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Spatio-Temporal Patterns of Livestock Predation by Leopards in Bardia National Park, Nepal

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Abstract: Human–wildlife conflict is a challenging issue that requires the attention of conservationists worldwide. Habitat fragmentation and encroachment reduce the abundance of prey species, and an increase in the number of predators leads to a higher risk of conflict with large cats such as leopards, jeopardizing conservation efforts. This study explored the spatio-temporal pattern of the human–leopard conflict in Bardia National Park, Nepal, from 2000 to 2020. To analyze the conflict with leopards, we used data (compensation cases filed in the park) from the buffer zone management office, the National Trust for Nature Conservation (NTNC), and the Department of National Park and Wildlife Conservation (DNPWC). Leopard attacks on livestock are increasing exponentially, with 3335 livestock killed in 2652 attacks occurring during the study period. Although livestock depredation by leopards occurred all over the park, the southern cluster has most documented livestock damage (64.01%). The eastern and northern clusters reported fluctuating and dispersed predation events, respectively. Our spatial analysis indicated no effect of topography (slope) on livestock depredation by leopards. We recorded the highest number of leopard attacks and predation during the dry winter season when the nights are longer and livestock remain in their sheds. This carnivore mostly limited its prey to small-sized livestock (95.77%) such as goats, sheep, and pigs, whereas attacks on large-sized (cow and buffalo) livestock were least frequent. Among small-sized livestock, goats are the most predated (66.92%), followed by pigs (20.30%), in all seasons. The escalating human–leopard conflict in BNP is thus a severe threat to conservation efforts as the park has already invested a substantial amount of money (approx. USD 80,000) compensating for livestock lost in leopard attacks over the last two decades. Improving habitat conditions to reduce competition inside the park, developing an insurance scheme for livestock and humans, providing support for upgraded sheds, and the development of practical and feasible strategies that focus on specific animals and clusters of the national park are needed to reduce conflicts to maintain the co-existence between wildlife and human beings.

Keywords: human–wildlife conflict; leopard; livestock; predation; compensation

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1. Introduction

Large carnivores, humans, and their livestock have co-existed for thousands of years. However, recent decades have shown a dramatic increase in human–wildlife conflict (HWC) globally. The rapid increase of the human population [1] and the number of residences in proximity to the protected area exacerbate conflict with wildlife [2]. With increase in the human population, the rapid expansion of infrastructure development and the shrinkage of habitat, most of the wildlife of higher significance are restricted to protected areas. Such animals often visit the surrounding area of the park for food, cover, and shelter, resulting in frequent interactions with human beings and livestock. Increasing cases of human–wildlife interactions can lead to severe conflicts, particularly when human casualties occur [3],

especially caused by large wildlife. Therefore, prevention and mitigation become more challenging when keystone wildlife is involved [4,5].

HWC no longer remains a simple competition over shared resources among co-existing individuals. Instead, it has become an important political issue [6] as people's livelihoods are directly affected, and large amounts of financial resources are required to resolve the related issues. Raids on crops, property damage, livestock predation, and human casualties are the most common forms of loss and damage from wildlife [4]. An increase in park–people conflict in protected areas is creating serious challenges to the motivation for wildlife conservation [4] and maintaining a healthy ecosystem. Wildlife attacks on livelihood assets and the consequent economic losses often result in the reduced support of local communities for wildlife conservation [7]. The retaliatory killing of wildlife to prevent livestock depredation and economic loss is a major problem for wildlife. However, these retaliatory killings have often led to worse consequences including vanishing predators, such as tigers in Northeast China [8]; lions in Africa [9–11]; mountain lions (*Puma concolor*) in Argentine Dry Chaco [12]; and leopards in South Africa [13] and Southwest Asia [14]. Human–wildlife conflict has not only created a threat to the long-term survival of the wildlife but has also impacted well-being of the local people residing around the park [15]. The financial losses resulting from livestock depletion are equivalent to USD 142.61 per household [16], which is a significant amount for households whose average monthly income from livestock husbandry contributes nearly 100% to the total income of rural communities [17]. Developing harmony among co-existing communities and large cats such as leopards will maintain a healthy ecosystem and open various avenues of economic development.

The common leopard (*Panthera pardus*) mostly exists as a competitive predator along with other carnivores in the Hindu-Kush Himalayan mountain range [18]. Bardia National Park (BNP) remains no exception to this, with leopards sharing habitat with Royal Bengal tigers *(Panthera tigris)* and competing for prey [19,20]. Improvement in habitat conditions, establishment and development of corridors and connectivity, ban on hunting and public awareness programs have increased the leopard population in Bardia National Park [19]. Although it is hard to generalize what factors lead to livestock depredation by big cats (with a narrow dietary niche), previous evidences have shown that depredation rates are associated with several factors such as: (a) climatic conditions such as rainfall and temperature [21–23], (b) natural factors such as the abundance of prey [14,24,25], condition of ambush and hiding cover, and competition among predators [20] and (c) socio-economic settings, such as livestock husbandry practices [19,26,27], characteristics of villages [28,29], the condition of livestock enclosures [30,31], and free ranging stock animals as easy prey and their herd size [32–34]. People living in the periphery of BNP predominantly practice livestock husbandry for their livelihood, and the number of people living near the park is increasing rapidly [35], resulting in frequent interactions with leopards. In addition to environmental conditions, individual health and age, the socio-economic status of the community, and landscape factors such as habitat shrinkages and fragmentations [36] also affect the form, frequency and intensity of the conflict [37]. Moreover, conflict with leopards, having more adaptive capacity to wider habitat conditions, is often higher than tigers, which appear to have smaller niches [19]. The restoration and conservation of high-value species, such as the leopard, highly depend on minimizing and controlling the conflict and interaction in coexisting communities. The conflict with leopards has created other social, economic and political debates and has also caused friction between conservation partners [1,38] requiring different conflict resolution schemes. These conflicts can be co-managed via compensation schemes, insurance mechanisms, participatory planning, and equitable benefit sharing [39] among the conservation actors. Among different conflict resolution mechanisms, the government of Nepal has designed and is implementing the Relief Distribution guidelines (2009) to compensate/relieve the economic losses from wildlife. Compensation schemes are designed to increase the resilience of communities living near to the conflicting wildlife and help reduce the financial impacts on communities

living around the park. The park authorities provide financial support to households suffering from conflict based on the Nepal government's relief distribution guideline.

Livestock loss due to leopard attacks is one of the major challenges for the park authorities of BNP, and it certainly requires a thorough study on the trends surrounding human–leopard conflicts. This could include examining the patterns of previous attacks and developing realistic mitigation strategies that will be beneficial to both the park authorities and surrounding communities. Existing provision can compensate livestock depredation by leopards through financial support after an investigation by government authorities. Few studies have analyzed the HWC in BNP (e.g., [19,20,40,41] among others). Few analyses of trends and patterns of livestock killed by leopards and payments made as compensation by the government exist, and the ones that do are mostly scattered and site-specific. Detailed analysis of the trends and spatio-temporal patterns of HWC in BNP can be more valuable to the management authorities to formulate realistic strategies to mitigate the prevailing rate of livestock damages, identify sustainable compensation schemes to enhance conservation efforts, and develop cluster-specific conservation plans in relation to the types of prey killed in different locations. In this context, this study aims to:a) describe spatio-temporal variables correlated with livestock predation events; b) Identify hierarchical regions of high risk of human-leopard conflict; c) Summarize economic losses and investment to mitigate human- leopard conflict. The seasonal and monthly patterns of depredation are also useful in the analysis of the prey species density inside the park and in developing season-specific plans to reduce competition among co-existing predators, which can be a major milestone for developing strategies to tackle the human–leopard conflict.

2. Materials and Methods

2.1. Study Area

Bardia National Park (Figure 1) is located in Bardiya District of Lumbini Province in Nepal, also spreading through Surkhet and Banke Districts with a core area of 938 km^2. Geographically, the park is located at 28°15′ to 28°35.5′ North and 80°10′ to 81°45′ East. It connects Banke National Park in the east and Katarniyaghat Wildlife Sanctuary of India in the south through the Khata corridor. This park was established in 1988 to protect the representative ecosystems and conserve wildlife habitats and the prey species of carnivores. It is one of the biggest and undisturbed national parks in Nepal. The park lies in the tropical to sub-tropical zone, where alluvial grassland and sub-tropical deciduous and riverine forest provides a suitable habitat for large wildlives. The park has three distinct seasons: hot and dry (mid-February to mid-June), hot and wet (mid-June to late September) and cool and dry (late September–mid-February), where rainfall is mostly clustered in monsoon. This national park is one of the major habitats for wildlife of high conservation significance, including tigers and leopards, and is an alternative habitat for the one-horned rhinoceros. The tiger population is increasing in the park [42], leading to high competition for prey among the carnivores, including leopards [43]. The record from the park shows that at least 62 species of mammals, 52 species of reptiles and amphibians and 121 species of fish inhabit this park.

The Buffer Zone (BZ) of Bardia national park spreads over an area of 507 km^2 with established and institutionalized user groups (262) and user committees (19). The institutional set-up serves the purpose of sharing park revenue for community development, conservation activities, facilitating compensation filing and claims, and income generation and awareness activities as an extension of park authorities. Most communities living around Bardia National Park (BNP) and its buffer zone depend on forest resources for forage, animal bedding and fodder to meet daily livestock needs [44] and practice livestock rearing as a source of income. Local communities claim usage rights for customary forest products, as well as the rights of passage, fishing, and other Park resources, which often expose humans and their assets to the wildlife. The Management Plan of Bardia National Park, 2022, estimates the total livestock population in the BZ to be around 75,000, where livestock such as goats, cows, buffaloes, and pigs are common. The population density is

increasing around the national park, and the human–leopard conflict is mounting in BNP and its buffer zones [43].

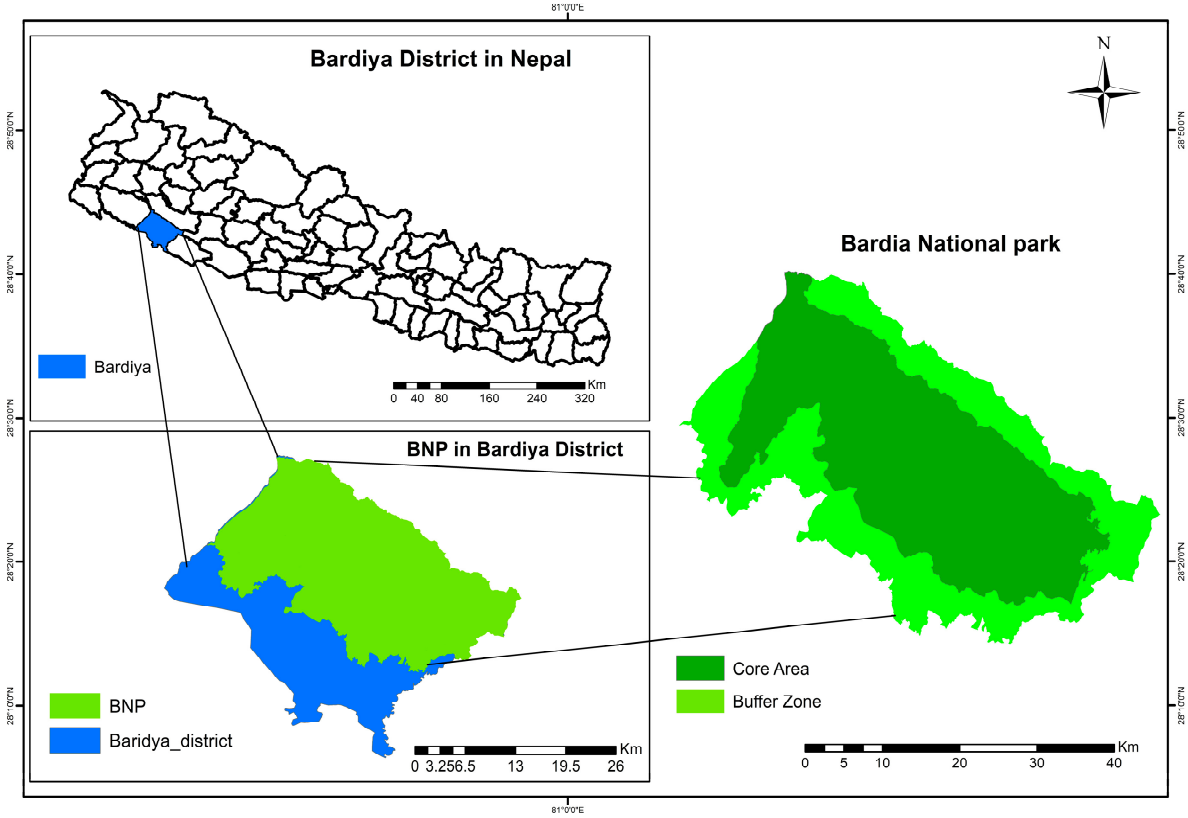

Figure 1. Map of Bardia National Park showing both core area and buffer zone.

2.2. Data Collection and Analysis

We obtained data on livestock depredation incidents during 2000–2020 from the office of the National Park and the buffer zone management committee. The data for this study were collected from May to July, 2021. The primary source of information was the applications for compensation claims submitted by local communities as a part of the process for compensation. Park authorities, upon receiving the claim, visited the incidence site, took photos and recorded the GPS coordinates of each site, and studied paw marks, the nature of wounds on prey, nature of attack, etc., to verify the leopard attack and to avoid any confusion on whether the attack was by other felids. We also triangulated the information with anecdotal records and discussed it with park authorities before analyzing it. During discussion, we focused on any chance of recording a false compensation claim. The park authorities believed the chance of a false claim was minimal, as the process requires approval from park authorities, photo evidence is necessary and local communities need to act as eyewitnesses during the whole process.

We thoroughly reviewed every compensation claim form to analyze the extent and temporal, seasonal and geographic trends of human–leopard conflicts. We collected the livestock depredation data, including livestock type (cattle, buffalo, goats, sheep or pigs), date and location (Village Development Committee/municipality), buffer zone user committee, owner and amount of compensation received over the last 20 years. We classified months into hot and dry summer (March to May), monsoon (June to September) and dry winter (October–February) seasons [45] for temporal analysis. Similarly, we categorized cattle and buffalo as 'large livestock' and goats, sheep, and pigs as 'small livestock' to test the associations between leopard and livestock size. We used R software (R Core Team, 2021) for the Chi-square test of independence to test the relationship between predators

and seasons. Furthermore, we fitted an exponential regression to evaluate the relationship between livestock attacks and financial compensation provided from 2000 to 2020.

For spatial analysis, we categorized and mapped all BZUCs (19) into four clusters namely western (Patabhar, Bindra, Asharegaudi and Geruwa), southern (Surayptuwa, Thakurbaba, Shivapur, Shreeramnagar, Babai), eastern (Kareliya, Bhada, Bagkhor, Siddapuri, Koldada Milijuli), and northern (Chepang, Chhinchu, Lekhparajul, Hariharpur and Taranga) based on direction and access to the park's headquarters. The spatial analysis was conducted using ArcGis 10.4, and the number of incidents and kills was analyzed with cluster and slope. We used the slope map of Bardia National Park to establish if any relation between livestock attacks by leopards and the slope of the area exists. Similarly, we classified total predated livestock numbers (in BZUC level) in the last two decades into four categories, very low (0–200), low (200–400), medium (400–600), and high (600–800), for simplicity to present in the map.

3. Results

3.1. Spatial Analysis

BNP reported 2652 livestock attacks by leopards in the last two decades, which involved the predation of 3335 animals. Although leopards attacked in all clusters, the southern cluster experienced the most attacks (65.05%) and predation by leopard (64.02%) in the study period. On the contrary, the western part showed the lowest attack (3.96%) and predation (4.1%) rates. It was also found that more than one animal was killed by a leopard per attack. Table 1 and Figure 2 show the detailed spatial distribution of attacks and predation.

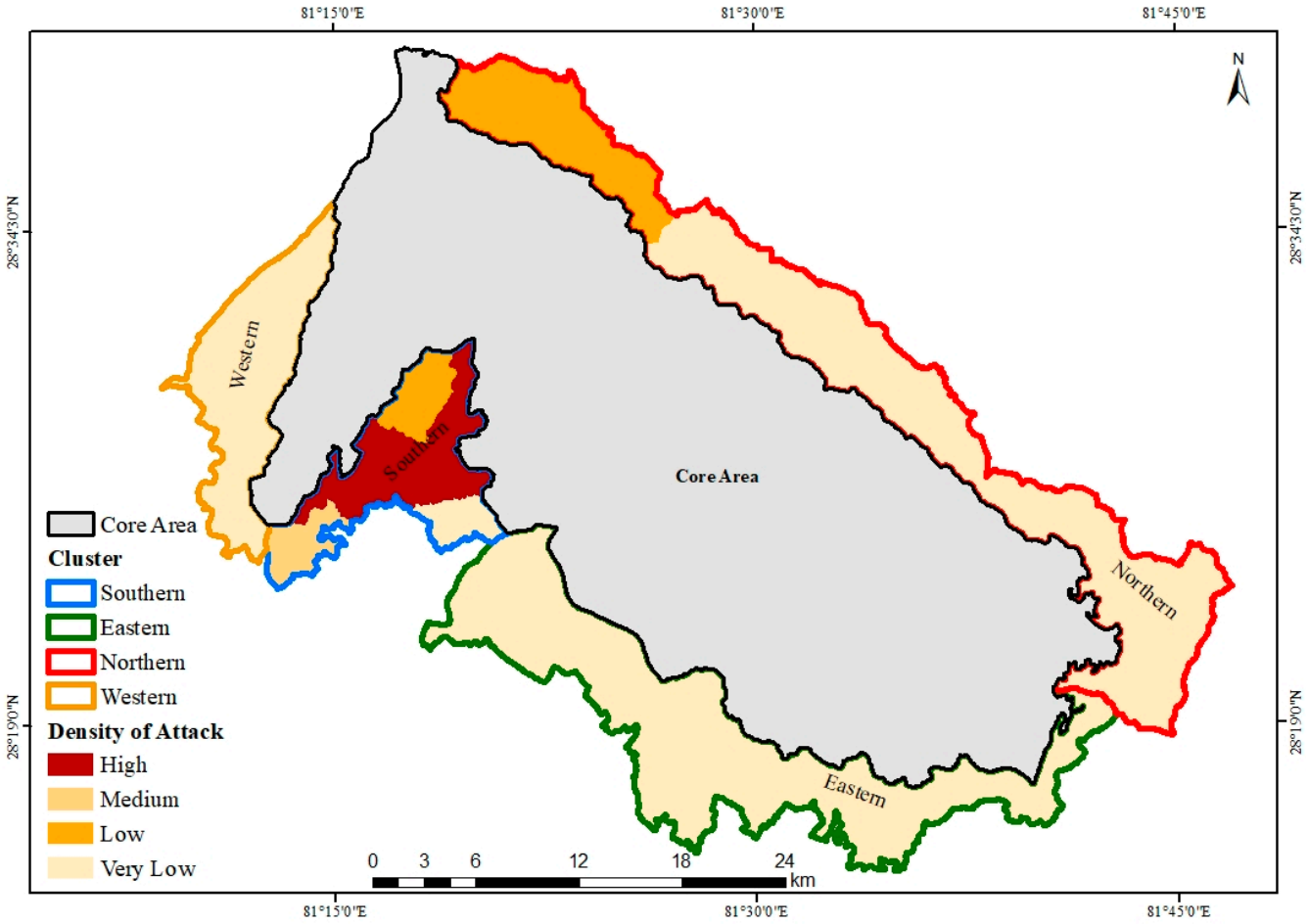

Figure 2. Map showing density of predation in each cluster (density of predation in BZUCs of each cluster is categorized as very low (0–200), low (200–400), medium (400–600), and high (600–800)).

Table 1. Summary of spatial analysis of leopard attacks on livestock.

Cluster	Attack Number (%)	Predation Number (%)	Average Predation Per Year
Eastern	526 (19.83)	652 (19.55)	31.05
Northern	296 (11.16)	411 (12.32)	19.57
Southern	1725 (65.05)	2135 (64.02)	101.67
Western	105 (3.96)	137 (4.11)	6.52
Total	2652 (100)	3335 (100)	158.81

3.2. Temporal Analysis

Leopards preferred the dry winter season, accounting for 43% of total predation in the last two decades. The lowest attack rate on livestock (25%) was documented in hot and dry summer season. Figure 3 shows the season-specific attacks on livestock by leopards. However, livestock predation by leopards did not vary significantly with the season of attack (χ^2 = 24.961, df = 26, *p*-value = 0.5212).

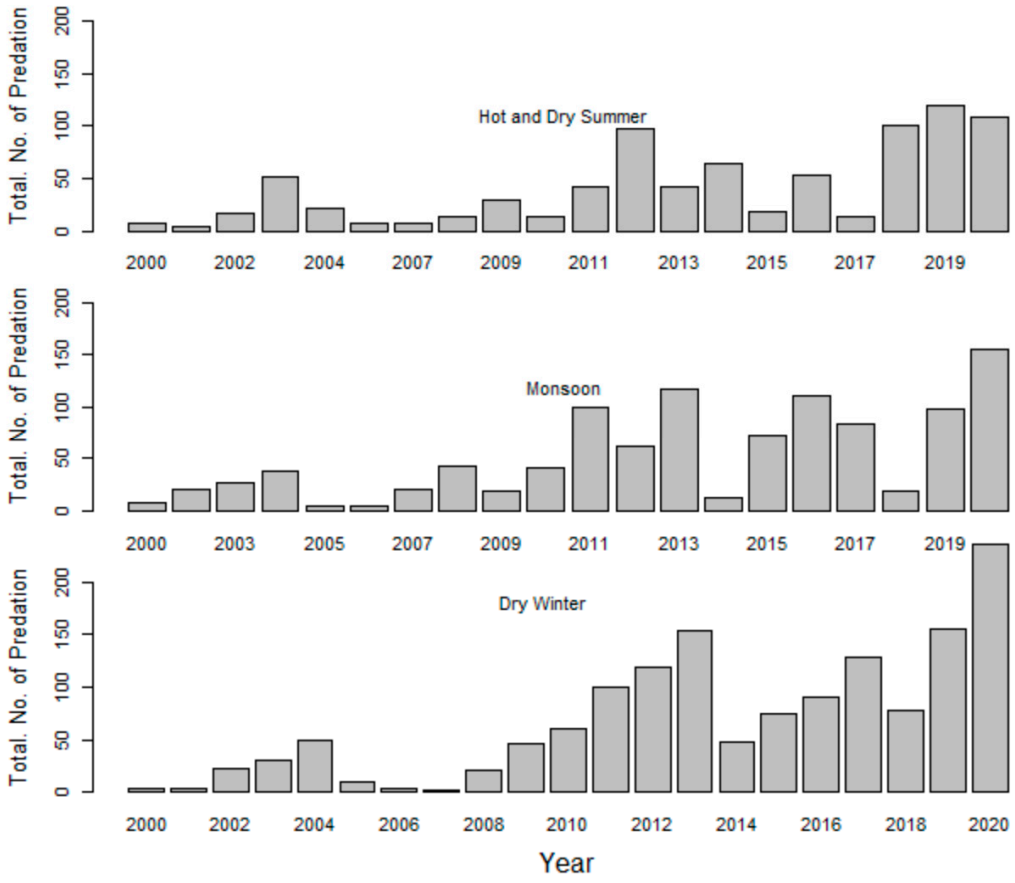

Figure 3. Incident of livestock predation by leopards per season.

3.3. Prey Predated

Leopards limited their prey to small-sized livestock (goat, sheep, pig, rabbit, and chicken), accounting for 95.77% of total predation. Goats were the most predated (66.92%), followed by pigs (20.3%). Figure 4 shows a detailed breakdown of the types of prey predated.

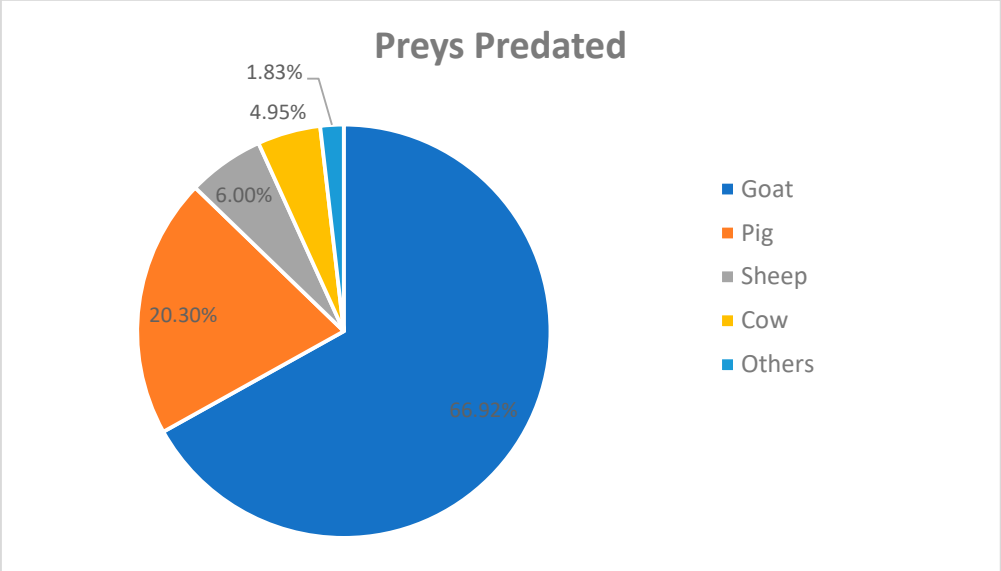

Figure 4. Livestock killed by leopards.

We also analyzed the prey preference of leopards by season. The analysis showed that goats were the most preferred choice of prey in each season, followed by pigs. Meanwhile, buffalos were the least predated animal in all seasons and the killing of rabbits and chickens was more accidental (Figure 5).

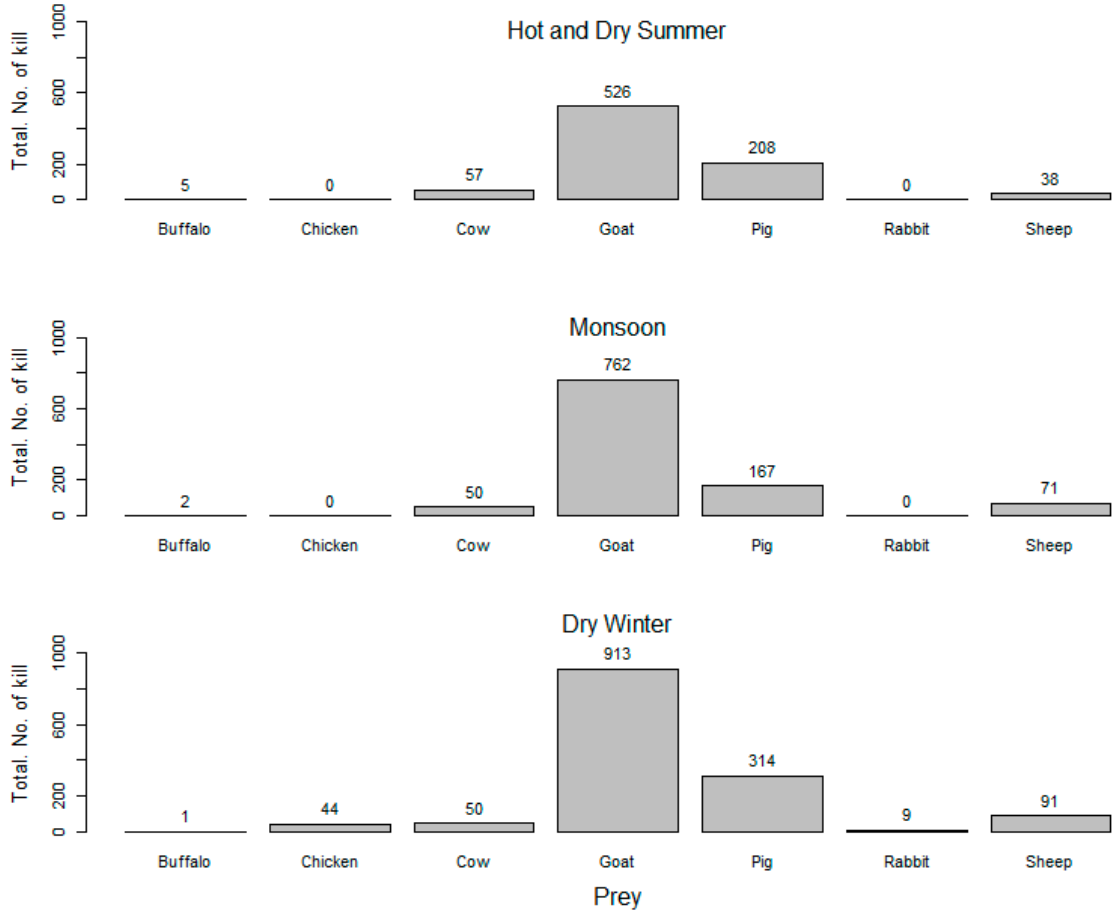

Figure 5. Prey preference of leopards by season.

3.4. Livestock Depredation Trend

The park recorded 2652 attacks on livestock by leopards during 2000–2020 that involved the loss of 3335 livestock with an average of around 160 killings per year (with the highest (500) in 2020 and lowest (8) in 2006). Attack and predation align with each other, following similar trends; however, there was slight decrease in the number of kills from 2013 to 2018 (Figure 6). Over the last decade, attack and predation have been increasing at a higher rate than in previous years.

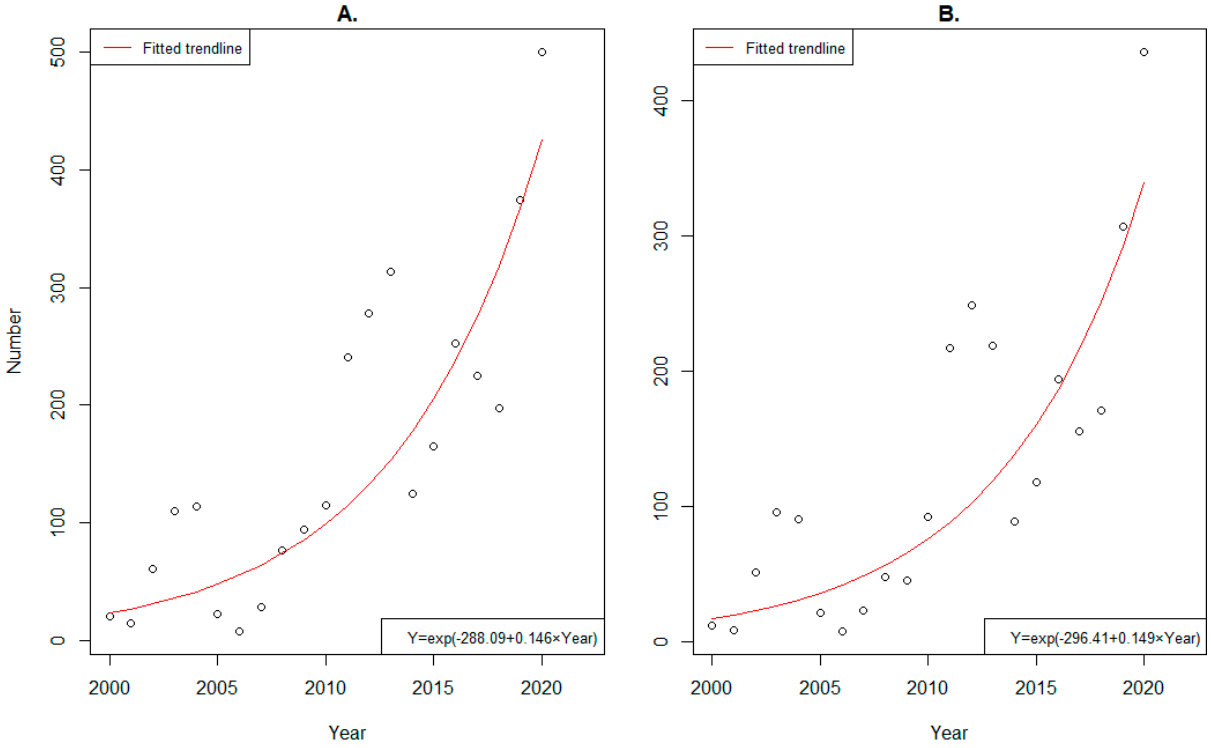

Figure 6. Trend of (**A**) number of livestock depredation cases and (**B**) number of incidents in the study period.

We also analyzed the number of incidents and kills by cluster (Figure 7), which showed that the attacks and predation in the northern cluster are scattered. The western cluster had the highest number of livestock depredation cases, recorded in 2017, whereas the eastern cluster had the highest rate of livestock depredation recorded in between 2000 and 2005. The southern cluster faced highest number of depredation cases over the last two decades. Moreover, in the eastern cluster, the trend of livestock depredation has been fluctuating, with a slight increase in the last five years.

Furthermore, we could not establish any relation of livestock attack by leopards with respect to slope of the park areas (Figure 8). Even for the similar slopes in the southern, eastern and western clusters, there are different patterns of attack by leopards on livestock. However, the northern cluster with higher slopes experienced relatively few attacks compared to the other clusters.

3.5. Compensation Trend

The park authorities have invested more than 7.8 million NRs (approx. USD 80,000, 100 NRS = USD 1.0) for livestock depredation compensation due to leopards in last 20 years. The annual compensation amount has been increasing rapidly, particularly in recent years (Figure 9), and it might increase further in the years to come.

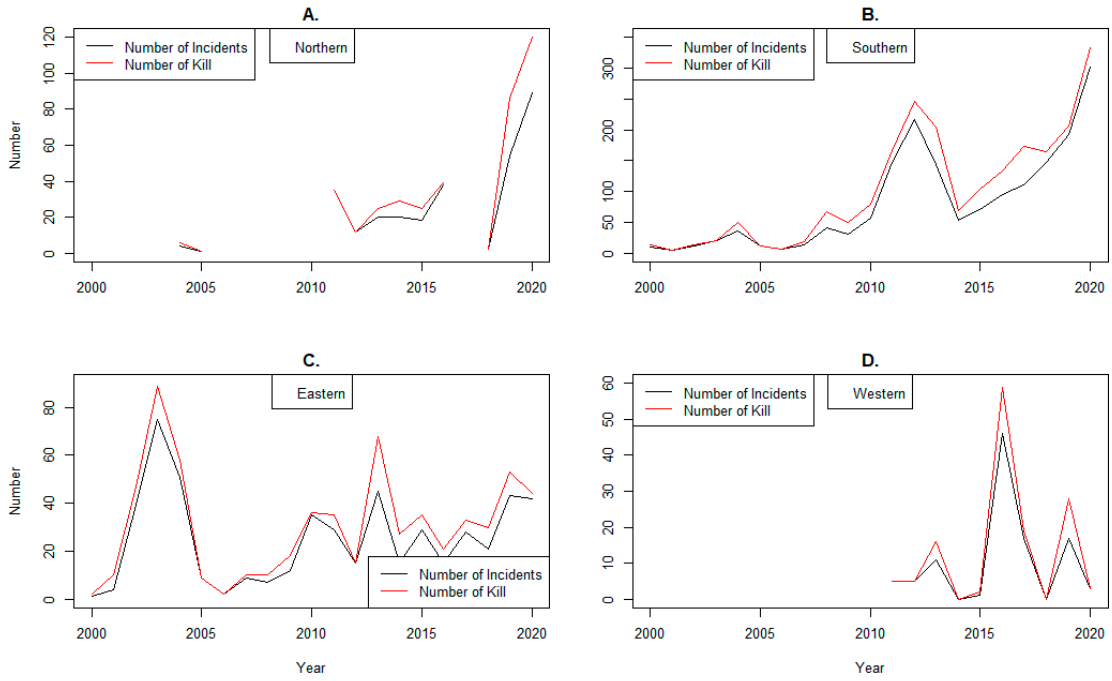

Figure 7. Trend of livestock depredation incidents and number of incidents by cluster. (**A**) Northern; (**B**) southern; (**C**) eastern; (**D**) western.

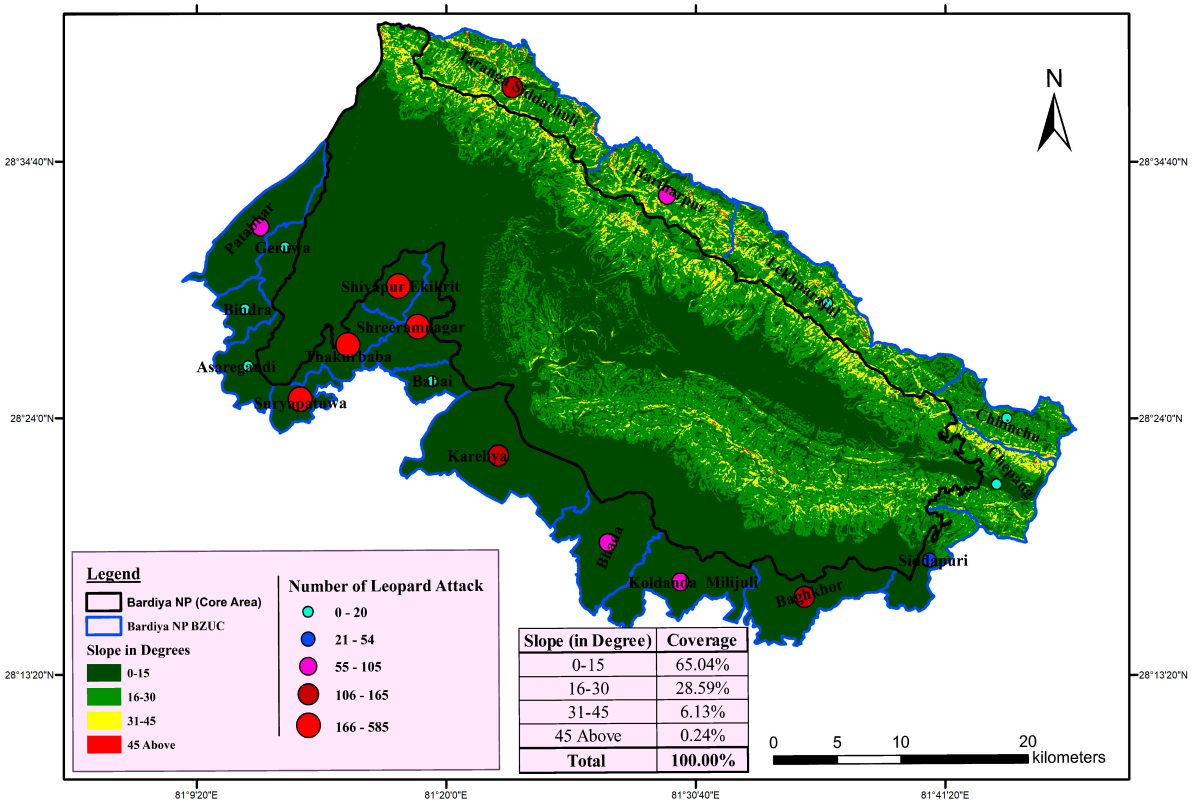

Figure 8. Livestock attacks by leopards as per the slope in BNP.

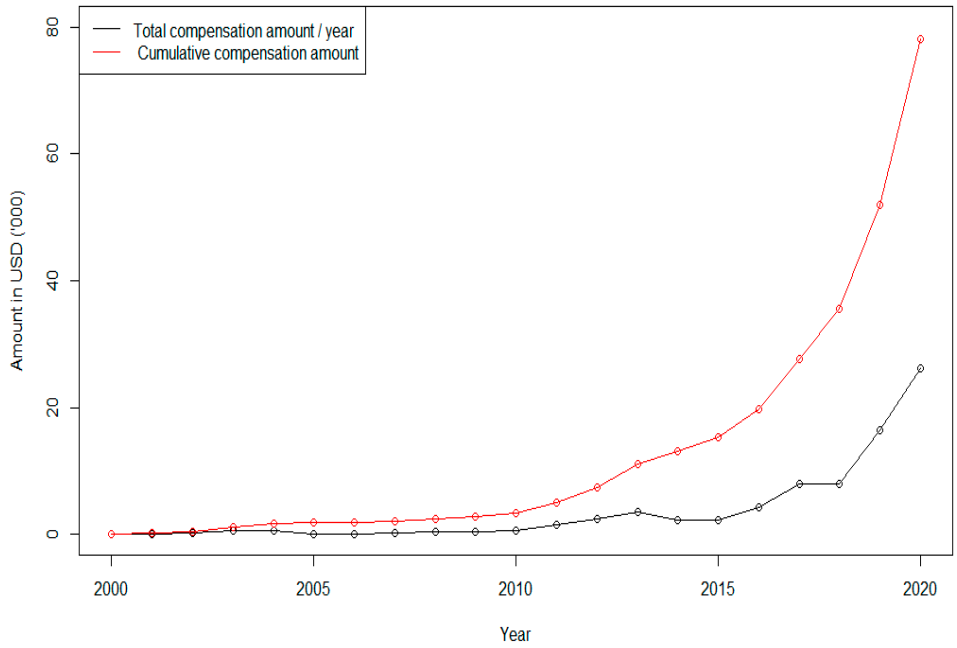

Figure 9. Trend of compensation provided per year in the study period.

The correlation between the number of killings and total amount of compensation per year was tested using Pearson test. The results show that the compensation amount and number of killings are significantly correlated, with a correlation coefficient of 0.85 and p-value of 1×10^{-5} (Figure 10).

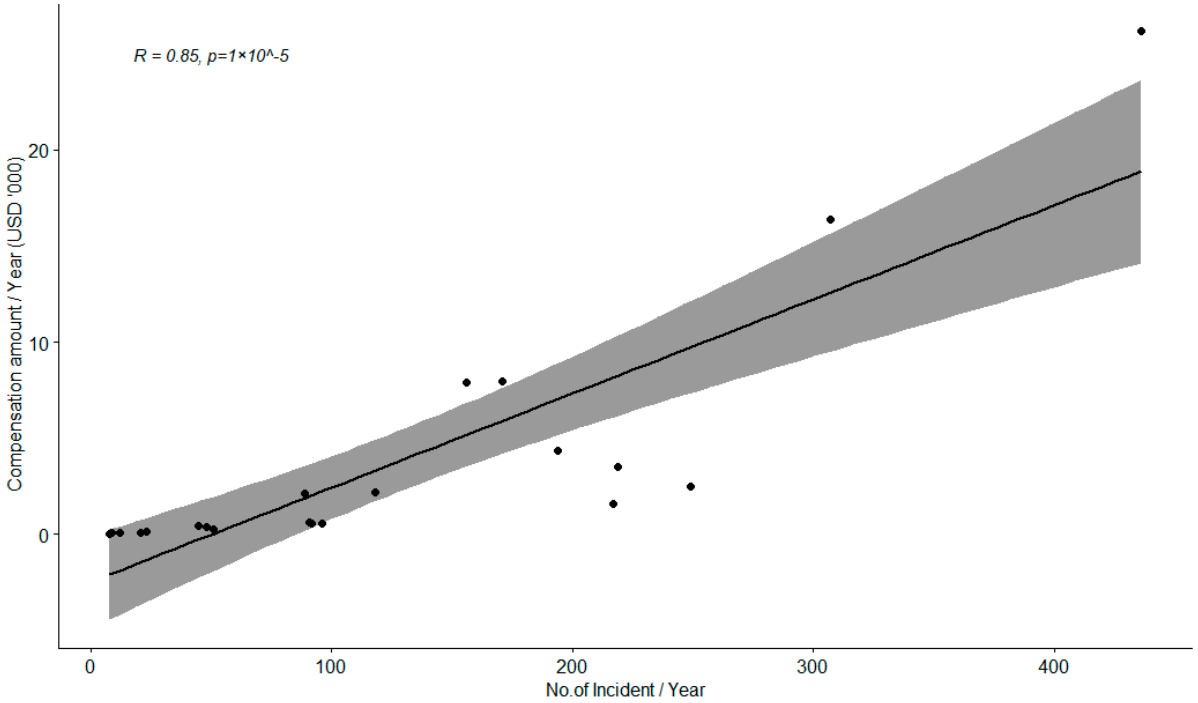

Figure 10. Correlation between compensation amount and number of incidents per year.

4. Discussion

Human–leopard conflict has increased rapidly in Bardia National Park in the last two decades, which is a similar finding to that of [19], who also recorded increasing cases of conflict with large carnivores in BNP between 2015 and 2019. This number (160 per year) is higher than that of a similar study in Chitwan National Park, Nepal (123 per year) [46]

and in the Akole taluka landscape of Maharashtra, in India (81 per year) [47], while lower (263.2 ± 9.9 per year) than that of a study in Corbett Tiger Reserve, Uttarakhand, India [48]. The reason for the low predation rate in Nepali protected areas can be attributed to the prevalent system of restricted grazing inside the core area, different from the free grazing system in India [46,49,50]. In addition, livestock rearing in communities near the park boundary is related to subsistence livelihood, restricting the number of livestock per household.

Similarly, the higher number of livestock depredation by leopards in BNP could be associated with competition for prey between leopards and tigers due to the increased tiger population in BNP [43]. The population density of tigers has doubled in BNP from ~3 adult individuals/100 km^2 in 2013 (95% CI, 3.02–3.7) [51] to ~7 adult individuals/100 km^2 in 2022 (95% CI, 6.47–7.94) [52], perhaps displacing leopards towards the periphery of the park [53], where prey are limited in number and livestock often graze, creating opportunity for livestock depredation [54]. Leopards tend to avoid bigger carnivores such as tigers [55] and are often displaced towards the edges of forests [56] to avoid social interference [54], as also reported in Chitwan National Park [46] and Macharia National Park, Pakistan [57].

Similar instances of higher livestock depredation in the winter season were recorded in Gir National Park and Sanctuary, Gujarat, India [58], in North Bengal [59] and Chitwan National Park, Nepal [46]. Unlike our finding, [20] reported that in the eastern and western areas of Bardia National Park, overall higher livestock depredations from tigers and leopards were reported during the summer and spring. In winter, livestock are kept together with restricted movement in the corrals with low walls to prevent cold weather, increasing vulnerability and thus increasing predation chances [19,60]. In addition, leopards, as a nocturnal predator, get plenty of time for attack during winter, when nights are longer and livestock are unattended [57], resting or less vigilant [61]. Thus, we can observe higher kills per incident. We also observed no prominent difference among the seasons of predation by leopards. This might be because of the increased population of the main competing predator (tigers) [42] and competition between tigers and leopards creating high predation pressure for prey inside the core area of the park [43], where leopards are displaced to the park's periphery. In addition, livestock are easily available food for leopards displaced to buffer zones, which often act as extended habitat providing secondary cover for free ranging carnivores such as leopards.

Leopards highly predated small-sized livestock (95.77%, n = 3194). Among the small-sized livestock, goats experienced the largest amount of predation (66.93%, n = 2232). Studies [21,33,34,46,48,56,57], have reported similar results, showing leopards prefer small-sized livestock, with goats being the most predated one. Leopards tend to attack smaller-sized livestock as they are easy to attack and wound with less energy [62]. In addition, livestock with a small body size are easy to drag quickly to safer zones after the attack has taken place [15,57]. High predation on goats can also be attributed to their high abundance, relatively, around the buffer zone communities [56].

We could not establish any existing relationship of leopard attack with the slope. This aligns with a previous study [63], which depicted the slope as the least important predictor among the most driving variables for leopard movement and livestock conflict by leopards [63]. The presence of other physical barriers such as rivers (Karnali and Babai), roads, and settlements might have played an important role as well. The southern part of BNP was the most vulnerable, accounting for 64% of the total predation, which is consistent with a similar study conducted in Bardia National Park [51]. As the southern part is connected to the Katarniyaghat Wildlife Sanctuary of India in the south through the Khata corridor, there has been an increase in wildlife movement in recent years, with frequent encounters occurring with livestock and human beings [64]. The number of incidents and kills in the northern part of the BNP is relatively low as we based our study only on compensation claim files. The authors of [19] reported more than 1476 livestock depredation cases by leopards from 2015 to 2019, which is higher than our result. As the northern part of the buffer zone is quite far from park headquarters, the complex and

convoluted compensation process can be another reason for opting not to file compensation process [65], consequently resulting in fewer reports of livestock depredation by leopards.

The compensation strategy was designed to minimize HWC through increase in the tolerance level of the community [66]. BNP distributes compensation based on the government of Nepal's relief distribution promulgated in 2009. In the last two decades, BNP has already spent approximately USD 80,000 for livestock depredation by leopards. Other predators such as tigers also inhabit this park and crop raiding by herbivores is common, ballooning the compensation amount. If the depredation rate follows a similar trend, it is safe to assume the need of much larger compensation amounts in the coming years to sustain the leopard population in BNP. However, an increase in the number of attacks reported to park authorities for compensation can be related to the compensation scheme. There is a strong correlation between the number of attacks reported to park authorities for compensation and the actual number of incidents. The compensation amount is calculated by summing the amounts distributed for each incident, with different rates of compensation depending on the type of livestock killed. As the number of incidents and total compensation amount are interdependent, establishment and implementation of a compensation scheme has led to an increase in the number of incidents reported for compensation. Therefore, it is essential to have a robust and efficient monitoring mechanism to prevent false claims.

Human–wildlife conflicts are unavoidable. Thus, a win–win situation with a favorable environment and facilitative interaction is required for coexistence [39,67]. Park has been working to minimize the conflict through support for the construction of concrete wall, mesh wire fencing and electric fencing around the settlement, and changing cropping patterns. However, long-term solutions are needed to address the conflict. For a better scenario, we recommend strategies to improve the wild prey density inside the park by improving the prey's habitat. If the prey is easily available inside the park, the predation outside can be reduced. In combination with these strategies, livestock in the nearby communities needs security and guards with properly lighted and improved corrals. The national park can provide local communities with a livestock insurance scheme, which can offset the economic losses caused by leopard predation, resulting in a reduction in compensation claims. Moreover, the park shall look beyond the national strategies and develop its cluster-specific management plans, incorporating the ideas to address ongoing scenario of livestock loss. These plans must balance economic, political and participatory approaches to avoid exacerbating livestock depredation and other conflicts [68].

In addition, compensation payment creates a substantial economic burden on the park and the nation. In contrast, it is not able to ensure the desired tolerance towards wildlife damage as the amount is not enough and entails a long, tedious process [39,66,67]. A study showed that, on average, the payments are received after more than half a year of the incident in Chitwan National Park [39], and all the processes for compensation application are also same in the Bardia National Park. Thus, financial compensation is only a temporary solution [11] and there is an utmost need to find locally efficient strategies beyond compensation.

We obtained the aforementioned results based only on the compensation request filed. This may not exactly reflect the actual scenario, as few cases might not have been recorded due to various reasons such as difficulty in locating and verifying carcasses [21], the tedious process of filing for compensation [66] and distance to the park headquarters. In addition, we did not record incidents outside the national park, as Division Forest Office is responsible for handling such compensation requests. Furthermore, the practice of recording GPS points of leopard attacks has recently been initiated. However, the unavailability of coordinates of leopard attacks during most of the study period can also be a limiting factor with regard to establishing the relation of attack with the slope. There is a need for more robust techniques to record the conflict from all locations that will allow the park authorities to locate the movement of the wildlife of high significance, which frequently encounters the communities living around the park.

5. Conclusions

Leopards predated mostly on small-sized livestock, with an increasing exponential trend where most predation was in the winter season. This study recorded most attacks in the southern cluster of the park, with no relation of attack to the slope. The compensation amount is mounting, and it is not a long-term solution to mitigate the conflict. Wildlife and cluster-specific conflict management plans are required to cover insurance schemes, changes in feeding patterns, and strengthening corral systems. Moreover, the escalating trend of conflict can be minimized by efficient prey availability inside the core area via reduced competition with other predators in the park.

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