaun (3.10%), and Bijhari (1.90%). Livestock predation was significantly associated with prey size, season, attack location, and forest range. The predominance of attacks in animal sheds highlights the importance of livestock husbandry practices in shaping human–leopard conflict. Predator-resistant enclosures, improved nighttime confinement, community-based mitigation measures, and continued long-term monitoring are recommended to reduce livestock losses and support coexistence between rural communities and leopards in the Shivalik Himalayan region.

Keywords: Hamirpur, Leopard, Conflict, Depredation, Livestock, Himalayan, Sustainability.

1. INTRODUCTION

Predation by leopards (*Panthera pardus*) on livestock is a complicated convergence of social, economic, and ecological issues, especially in areas where human settlements and leopard habitats are closely located (Dhakal et al., 2023). As an adaptable apex predator, the leopard frequently encounters human conflict because of the

Available online: July 07, 2026

perceived or actual harm it poses to livestock. This results in retaliatory killings and further jeopardizes leopard populations (Carter et al., 2014; Cleave et al., 2018; Kumar et al., 2017; Kichloo et al., 2024). Human activities such as grazing cattle and the collection of non-timber forest produce in forests and protected areas result in overlapping use of space with leopards, increasing the likelihood of leopard attacks (Gurung et al., 2008; Shivakumar et al., 2023). The proximity of humans to protected areas is also one of the factors contributing to the increase in wildlife attacks on livestock in recent years (Sijapati et al., 2021).

The leopard's diet is highly diversified, and it is extremely adapted to various ecological conditions. Due to their adaptability to rapidly changing habitats, leopards can readily coexist with human settlements by preying on livestock and stray animals (Daniel, 1996; Hayward et al., 2006; Kumar et al., 2017., Raza et al., 2024). Decline of the prey base in forest areas compels leopards to search for prey near livestock sheds and other human habitations, where domesticated animals such as cows, sheep, goats, and other domestic species become easy targets (Kala et al., 2013). Common leopards' predation of livestock fluctuates with the seasons (Bhardwaj et al., 2024).

The leopard population in Himachal Pradesh is reported to be 510, according to the 2024 estimate by ZSI. In recent years, there has been an increase in human–wildlife conflict in Himachal Pradesh due to several factors, mainly urbanization, expansion of roads, industrialization, and housing development to meet the needs of a growing population (Kumar et al., 2017; Thakur et al., 2024). Increasing interactions between people and wildlife have created management challenges and have multiple implications, ranging from fear of wildlife to severe attacks on humans. Livestock depredation by different carnivores in their habitat and in unprotected forests has increased in India, causing economic loss to farmers, which may contribute to the rise in human–carnivore conflict (Woodroffe et al., 2007; Qamar et al., 2010; Ramesh et al., 2020; Treves & Karanth, 2003). The thriving and sustainability of leopard populations have also been associated with the availability of domestic livestock (Athreya & Belsare, 2007).

Human–wildlife interactions are increasingly common in landscapes where people and wildlife share space. While coexistence can provide ecological and social benefits, negative interactions such as livestock depredation may occur when the needs of humans and wildlife overlap, creating challenges for both conservation and local livelihoods (Treves & Karanth, 2003; Carter et al., 2014; Ripple et al., 2014).

Livestock depredation by leopards can impose substantial economic costs on rural households and may contribute to negative perceptions towards wildlife conservation. Such losses are particularly important in mountain farming systems where livestock constitute a major component of household livelihoods. Understanding the factors influencing leopard predation on livestock is important for developing effective conflict mitigation strategies and promoting human–leopard coexistence. According to Greyling et al. (2023), the main causes of leopard predation on livestock include habitat degradation and fragmentation, prey depletion, and poor livestock management practices. Habitat degradation forces leopards to hunt outside their usual habitats, and they frequently enter livestock enclosures (McManus et al., 2022). Decline in prey numbers in protected areas forces leopards to use livestock as a substitute food source (Davis et al., 2021). Inefficient livestock management practices, such as leaving livestock to roam unsupervised or using poorly constructed enclosures, further increase vulnerability to predation (Puls et al., 2021). Moreover, a gap between scientific research on sustainable practices and animal management methods exacerbates the problem (Pozo et al., 2021).

Although human–leopard conflict has been documented in Himachal Pradesh, systematic long-term assessments of livestock depredation patterns spanning more than two decades remain scarce in the Shivalik Himalayan region. The objectives of the present study were to (i) quantify long-term temporal patterns of leopard depredation on livestock during 2001–2023, (ii) assess variation in depredation among seasons, livestock categories, attack locations, and forest ranges, and (iii) identify management implications for reducing human–leopard conflict in Hamirpur District of Himachal Pradesh.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in the Hamirpur District of Himachal Pradesh, located in the lower west-central outer Himalayas of the Shivalik Hills, at elevations ranging from 400 m to 1,232 m above sea level. The western Hamirpur area covers the entire Barsar region, including. In contrast, parts of southern Nadaun tehsil, while the eastern Hamirpur area includes the entire Bhoranj tehsil area of the Shivalik Hills. The geographical area of the study site is 1,118 km².

The boundary of Hamirpur District coincides with Hamirpur Forest Division, which is further divided into five forest ranges (Hamirpur, Aghar, Barsar, Bijhari, and Nadaun). The geographical location of Hamirpur District and the forest ranges included in the study are shown in Figure 1.

The study was based on secondary data obtained from official livestock depredation compensation records maintained by the Forest Department, Hamirpur Forest Division, Himachal Pradesh, for the period 2001–2023. These records document verified livestock depredation incidents for which compensation claims were processed. The dataset was derived from official compensation records submitted by livestock owners and maintained by the Forest Department. Such records may underestimate actual livestock depredation because some incidents may remain unreported, although the magnitude of this reporting bias could not be quantified from the available data. As with all compensation-based datasets, the possibility of reporting bias cannot be excluded. Some depredation events may remain unreported if livestock owners do not submit compensation claims, whereas reporting rates may vary over time due to differences in awareness, accessibility of compensation mechanisms, or administrative procedures. Consequently, the dataset represents reported depredation incidents rather than absolute predation rates. However, because the same administrative reporting system was used throughout the study period, the records provide a valuable basis for examining long-term temporal patterns in reported livestock depredation.

2.2. Study Period

The study covered a period of 23 years (2001–2023). A depredation incident was defined as a reported leopard attack resulting in the loss of one or more livestock animals. For seasonal analysis, livestock depredation records were classified into four seasons based on the regional climatic pattern of Himachal Pradesh: winter (December–February), summer (March–June), monsoon (July–September), and autumn (October–November). Because these seasonal categories differ in duration, seasonal comparisons based on

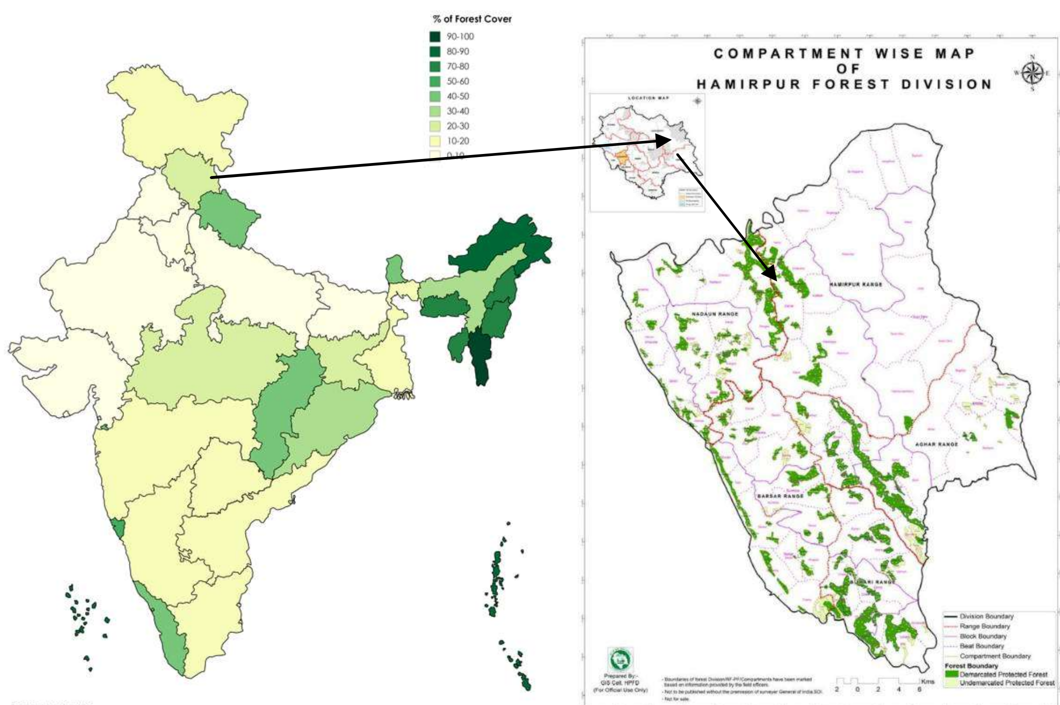

Figure 1. Map showing the location of Hamirpur District and the five forest ranges included in the study in Himachal Pradesh, India. The study area comprises the Hamirpur, Aghar, Barsar, Nadaun, and Bijhari forest ranges, which together cover the entire forest administrative jurisdiction of Hamirpur District. These ranges provided the spatial framework for analysing 23 years (2001–2023) of officially reported leopard-induced livestock depredation incidents based on Forest Department compensation records

total counts should be interpreted with caution. For analytical purposes, livestock were classified into two categories. Small livestock included goats and sheep, whereas large livestock included cattle, buffaloes, oxen, buffalo calves, horses, and mules. The classification was used to examine differences in depredation patterns between relatively small-bodied and large-bodied domestic animals commonly reared in the study area.

Forest range-wise distribution of incidents was also recorded. Descriptive statistics, including annual frequency counts, total livestock mortalities, proportional distributions (%) across livestock categories, attack locations, seasons, and forest ranges, and kill-per-incident ratios, were calculated to summarize livestock depredation patterns during the study period.

2.3. Statistical Analysis

Descriptive statistics were used to summarize livestock depredation patterns across seasons, livestock categories, attack locations, and forest ranges. Chi-square (χ^2) tests of independence were used to examine associations between depredation frequency and season, livestock category, attack location, and forest range. Statistical significance was assessed at $\alpha = 0.05$. All expected cell frequencies exceeded five, satisfying assumptions for chi-square analysis.

To evaluate long-term temporal trends in livestock mortality, a non-parametric Mann–Kendall trend test was performed using annual livestock mortality data from 2001 to 2023. The Mann–Kendall test statistic (τ) and associated p-value were used to assess statistical significance, while Sen's slope estimator quantified the magnitude and direction of temporal change (Mann, 1945; Kendall, 1975; Sen, 1968). The Mann–Kendall test was selected because it is widely used for ecological time-series data and does not require assumptions of normality.

As the dataset was derived from official compensation records, analyses reflect reported depredation incidents rather than absolute predation rates. All statistical analyses were performed using R software (version 4.5.1).

3. RESULTS AND DISCUSSION

3.1. Temporal Trends in Livestock Depredation

A total of 1,079 reported depredation incidents resulted in 1,420 livestock mortalities during the study period (2001–2023), corresponding to an average kill-per-incident ratio of 1.32 livestock per depredation event. Annual livestock mortality varied considerably among years, ranging from 10 animals in 2004 to 158 animals in 2001 (Figure 2).

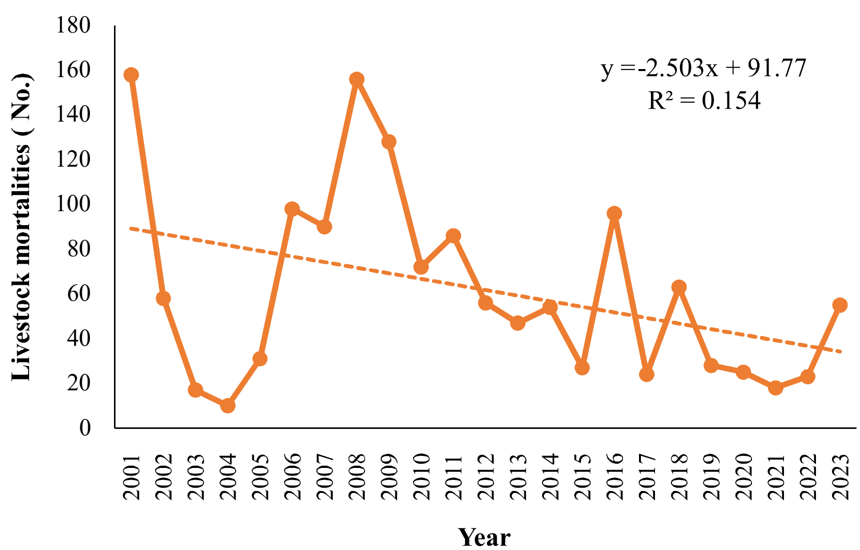

Figure 2. Annual livestock mortalities resulting from leopard depredation in Hamirpur District, Himachal Pradesh, during 2001–2023. The figure illustrates year-to-year variation in reported livestock mortalities based on official Forest Department compensation records. Mann–Kendall trend analysis indicated a significant declining trend in annual livestock mortality over the study period

Mann–Kendall trend analysis revealed a significant declining trend in annual livestock mortality during the study period ($\tau = -0.40$, $p = 0.045$). Sen's slope estimator indicated an average decline of approximately 2.92 livestock mortalities per year. Although periodic increases were observed in certain years, particularly during 2008, 2009, and 2016, the overall long-term trend was significantly negative.

3.2. Seasonal Variation in Livestock Depredation

Seasonal variation in livestock mortality due to leopard depredation was significant ($\chi^2 = 164.63$, df = 3, $p < 0.01$). Of the 1,420 livestock mortalities recorded during the study period, 461 (32.46%) occurred during summer, followed by 375 (26.41%) during the monsoon season, 295 (20.77%) during autumn, and 289 (20.35%) during winter (Figure 3). The higher number of reported livestock mortalities during summer and monsoon may reflect increased exposure of livestock to leopard predation during these periods.

Seasonal comparisons should be interpreted cautiously because seasonal categories differed in duration (summer = 4 months, monsoon = 3 months, autumn = 2 months, and winter = 3 months). Nevertheless, significant seasonal variation in reported livestock mortality was evident across the study period.

Livestock depredation differed significantly between livestock categories ($\chi^2 = 373.51$, df = 1, $p < 0.01$). Of the total 1,420 livestock mortalities recorded during the study period, 1,195 (84.15%) involved small livestock, whereas 225 (15.85%) involved large livestock (Figure 4).

3.4. Site-wise Distribution of Depredation Incidents

A total of 1,079 reported depredation incidents were analyzed according to attack location. Most incidents occurred in livestock sheds (744; 68.95%), followed by grassland/grazing areas (272; 25.21%), whereas forest areas accounted for the lowest proportion of incidents (63; 5.84%) (Figure 5). Depredation frequency differed significantly among attack locations ($\chi^2 = 351.47$, df = 2, $p < 0.01$).

3.5. Range-wise Distribution of Livestock Depredation

Range-wise analysis revealed significant variation in livestock mortality among the forest ranges of Hamirpur Division ($\chi^2 = 915.29$, df = 4, $p < 0.01$). Of the 1,420 livestock mortalities recorded during 2001–2023, the highest proportion occurred in Hamirpur Range (1,047;

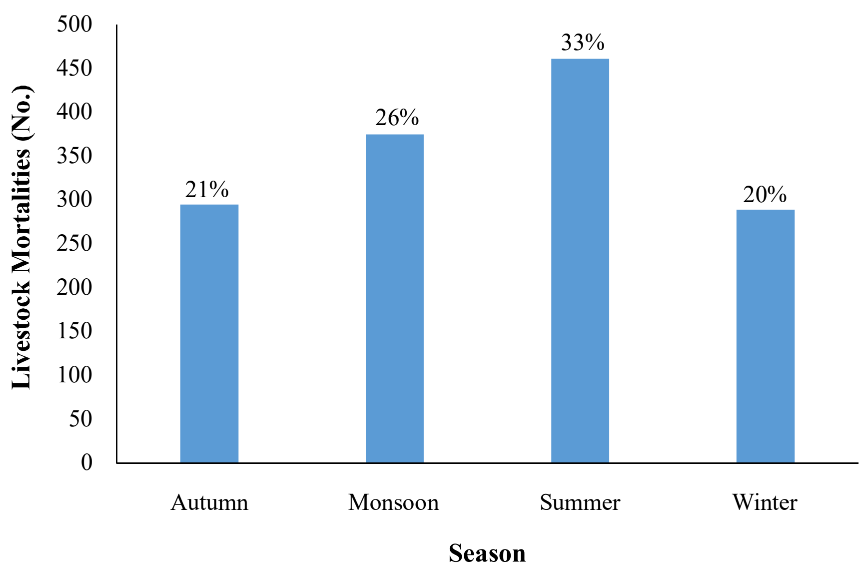

Figure 3. Seasonal distribution of livestock mortalities caused by leopard depredation in Hamirpur District, Himachal Pradesh, during 2001–2023. Bars represent the total number of livestock mortalities recorded in each season from official Forest Department compensation records, with percentages indicating each season's contribution to the overall total. The figure shows that reported livestock mortalities were highest in summer and lowest in winter

73.73%), followed by Aghar Range (184; 12.96%), Barsar Range (118; 8.31%), Nadaun Range (44; 3.10%), and Bijhari Range (27; 1.90%) (Figure 6).

3.6. Temporal Trends in Livestock Depredation

The present study revealed a significant declining trend in livestock mortality caused by leopard depredation during 2001–2023. Mann–Kendall trend analysis confirmed a statistically significant decrease in annual livestock mortality ($Z = -2.01$, $p = 0.045$), although occasional fluctuations were observed in certain years. Notably, elevated livestock mortality was recorded in 2016 and 2018; however, the available compensation records did not contain ecological, climatic, or management-related information that could explain these short-term increases. Consequently, the causes of these fluctuations could not be formally evaluated and no causal inferences can be drawn from the present dataset. Such temporal variability may be influenced by a combination of ecological and socio-economic factors, including changes in livestock management practices, reporting behaviour, local prey availability, and leopard movement patterns. However, these factors were not directly measured in the present study, and therefore their relative contribution to the observed decline in livestock mortality could not be formally assessed.

Despite the significant declining trend, livestock depredation remained a recurring source of human–leopard conflict throughout the study period. Moreover, substantial spatial variation was observed among forest ranges, with Hamirpur Range accounting for the majority of reported livestock mortalities. The present dataset does not permit identification of the specific drivers responsible for the observed decline, and it therefore remains unclear whether the trend reflects improved livestock management, mitigation efforts, changes in reporting behaviour, ecological factors, or a combination of these influences. Continued monitoring and research are therefore necessary to better understand the drivers of depredation and to support evidence-based conflict mitigation in the region.

3.7. Seasonal Patterns of Depredation

Seasonal variation in livestock depredation was significant, with the highest proportion of livestock mortality recorded during the summer season. Comparable seasonal patterns have been reported from other Himalayan and South Asian landscapes where livestock grazing practices influence predator–livestock encounters (Lamichhane et al., 2023; Kshettry et al., 2017). The increased incidence during summer may be associated with seasonal livestock management practices. Owing to reduced

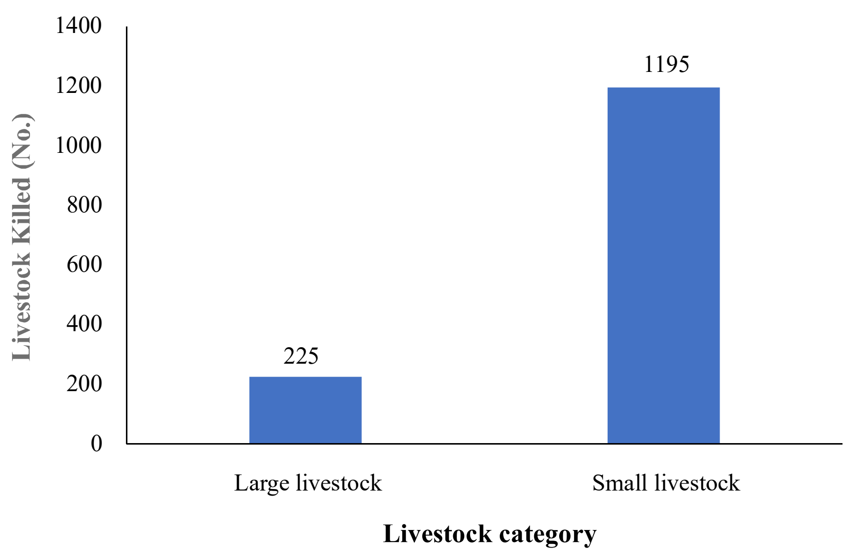

Figure 4. Distribution of livestock mortalities by livestock category in Hamirpur District, Himachal Pradesh, during 2001–2023. Bars show the total number of reported livestock mortalities in each livestock category, and percentages indicate their contribution to the overall total. Small livestock accounted for a substantially higher proportion of reported mortalities than large livestock

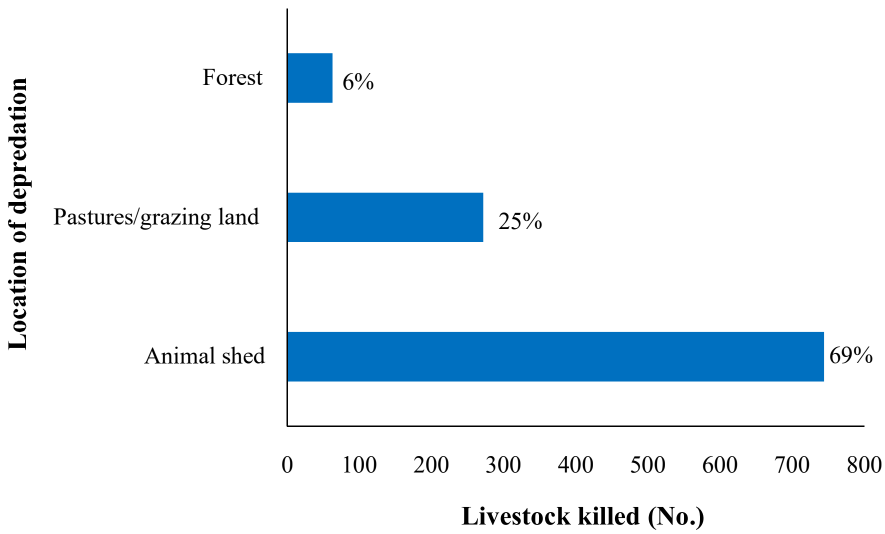

Figure 5. Distribution of reported leopard depredation incidents across different attack locations in Hamirpur District, Himachal Pradesh, during 2001–2023. Bars represent the total number of reported depredation incidents recorded in animal sheds, pastures/grazing land, and forest areas based on official Forest Department compensation records, with percentages indicating each location's contribution to the overall total. The figure shows that most reported depredation incidents occurred in animal sheds, whereas relatively few were reported from forest areas

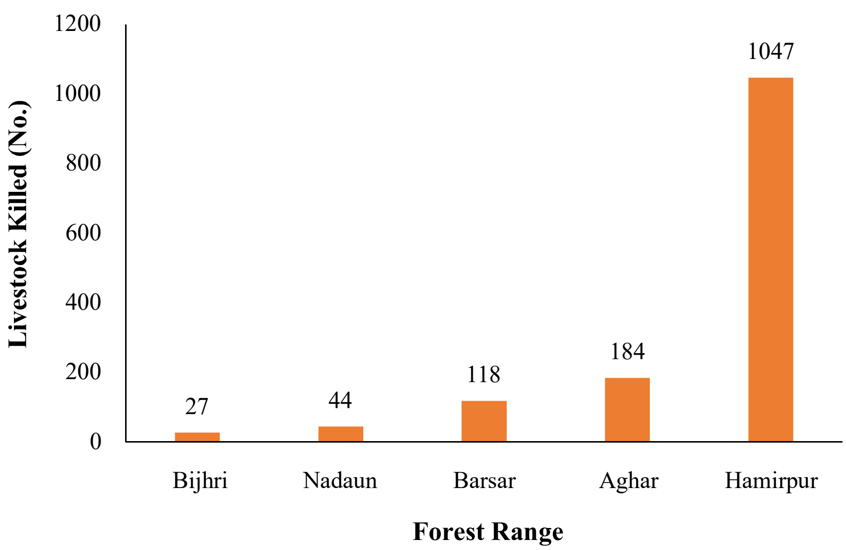

Figure 6. Forest range-wise distribution of livestock mortalities attributed to leopard depredation in Hamirpur Forest Division, Himachal Pradesh, during 2001–2023. Bars show the total number of reported livestock mortalities in each forest range, and percentages indicate their contribution to the overall total. Reported livestock mortalities were concentrated in Hamirpur Forest Range, with considerably lower numbers in the remaining four forest ranges

fodder availability around settlements, livestock are often grazed in nearby grasslands and forest-adjacent areas, thereby increasing the likelihood of encounters with leopards. In some instances, leopards may also follow livestock movements and attack animals near livestock enclosures.

However, grazing intensity, fodder availability, and leopard movement patterns were not quantified in the present study. Therefore, these explanations should be considered as plausible interpretations rather than confirmed causal mechanisms.

3.8. Livestock Category Preferences

A substantial majority of livestock mortalities recorded during the study period involved small livestock, particularly goats and sheep. This pattern is consistent with the general predatory behaviour of leopards, which often prefer smaller prey because they are easier to subdue, transport, and consume while minimizing the risk of injury. Similar observations have been reported from several Himalayan and South Asian landscapes, where goats and sheep frequently constitute the most vulnerable livestock categories owing to their smaller body size and ease of capture (Odden et al., 2002; Athreya et al., 2013).

The predominance of small livestock depredation may also reflect local livestock husbandry practices, as goats and sheep are frequently grazed in open areas and may be housed in comparatively less secure enclosures. However, the present dataset did not include information on livestock abundance or management practices; therefore, these explanations should be interpreted cautiously.

3.9. Attack Location Patterns

One of the most notable findings of the present study was that nearly 69% of reported depredation incidents occurred in animal sheds. This suggests that livestock enclosures represent an important interface for human–leopard interactions in the study area. Livestock confined within poorly protected sheds may be particularly vulnerable to nocturnal leopard attacks, especially where enclosures are located close to forest fragments, agricultural fields, or natural vegetation cover. Poorly constructed livestock sheds, inadequate night-time security, and the proximity of enclosures to forest fragments or dense vegetation may further increase vulnerability to leopard attacks. In rural Himalayan landscapes, livestock are often housed in traditional structures that may not effectively prevent predator entry. Similar observations have been reported from other human-dominated landscapes, where poorly protected night-time enclosures increase livestock vulnerability to carnivore attacks (Inskip and Zimmermann, 2009; Athreya et al., 2013). The concentration of attacks in animal sheds suggests that livestock protection measures implemented at the household level could substantially reduce depredation risk. This finding highlights the importance of prioritizing predator-resistant housing as a key component of conflict mitigation programmes.

In contrast, depredation incidents in grazing areas were

Table 1. Chi-square analysis of livestock depredation according to season, livestock category, attack location, and forest range

Variable	Category	Number (n)	χ^2	d.f	p-value
Season	Winter	289			
	Summer	461			
	Monsoon	375	164.63	3	<0.001
	Autumn	295			
Livestock category	Small livestock	1195			
	Large livestock	225	373.51	1	<0.001
Attack location	Animal shed	744			
	Pasture/Grazing land	272	351.47	2	<0.001
	Forest	63			
Forest range	Hamirpur	1047			
	Aghar	184			
	Barsar	118			
	Nadaun	44	915.29	4	<0.001
	Bijhari	27			

comparatively low, possibly because livestock are often accompanied by shepherds, guard dogs, or farmers during grazing. Similar observations have been reported from other leopard-inhabited landscapes, where livestock protected by human supervision and guarding animals experience lower predation risk than those housed in poorly secured enclosures. The predominance of shed-based attacks highlights the importance of improving livestock housing through predator-resistant enclosures, secure doors, reinforced fencing, and enhanced night-time protection measures.

3.10. Range-wise Variation

Range-wise analysis revealed that the majority of livestock mortalities occurred in Hamirpur Range. Anthropogenic landscape modification may play an important role in shaping human–leopard interactions in the study area. Fragmented forest patches interspersed with agricultural fields and expanding rural settlements could increase spatial overlap between livestock shelters and leopard movement areas. Such habitat configurations may facilitate opportunistic predation, particularly where livestock enclosures are located near forest edges. Human–carnivore interactions are often intensified in fragmented landscapes where wildlife habitats, agricultural land, and human settlements occur in close proximity, thereby increasing opportunities for livestock depredation (Carter et al., 2014).

Leopards are known for their behavioural plasticity and adaptability in human-dominated landscapes (Cleave et al., 2018; Shivakumar et al., 2023), which may enable them to utilize livestock as an alternative prey source under certain conditions. However, habitat characteristics, prey abundance, and leopard movement patterns were not directly measured in the present study; therefore, these explanations should be considered as plausible interpretations rather than confirmed causal mechanisms.

From an economic perspective, even small-scale livestock losses can have disproportionate impacts on rural household income, thereby intensifying negative perceptions towards wildlife conservation. Addressing human–leopard conflict, therefore, requires integrated management strategies that consider ecological, landscape, and socioeconomic dimensions.

3.11. Management Implications

The findings of the present study have important implications for conflict mitigation and livestock protection in the region. Since nearly 69% of reported depredation incidents occurred in animal sheds, improving the design and security of livestock enclosures should be a priority management intervention. Predator-resistant sheds, reinforced doors, secure fencing, and improved night-time livestock confinement may substantially reduce livestock vulnerability to leopard attacks.

Additional measures such as community awareness programmes, improved livestock-guarding practices, timely compensation mechanisms, and targeted monitoring in conflict-prone areas may further help reduce human–leopard conflict. Capacity-building programmes for livestock owners focusing on predator-safe livestock management, enclosure reinforcement, recognition of leopard presence, and improved livestock guarding practices may further reduce livestock vulnerability. Successful implementation of conflict mitigation measures will require active participation of local communities, sustained institutional support, and adoption of practical livestock protection measures at the household level. Adoption of site-specific and evidence-based mitigation strategies will be essential for promoting coexistence between local communities and leopards in the Himalayan landscape

3.12. Study Limitations and Future Research

The present study was based on official compensation records maintained by the Forest Department. Although these records provide a standardized and long-term source of information on livestock depredation, they may be subject to reporting bias. Under-reporting may occur when livestock owners do not file compensation claims, whereas minor depredation events may remain undocumented. Administrative inconsistencies or misclassification of incidents also cannot be entirely ruled out. Consequently, the findings reflect patterns in reported depredation incidents rather than absolute predation rates.

The dataset did not include independent estimates of leopard population density, wild prey abundance, habitat change, climatic variables, land-use change, or other ecological covariates. Therefore, causal relationships between ecological factors and depredation patterns could not be formally evaluated. Similarly, temporal variation in reported incidents may partly reflect differences in reporting efficiency, awareness, and accessibility of compensation mechanisms.

Future studies integrating ecological monitoring, prey-base assessments, spatial habitat analyses, and advanced statistical modelling would improve understanding of the drivers of livestock depredation and support more effective conflict mitigation strategies.

4. CONCLUSION

The present study provides a comprehensive assessment of leopard-induced livestock depredation in Hamirpur District, Himachal Pradesh, based on 23 years of official compensation records (2001–2023). A total of 1,079 reported depredation incidents resulted in 1,420 livestock mortalities, with small livestock accounting for the majority of losses. Most depredation incidents occurred in animal sheds, while Hamirpur Range experienced the highest proportion of livestock mortality.

Mann–Kendall trend analysis revealed a significant declining trend in annual livestock mortality during the study period, although temporal fluctuations were observed in certain years. Significant variation in depredation patterns was also observed across seasons, livestock categories, attack locations, and forest ranges. These findings highlight the importance of livestock husbandry practices and local landscape characteristics in influencing human–leopard interactions.

Given that nearly 69% of reported depredation incidents occurred in animal sheds, strengthening livestock protection measures through predator-resistant enclosures, reinforced fencing, improved night-time confinement, and community-based conflict mitigation strategies should be prioritized. Capacity-building programmes for livestock owners focusing on predator-safe livestock management, enclosure reinforcement, recognition of leopard presence, and improved livestock guarding practices may further reduce livestock vulnerability. While compensation mechanisms currently provide financial relief to affected livestock owners in the study area, additional preventive measures are required to reduce depredation risk and improve long-term coexistence. Successful implementation of conflict mitigation measures will require active participation of local communities, sustained institutional support, and adoption of practical livestock protection measures at the household level. Continued monitoring of depredation patterns, combined with ecological studies on leopard populations, prey availability, and habitat dynamics, will be essential for developing evidence-based management strategies that promote coexistence between rural communities and leopards in the Himalayan region.

Acknowledgements

We hereby express profound gratitude to the Conservator of Forests, Hamirpur, for providing access to the data of the divisions of the Hamirpur district. The authors sincerely thank the Conservator of Forests, Hamirpur Forest Circle, for providing access to the livestock depredation records used in this study.

Funding

This research received no external funding.

Conflict of interest

There are no conflicts of interest related to the content of this manuscript.

CRediT author contribution statement

Sangeeta Chandel: Conceptualization, Resources, Investigation, Data acquisition, Project administration, Writing – review & editing. Bhagwati Prashad Sharma: Methodology, Supervision, Validation, Writing – review & editing. Vijay Kumar: Investigation, Validation, Data interpretation, Writing – review & editing. Varun Sankhyan: Formal analysis, Methodology, Data curation, Visualization, Statistical analysis, Writing – original draft, Writing – review & editing. All authors have read and approved the published version of the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors used generative AI tools to assist with language editing and the improvement of readability. All content was carefully reviewed and revised by the authors, who take full responsibility for the content of the manuscript.

Data availability statement

The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

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