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Original investigation

Livestock depredation by leopards around Chitwan National Park, Nepal

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ABSTRACT

Leopards are known to prey on livestock throughout their range. Depredation of livestock makes leopards vulnerable to retaliatory killings and reduces public support for conservation. We examined spatiotemporal patterns, correlates, as well as economic losses and compensation paid for livestock depredation by leopards in buffer zone of Chitwan National Park, Nepal during 2007–2016. Records of compensation applications filed by livestock owners with the park and buffer zone authorities were collected and then triangulated through a questionnaire survey (n = 123). Of the 424 livestock that were reportedly killed by leopards, goats were disproportionately represented (87.3%), 20% more than expected from their relative livestock population, followed by pigs (8.7%) and cattle (4%). A conflict map prepared depicted d̈epredation hotspotsänd clustering of incidents in certain parts of the area. There was a general decrease in livestock killings during the ten-year period. The killings varied significantly among years and months, but not among seasons. None of the examined factors namely, human population (abundance), livestock population (abundance), forest area in buffer zone, national park boundary (defined as the length of buffer zone user committee border abutting the park), livestock depredation by tigers, rainfall, and temperature were correlated with livestock depredation. Depredation by leopards resulted in a total economic loss of US$ 24,621 ($2462 per year) and compensation amounted to a total payment of US$ 19,719 ($1972 per year). We suggest improved husbandry practices, promotion of livestock insurance scheme, and conservation education for vulnerable communities in buffer zone.

Introduction

Human-carnivore conflict is one of the most challenging aspects of carnivore conservation worldwide (Treves and Karanth, 2003; Khorozyan et al., 2015). Conflict occurs when carnivores pose a direct threat, real or perceived, to humans and livestock (Treves and Karanth, 2003; Inskip and Zimmermann, 2009) resulting in human and livestock losses. As a consequence, conflict is a primary driver of the global decline in large carnivores affecting a wide range of mammalian carnivores (Graham et al., 2005; Michalski et al., 2006; Inskip and Zimmermann, 2009; Ripple et al., 2014).

Among the big cats ranging across most of Africa and Asia, the leopard is the most adaptable and widely distributed species (Nowell and Jackson, 1996). Leopards now occupy 25–37% of its historic range (Jacobson et al., 2016). Despite large range and high adaptability, the IUCN Red List assessment (2016) has categorised the species as v̈ulnerablëdue to >30% global decline over three generations (www.iucnredlist.org/species/15954/102421779, accessed on December 22, 2018) resulting from habitat loss, hunting, prey depletion and conflict with humans (Ripple et al., 2014; Jacobson et al., 2016). But locally some populations may have remained stable or even increased.

Leopards are widely distributed across Nepal, occurring from the lowland Terai (<100 m) to the Himalayan highlands (>4000 m). They occupy a wide range of habitats, including the tall grasslands of Terai, dense or sparse forests in the tropics, temperate, and alpine

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regions, scrubs, and mountain cliffs. A large part of their range falls outside protected areas where they occur in forests and forest corridors, and occasionally in agricultural areas like banana and sugarcane plantations. Historically, leopards were extensively distributed across Nepal, but due to human disturbance, their habitats got shrunken (Thapa, 2011). However, different habitat restoration measures, including the effective management of protected areas, forest patches and corridors, as well as community forestry programs, implemented since the 1990s, provided additional habitat for leopards. Consequently, human-leopard conflict has been currently one of the most frequent human-carnivore conflicts recorded in Nepal (Lamichhane et al., 2018).

Chitwan National Park (CNP) has one of the largest leopard populations in Nepal with an estimated size of 66-105 individuals in 2013 estimated using camera trap with capture-recapture method (Lamichhane et al., 2019). Leopards in and around CNP occur sympatrically with other carnivores, such as the tiger *Panthera tigris*, the Asiatic wild dog *Cuon alpinus*, the striped hyena *Hyaena hyaena*, the clouded leopard *Neofelis nebulosa*, the jungle cat *Felis chaus*, the fishing cat *Prionailurus viverrinus*, and the golden jackal *Canis aureus*. Leopards in CNP feed primarily on wild animals: — ungulates (78%), birds and rodents (6%), and primates (4%), with domestic animals constituting 12% of their local diet (Thapa, 2011).

As tigers occupy prime habitat, leopards are often pushed into marginal forests to avoid direct competition (Odden et al., 2010; Harihar et al., 2011). This scenario might contribute to increased livestock depredation in peripheral areas (Odden et al., 2010) resulting in resentment among local people leading to retaliatory killing of leopards (Khan et al., 2018), and their removal by authorities. Peripheral areas may function as population sinks resulting in the decline or extinction of carnivore populations (Woodroffe and Ginsberg, 1998).

To address human-carnivore conflict, an explicit understanding of patterns of livestock depredation is crucial (Dar et al., 2009) to identify regions and periods with high levels of depredation. Ecological, social, and meteorological attributes of depredation incidents as well as economic losses from depredation and associated compensation payments need to be assessed (Michalski et al., 2006; Goodrich, 2010; Dhungana et al., 2018). Considering their relative abundance compared to tigers, and being unplaced in protected species list category in Nepal's National Parks and Wildlife Conservation Act, 1973 leopards are of low conservation priority, hence, studies on their ecology, population status, and human-leopard conflict are limited in Nepal (Thapa, 2011) hindering the development of effective conservation and conflict management strategies for leopards.

Thus, we investigated the (1) spatiotemporal patterns of livestock depredation by leopards, (2) social and environmental correlates associated with livestock depredation, and (3) economic losses incurred and associated compensation payments, in the Buffer Zone User Committees (BZUC) of CNP across one decade (2007–2016). Regarding correlates, we predict that higher level of livestock depredation by leopard would occur in areas with: — (1) larger human population (abundance), (2) larger livestock population (abundance), (3) higher forest area in the buffer zone, and (4) longer national park boundary (Gubbi, 2012; Dhungana et al., 2018) as well as (6) lower level of livestock depredation by tigers because there exists inverse relationship between tiger and leopard densities (Harihar et al., 2011). Similarly, we expected higher depredation during periods of higher temperature (Dar et al., 2009), and of lower rainfall because of probable reduction in plant productivity and consequently wild prey biomass.

Study area

CNP established in 1973, is the first protected area in Nepal. Located in the southern part of central Nepal along the Nepal-India border (Fig. 1), it covers an area of 953 km^2 and borders Parsa National Park in the east and Valmiki Tiger Reserve (India) in the south. The park was declared as UNESCO World Heritage Site in 1984. It is a global biodiversity hotspot that supports the natural ecosystem of the Terai region, providing habitat for several globally endangered species including the tiger, Asian elephant *Elephas maximus*, one-horned rhinoceros *Rhinoceros unicornis*, and gharial crocodile *Gavialis gangeticus*. Nearly three-quarters (73%) of the park are occupied by Sal *Shorea robusta* forests, followed by grasslands (12%), and riverine forests (7%) (Thapa, 2011).

We conducted this study in the park's officially designated buffer zone, extending approximately 5 km from the boundary (Fig. 1). Approximately 30–50% of CNP's revenue is shared among the adjoining communities. The buffer zone initially designated in 1996 encompassing an area of 750 km^2 comprises forests, farmlands, and human settlements. Currently, the buffer zone spans 729 km^2, following the exclusion of 21 km^2 area in core zone in 2016. The buffer zone has been divided into 22 BZUC as management units which are demarcated considering socio-environmental factors (Fig. 1) for mobilization of resources and people towards its conservation. It serves as a source of forest resources for local people as well as wildlife habitat, providing corridors for wildlife movement from the park into adjoining landscapes and vice versa. Main livestock species reared include goat, pig, cattle, buffalo, and sheep. While stall feeding of livestock is on rise, guarded open grazing is practiced mostly in public lands around villages. Smaller stocks such as goat, pig, and sheep are usually kept in pens at night whereas cattle and buffalo are kept on open sheds. Improved breeds are replacing native breeds. The majority of local people are subsistence farmers who depend heavily on forests for agriculture and livestock husbandry (Dhungana et al., 2016), which form important means of livelihood and rural income.

Methods

Spatio-temporal patterns and mapping of livestock depredation by leopards

We collected data on livestock depredation by leopards in the park's buffer zone for 2007–2016. We obtained data on reported incidents of livestock attacks by leopards and compensation payments from the CNP office and buffer zone management committee (Gubbi, 2012; Dhungana et al., 2018; Lamichhane et al., 2018). Data included the type of livestock killed (goat, pig, and/or cattle), date, and location (specific BZUC). A mechanism with clear methodologies has been established in CNP to validate attacks, estimate the value of killed livestock, and process compensation applications so as to avoid false claims and exaggerations (Dhungana et al., 2016). Following Dhungana et al. (2016), we used questionnaires to triangulate and augment data for 29% of the livestock owners claiming losses to leopards (n = 123), randomly chosen over a seven month period (April–October 2017).

We used ArcGIS 10.3 (ESRI, Redlands, USA) to generate a conflict map using data from the Department of National Parks and Wildlife Conservation, highlighting the spatial distribution and extent of livestock depredation. Using the number of livestock depredation events as a proxy, we categorized and mapped the BZUC according to very high (>50), high (11–50), low (1–10) and no depredation (Dhungana et al., 2018). Based on the relative availabilities of livestock (abundance) in BZUC, sourced from a 2011–2012 census (CBS, 2013), we used a χ^2 Goodness-of-Fit test to examine spatial pat-

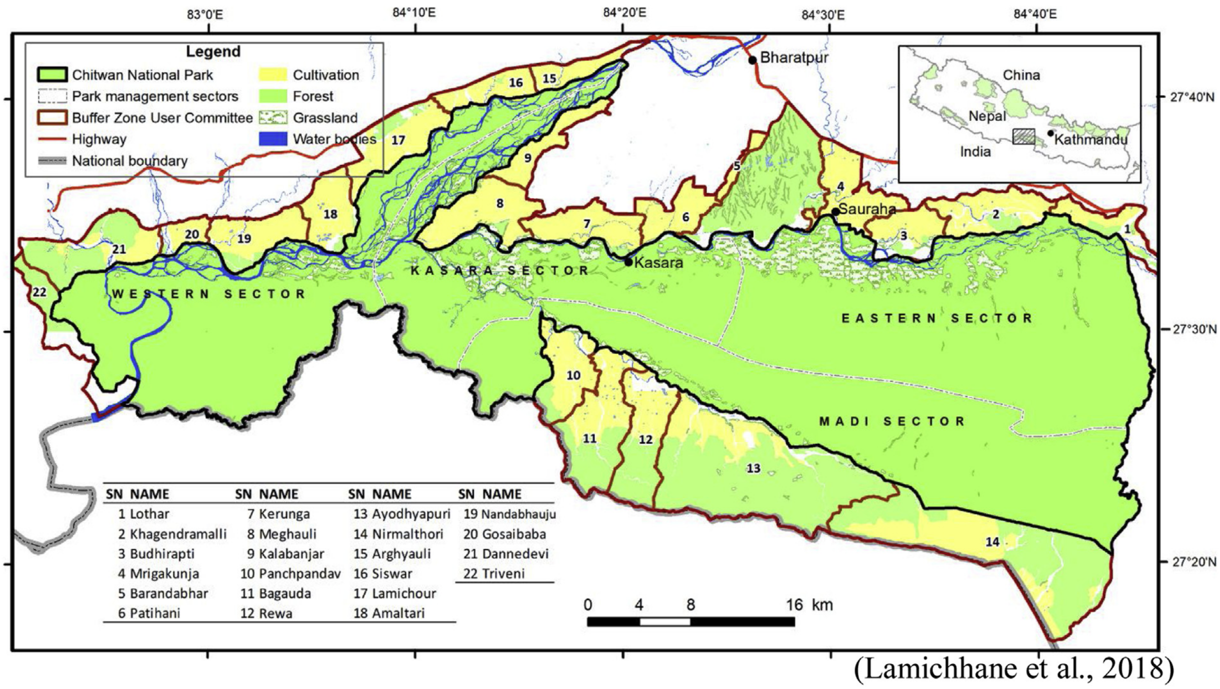

Fig. 1. Map of Chitwan National Park and adjoining buffer zone showing land cover, management sectors and 22 buffer zone user committees.

terns of livestock depredation among these BZUC. We defined the BZUC with very high depredation as depredation hotspots.

We used simple linear regression to examine the trend of livestock depredation across years and χ^2 tests to examine changes in livestock depredation: during 2007–2011 and 2012–2016, as well as yearly, seasonal (summer, 16 February–15 June; monsoon, 16 June–15 October; winter, 16 October–15 February), and monthly variations. We also used the χ^2 test to investigate whether losses of goat, pig and cattle were proportional to their relative availabilities in the buffer zone, as recorded during a 2011–2012 census (CBS, 2013). We used the Bonferroni confidence interval method to determine which of the three livestock species suffered losses significantly different than expected from relative availabilities, and calculated their percentage deviation from expected rates (Iliopoulos et al., 2009).

Correlates of livestock depredation by leopards

We used Central Bureau of Statistics (CBS, 2012) data from the 2011–2012 census to define human populations for each BZUC. We computed the total livestock population, comprising goats, pigs and cattle in each BZUC by converting their respective densities in the corresponding district recorded during 2011–2012 census (CBS, 2013). Using ArcGIS 10.3, we defined forest area (km^2) and national park boundary (km) for each BZUC from 2011 topographical maps obtained from the Department of National Parks and Wildlife Conservation. We collected data on livestock (goats/sheep, pig, cattle and buffalo) depredation by tigers in each BZUC during 2007–2016 from CNP records and Dhungana et al. (2018). For the entire study period (2007–2016), we collected rainfall and temperature data from Rampur weather station (Department of Hydrology and Meteorology), located approximately 10 km from CNP.

We used Spearman's rank correlation to investigate the bivariate relationship between the number of livestock depredation incidents in the BZUC and other variables, including human population, total livestock population (goat, pig and cattle), forest area in the BZUC, national park boundary (Gubbi, 2012), and livestock depredation by tigers as well as mean monthly rainfall, annual rainfall, and mean monthly temperature for 2007–2016. Additionally, using R v. 3.2.3 (R Development Core Team, 2015) we did generalized linear models to investigate the multivariate relationship between the number of livestock depredation and all aforementioned independent variables.

Economic losses and compensation payments made towards livestock depredation

Compensation applications also included information on the amount of compensation claimed based on market price. We triangulated and augmented these data by surveying 29% of randomly selected owners who lost livestock to leopards (n = 123). Economic losses and compensation payments were summed for each year (considering incident date) and converted to US$ using the mean currency conversion rates from Nepalese Rupees to US$ in each particular year (Gubbi, 2012).

Results

Extent and nature of livestock depredation

During 2007–2016, a total of 424 livestock, including goats, pigs and cattle were reportedly killed by leopards in the buffer zone around Chitwan National Park (Table 1). Leopards primarily killed goats (87.3%), followed by pigs (8.7%) and cattle (4.0%). Three buffalos and one sheep were also killed by leopards, but were excluded from the analysis for being too small figures to include in statistical investigation. Moreover, eleven people were injured during leopard attacks between 2007–2010. Livestock losses to leopards varied significantly among species when compared to expected depredation as determined by their relative availabilities ($\chi^2 = 101.9$, df = 2, $P < 0.001$). Bonferroni confidence interval analysis revealed that goats, pigs and cattle were not killed in proportion to their relative availabilities. Goats were killed 20% more than expected, pigs 113.3% more than expected, whereas cattle were killed 82.7% less than expected ($P < 0.01$).

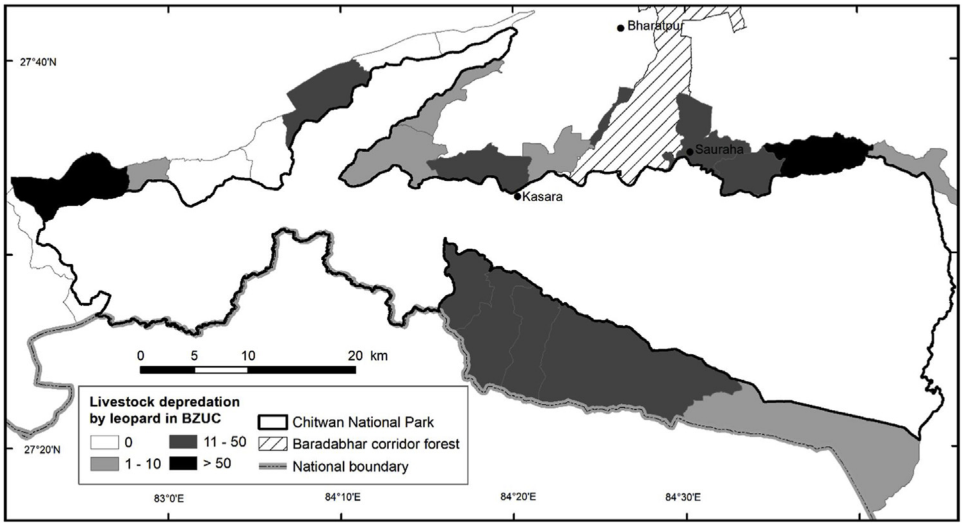

Fig. 2. Intensity of livestock depredation by leopards in Buffer Zone User Committees (BZUC) around Chitwan National Park, 2007–2016.

Table 1
Annual livestock depredation by leopards around Chitwan National Park, 2007–2016.

Year	Livestock type			
	Goat	Pig	Cattle	Total
2007	55	0	0	55
2008	54	6	0	60
2009	72	5	1	78
2010	36	13	3	52
2011	15	3	0	18
2012	12	2	0	14
2013	20	4	0	24
2014	41	2	3	46
2015	35	0	3	38
2016	30	2	7	39
Total	370	37	17	424

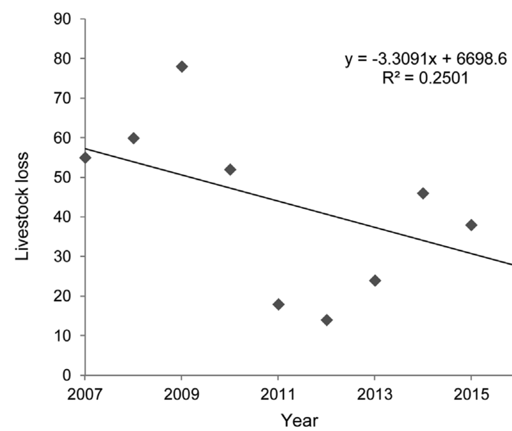

Fig. 3. Trend in livestock losses from leopards around Chitwan National Park, 2007–2016.

Spatial patterns of livestock depredation

The intensity of livestock depredation varied significantly across the buffer zone, with more clustering in some defined areas. The livestock depredation in the BZUC varied significantly as expected from relative livestock availabilities of these committees ($\chi^2 = 1010.8$, df = 21, $P < 0.0001$). Of the 22 BZUC, 17 experienced livestock depredation (mean = 24.9 livestock heads, range = 1–68) over the ten-year period. Two BZUC suffered very high livestock depredation (>50), 11 suffered high depredation (11–50), four had low depredation rates (1–10), no depredation by leopard was recorded in the remaining five (Fig. 2). The two BZUC with very high depredation (Daunnedevi — located in western area, n = 68; and Khagendramalli — located in eastern area, n = 55) were identified as depredation hotspots; cumulatively they accounted for 29% of all losses. In Daunnedevi, observed depredation was 150.1% higher than expected, whilst losses were 241.5% more than expected in Khagendramalli. The Barandabhar BZUC located in the extreme north-west from Barandabhar corridor forest, (see Figs. 1 and 2) experienced a 1448.2% higher livestock depredation than expected.

Temporal patterns of livestock depredation

During 2007–2016, leopards killed a mean of 42.4 livestock per year (SD ± 19; range = 14–78). Simple linear regression showed a decreasing, yet non-significant trend of livestock depredation during the period ($R^2 = 0.25$; $P > 0.05$; Fig. 3). Nevertheless, the number of livestock killed dropped significantly from a mean of 52.6 per year (SD ± 21.8; range = 18–78) during 2007–2011 to 32.2 per year (SD ± 12.4; range = 14–46) during 2012–2016 ($\chi^2 = 24.5$; df = 1; $P < 0.001$). Livestock depredation varied significantly among months ($\chi^2 = 56.1$, df = 11, $P < 0.001$; Fig. 4), showing bimodal pattern. Peaks occurred during June-July as well as November-December, which accounted for 23.3% (n = 99) and 25.9% (n = 110) of all losses, respectively. The lowest number of losses (n = 19) was observed in February. Livestock losses varied significantly among years ($\chi^2 = 100.7$, df = 9, $P < 0.0001$), but not among seasons ($\chi^2 = 1.2$, df = 2, $P > 0.05$). Summer, monsoon and winter seasons experienced 31.8%, 32.3% and 35.9% of livestock depredation respectively. Cumulatively, Patihani, Barandabhar and Mrigakunja BZUC, which surround the Barandabhar corridor forest (Figs. 1 and 2) experienced 54 (83.1%) depredation incidents between 2014–2016 compared with a total of 65 incidents during the ten-year period.

Correlates with livestock depredation

The frequency of livestock depredation by leopards around the park did not correlate significantly with any of the factors examined; i.e. human population, livestock population, forest area in the

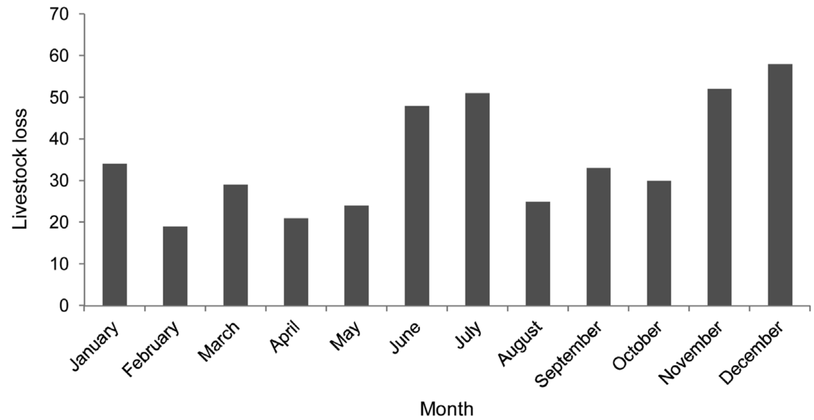

Fig. 4. Monthly livestock losses by leopards around Chitwan National Park, 2007–2016.

Table 2
Spearman Rank Correlations (r_s) between livestock depredation frequency and independent variables.

Variable	r_s	P	n
Human population	−0.02	0.93	22
Livestock population	0.15	0.49	22
Forest area in buffer zone	0.24	0.28	22
National park boundary	−0.16	0.46	22
Livestock depredation by tigers	−0.25	0.26	22
Monthly rainfall	−0.14	0.66	12
Annual rainfall	0.43	0.21	10
Monthly temperature	−0.12	0.72	12

None of the variables were significant at P = 0.05.

buffer zone, national park boundary, and livestock depredation by tigers as well as monthly rainfall, yearly rainfall and monthly temperature (Table 2). Generalized linear models found that none of the examined factors were significantly associated with frequency of livestock depredation by leopards (P > 0.2, for each variable).

Economic losses and compensation payments made towards livestock depredation

Livestock depredation by leopards resulted in a total economic loss of US$ 24,621 ($2462/year; SD ± 1109.8, range = $920–$4316.9) during the study (Table 3). The majority of losses were incurred by goat depredation (85.5%), followed by pigs (9.3%), and cattle (5.2%). During the ten-year study, a total compensation payment of US$ 19,719 ($1972/year; SD ± 1018.2, range = $887.6–$3774.1) was made towards livestock depredation by leopards (Table 3), covering 80.1% of reported losses. Of all depredation incidents, 55.9% were fully-compensated, 42.5% were partially-compensated, whereas seven incidents (1.6%) were not compensated.

Discussion

Most areas surrounding protected areas in Nepal have witnessed livestock killings by carnivores. Our spatial analysis showed a strong variation in the frequency of leopard attacks across the buffer zone of CNP, with no livestock losses in some BZUC to a maximum of 68 losses in others. We identified two ¨depredation hotspots¨— Daunnedevi in the west and Khagendramalli in the east (Figs. 1 and 2). In accordance with that reported by Michalski et al. (2006), the higher depredation recorded in Daunnedevi may have been aided by its greater forest coverage (65.3%, mean = 22.1%) connecting the park with the forested areas outside the buffer zone which could facilitate frequent leopard movements (RD, Pers. obs.). However, in Khagendramalli forest cover is low (12.4%, mean = 22.1%) reflecting a lower abundance of wild prey. In this hotspot, tiger density and habitat quality factors might have played more significant role. The reduced availability of wild prey have been suggested as the cause switching leopard diet to secondary (i.e. domestic) prey species in the buffer zone (Khorozyan et al., 2015) leading to higher levels of livestock depredation. The three BZUC, Patihani, Barandabhar, and Mrigakunja, surrounding the Barandabhar forest corridor (Figs. 1 and 2) suffered significant increases in livestock depredation in recent years, with 83.1% of all reported incidents occurred during 2014–2016. During this period, the resident tiger population in Barandabhar forest increased from four to eight individuals (National Trust for Nature Conservation, unpublished data) which might have pushed leopards to the Barandabhar edges resulting in elevated conflict levels. As detailed GPS locations of depredation sites were not available, we could not present the results in finer spatial scale. Instead, we used BZUC-wise data for depicting results.

Our study showed that leopards mostly depredated smaller stocks, such as goats (87.3% of all killings) during 2007–2016 comparable to that reported in other areas (Sangay and Vernes, 2008; Dar et al., 2009). Goats in CNP accounted for 55% of all livestock depredation by tigers during 2007–2014 (Dhungana et al., 2018). Although leopards prey on a wide range of species, from arthropods to adult sambar (*Rusa unicolor*) or gaur (*Bos gaurus*; Seidensticker, 1976), they generally prefer prey species weighing between 10–40 kg (Hayward et al., 2006) and 2–25 kg (Lovari et al., 2013). The optimal body size of goats (5–25 kg; Lovari et al., 2013) combined with their high abundance in the whole livestock population found around CNP (72.7%), their non-defensive behaviour, and the relative ease of killing and dragging them may have contributed to higher rate of goat depredation. Similar to our results of under-killing of cattle (4%), whose weight exceeds the optimal body size preferred by leopards (Hayward et al., 2006; Lovari et al., 2013), has been reported in Bhutan, India, Nepal and Pakistan (Sangay and Vernes, 2008; Tamang and Baral, 2008; Athreya et al., 2014; Khan et al., 2018).

Livestock depredation peaked bi-modally during the year, during June-July and November–December, as is comparable to that reported in Bhutan and Pakistan (Sangay and Vernes, 2008; Dar et al., 2009). Both periods correspond with peak agricultural farming when farmers are highly engaged in crop production leaving their livestock unattended or poorly guarded (Sangay and Vernes, 2008). Maclennan et al. (2009) reported negligent herding as main cause of losses to predators. More importantly, June-July coincides with the highest mean monthly rainfall (June = 311 mm, July = 490 mm; 2007–2016 mean = 157 mm) resulting in increased intermediate cover such as shrub and under-story growth that provides stalking cover for leopards (Balme et al., 2007) as reported

Table 3
Annual economic losses from livestock depredation by leopards around Chitwan National Park during 2007–2016, and associated compensation payments.

Livestock type	Amount (US$)	Year										Total (US$)
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Goat	Economic loss	1804.5	1980.0	3397.6	1614.8	817.6	677.3	1398.5	3911.0	3055.3	2393.3	21049.8
	Compensated	887.6	989.8	2727.1	1605.0	815.6	672.9	1264.1	3368.2	2527.6	2045.6	16903.5
Pig	Economic loss	0.0	193.6	154.5	632.8	102.7	358.9	537.9	171.1	0.0	138.9	2290.5
	Compensated	0.0	96.8	77.3	564.3	102.7	195.6	342.3	171.1	0.0	41.1	1591.2
Cattle	Economic loss	0.0	0.0	34.2	156.5	0.0	0.0	0.0	234.7	268.9	586.8	1281.2
	Compensated	0.0	0.0	17.1	136.9	0.0	0.0	0.0	234.7	268.9	567.2	1224.9
Total economic loss		1804.5	2173.7	3586.3	2404.0	920.3	1036.2	1936.4	4316.9	3324.2	3118.9	24621.4
Total compensated		887.6	1086.6	2821.5	2306.2	918.3	868.5	1606.4	3774.1	2796.6	2653.9	19719.6

in other areas (Patterson et al., 2004; Kolowski and Holekamp, 2006). The least amount of rainfall received in the months of November and December (0.26 mm and 0.49 mm, respectively) suggested that limited fodder was available for stall feeding of livestock, necessitating free grazing in forested areas where livestock are more vulnerable to attacks. Similar case was reported for leopards and tigers in Bardia National Park, Nepal (Tamang and Baral, 2008) and for lions *Panthera leo* in Kenya (Maclennan et al., 2009) where higher livestock losses occurred in drier months. However, in Machiara National Park, Pakistan no relationship between rainfall patterns and livestock depredation existed probably because water was not a limiting resource (Dar et al., 2009).

We found a decreasing trend in livestock depredation with 52.6 losses/year during 2007–2011 to 32.2 during 2012–2016 representing an annual loss to leopards of 0.04% of overall livestock, the lower margin of the global range of 0.02–2.6%/year to carnivores (Graham et al., 2005). The observed decrease in livestock losses might have been mainly contributed by: (1) increasing trend of stall feeding of livestock, (2) introduction of improved breeds (Dhungana et al., 2018), (3) an increase in wild prey densities from 62.6 animals/km^2 in 2008 to 73.6 animals/km^2 in 2013 (Karki et al., 2009; Dhakal et al., 2014), (4) the restriction of free livestock grazing in buffer zone forests, and (5) increased implementation of grassland management (burning, mowing, and cutting or uprooting of woody stems) and wetland management (creation and restoration of wetlands, and removal of invasive alien plant species) interventions inside national parks — likely favouring wild prey and leopard populations through increased availability of food and water resources.

As none of the examined correlates could explain human-leopard conflicts, other variables that were not included in this study should be investigated. A more detailed study of wild prey density, habitat quality, location and health status of problem leopards, leopard displacement from core tiger habitat, and tiger density (Kolowski and Holekamp, 2006; Harihar et al., 2011; Suryawanshi et al., 2013; Dhungana et al., 2018) is suggested. In addition, human disturbance, livestock herd size and livestock husbandry management (Patterson et al., 2004; Michalski et al., 2006; Wang and Macdonald, 2006; Khan et al., 2018) can be important factors. We recommend future studies examine such factors.

Our results only included reported compensation claims. Some claims might not have been filed due to the difficulty of locating carcasses for verification. Nevertheless, fewer incidents should not be overlooked as loss of a single stock can have catastrophic impacts on poor and marginalized households leading people to resent leopards and pursue retaliatory persecution. Six leopards were reportedly killed in retaliation around CNP during 2007 to June 2009 (Thapa, 2011).

In Chitwan, the annual economic loss from livestock depredation (US$ 2462) is lower than the amount reported ($6681) for Jigme Singye Wangchuck National Park, Bhutan (Wang and Macdonald, 2006) with similar area size of about 1700 km^2. However, only 55.9% of the compensation claims around CNP were fully-paid; most were only partially paid. The formulation of wildlife damage compensation guideline in 2009, and its subsequent amendments by government has been important in systematizing the compensation payments. The guideline initially set a compensation limit of compensation to $ 100 per livestock depredation incident. More recently, in 2016, it was increased to $ 300 for individual buffalo and improved breeds of cattle, and $ 100 for other livestock, including goats and pigs. Provision of fair payments for livestock depredation either by government, insurance companies, or other sources can offset the losses incurred by rural subsistence communities. Despite documented allegations of as false claims, negligence to preventive measures, and increased dependency on compensation schemes (Maclennan et al., 2009; Goodrich, 2010), we found no indication of false claims and misconduct by officials and farmers, based on questionnaire survey with livestock owners losing livestock to leopards (n = 123).

In conclusion, from our results, to minimize livestock depredation by leopards in the buffer zone surrounding CNP and long-term conservation of leopards we recommend first a better management of vulnerable livestock by constructing low-cost corrals, improving stock guarding, increasing night vigilance (Dar et al., 2009), providing foxlights or uninterrupted electricity supply for night time lighting and use of deterrence techniques.

Second, formulating and implementing a problem leopard management guideline together with speedy and fair compensation payments and the setting of a livestock insurance scheme (Khan et al., 2018) will minimize retaliatory killing of leopards following livestock losses. Third, implementing conservation education and awareness, greater public access to forest resources, and aligning available conservation benefits (e.g., channelling 50% of park revenues from ecotourism and forest resources back for developing host communities) down up to grassroots level are suggested.

In the end, though leopards can occur in higher densities in areas with abundant availability of domestic animals (Athreya et al., 2014) maintenance of a healthy wild prey base will be a key to reduce conflict (Khorozyan et al., 2015; Khan et al., 2018). Park authorities in collaboration with the communities affected by leopard depredation should formulate and implement a conflict management plan that would help leopard conservation whilst reducing livestock losses.

Declaration of interests

None.

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References

Athreya, V., Odden, M., Linnell, J.D.C., Krishnaswamy, J., Karanth, K.U., 2014. A cat among the dogs: leopard *Panthera pardus* diet in a human-dominated landscape in western Maharashtra, India. Oryx 50, 156–162.
Balme, G.A., Hunter, L.T.B., Slotow, R., 2007. Feeding habitat selection by hunting leopards *Panthera pardus* in a woodland savannah: prey catchability versus abundance. Anim. Behav. 74, 589–598.
CBS, 2012. National Population Census 2011, Household and Population by Sex (Ward Level) Parsa, Makwanpur, Chitwan, and Nawalparasi Districts. Central Bureau of Statistics, Thapathali, Kathmandu.
CBS, 2013. National Sample Census of Agriculture 2011/12, District Summary. Central Bureau of Statistics, Thapathali, Kathmandu.
Dar, N.I., Minhas, R.A., Zaman, Q., Linkie, M., 2009. Predicting the patterns, perceptions and causes of human-carnivore conflict in and around Machiara National Park, Pakistan. Biol. Conserv. 142, 2076–2082.
Dhakal, M., Karki (Thapa), M., Jnawali, S.R., Subedi, N., Pradhan, N.M.B., Malla, S., Lamichhane, B.R., Pokheral, C.P., Thapa, G.K., Oglethorpe, J., Subba, S.A., Bajracharya, P.R., Yadav, H., 2014. Status of Tigers and Prey in Nepal. Department of National Parks and Wildlife Conservation, Kathmandu, Nepal.
Dhungana, R., Savini, T., Karki, J.B., Bumrungsri, S., 2016. Mitigating human-tiger conflict: an assessment of compensation payments and tiger removals in Chitwan National Park, Nepal. Trop. Conserv. Sci. 9, 776–787.
Dhungana, R., Savini, T., Karki, J.B., Dhakal, M., Lamichhane, B.R., Bumrungsri, S., 2018. Living with tigers *Panthera tigris*: patterns, correlates, and contexts of human-tiger conflict in Chitwan National Park, Nepal. Oryx 52, 55–65.
Goodrich, J.M., 2010. Human-tiger conflict: a review and call for comprehensive plans. Integr. Zool. 5, 300–312.
Graham, K., Beckerman, A.P., Thirdgood, S., 2005. Human-predator-prey conflicts: ecological correlates, prey losses and patterns of management. Biol. Conserv. 122, 159–171.
Gubbi, S., 2012. Patterns and correlates of human-elephant conflict around a south Indian reserve. Biol. Conserv. 148, 88–95.
Harihar, A., Pandav, B., Goyal, S.P., 2011. Responses of leopard *Panthera pardus* to the recovery of a tiger *Panthera tigris* population. J. Appl. Ecol. 48, 806–814.
Hayward, M.W., Henschel, P., B'brien, J., Hofmeyr, M., Balme, G., Kerley, G.I.H., 2006. Prey preferences of the leopard (*Panthera pardus*). J. Zool. 270, 298–313.
Iliopoulos, Y., Sgardelis, S., Koutis, V., Savaris, D., 2009. Wolf depredation on livestock in central Greece. Acta Theriol. 54, 11–22.
Inskip, C., Zimmermann, A., 2009. Human-felid conflict: a review of patterns and priorities worldwide. Oryx 43, 18–34.
Jacobson, A.P., Gerngross, P., Lemeris Jr., J.R., Schoonover, R.F., Anco, C., Breitenmoser-Würsten, C., Durant, S.M., Farhadinia, M.S., Henschel, P., Kamler, J.F., Laguardia, A., Rostro-García, S., Stein, A.B., Dollar, L., 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ 4, e1974, http://dx.doi.org/10.7717/peerj.1974.
Karki, J.B., Jnawali, S.R., Shrestha, R., Pandey, M.B., Gurung, G., Thapa, M.M., 2009. Tigers and Their Prey Base Abundance in Terai Arc Landscape Nepal. Government of Nepal, Ministry of Forests and Soil Conservation, Department of National Parks and Wildlife Conservation, and Department of Forests, Kathmandu.
Khan, U., Lovari, S., Ali Shah, S., Ferretti, F., 2018. Predator, prey and humans in a mountainous area: loss of biological diversity leads to trouble. Biodivers. Conserv. 27, 2795–2813.
Khorozyan, I., Ghoddousi, A., Soofi, M., Waltert, M., 2015. Big cats kill more livestock when wild prey reaches a minimum threshold. Biol. Conserv. 192, 268–275.
Kolowski, J.M., Holekamp, K.E., 2006. Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biol. Conserv. 128, 529–541.
Lamichhane, B.R., Persoon, G.A., Leirs, H., Poudel, S., Subedi, N., Pokheral, C.P., Bhattarai, S., Thapaliya, B.P., De Longh, H.H., 2018. Spatio-temporal patterns of attacks on human and economic losses from wildlife in Chitwan National Park, Nepal. PLoS One 3 (4), e0195373, http://dx.doi.org/10.1371/journal.pone.0195373, 1–18.
Lamichhane, B.R., Leirs, H., Persoon, G.A., Subedi, N., Dhakal, M., Oli, B.N., Reynaert, S., Sluydts, V., Pokheral, C.P., Poudyal, L.P., Malla, S., de Ionghe, H., 2019. Factors associated with co[HYPHEN]occurrence of large carnivores in a human-dominated landscape. Biodivers. Conserv, http://dx.doi.org/10.1007/s10531-019-01737-4.
Lovari, S., Ventimiglia, M., Minder, I., 2013. Food habits of two leopard species, competition, climate change and upper treeline: a way to the decrease of an endangered species? Ethol. Ecol. Evol. 25, 305–318.
Maclennan, S.D., Groom, R.J., Macdonald, D.W., Grank, L.W., 2009. Evaluation of a compensation scheme to bring about pastoralist tolerance of lions. Biol. Conserv. 142, 2419–2427.
Michalski, F., Boulhosa, R.L.P., Faria, A., Peres, C.A., 2006. Human-wildlife conflicts in a fragmented Amazonian forest landscape: determinants of large felid depredation on livestock. Anim. Conserv. 9, 179–188.
Nowell, K., Jackson, P., 1996. Wild Cats: Status Survey and Conservation Action Plan. IUCN/SSC Cat Specialist Group. IUCN, Gland, Switzerland.
Odden, M., Wegge, P., Fredriksen, T., 2010. Do tigers displace leopards? If so, why? Ecol. Res. 25, 875–881.
Patterson, B.D., Kasiki, S.M., Selempo, E., Kays, R.W., 2004. Livestock predation by lions (*Panthera leo*) and other carnivores on ranches neighbouring Tsavo National Parks, Kenya. Biol. Conserv. 119, 507–516.
R Development Core Team, 2015. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D., Wirsing, A.J., 2014. Status and ecological effects of the world's largest carnivores. Science 343, 151–162.
Sangay, T., Vernes, K., 2008. Human–wildlife conflict in the Kingdom of Bhutan: patterns of livestock predation by large mammalian carnivores. Biol. Conserv. 141, 1272–1282.
Seidensticker, J., 1976. On the ecological separation between tigers and leopards. Biotropica 8, 225–234.
Suryawanshi, K.R., Bhatnagar, Y.V., Redpath, S., Mishra, C., 2013. People, predators and perceptions: patterns of livestock depredation by snow leopards and wolves. J. Appl. Ecol. 50, 550–560.
Tamang, B., Baral, N., 2008. Livestock depredation by large cats in Bardia National Park, Nepal: implications for improving park-people relations. Int. J. Biodivers. Sci. Manag. 4 (1), 44–53.
Thapa, T.B., PhD Thesis 2011. Habitat Suitability Evaluation for Leopard (*Panthera Pardus*) Using Remote Sensing and GIS in and Around Chitwan National Park, Nepal. Saurashtra University, Rajkot, India.
Treves, A., Karanth, K.U., 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. Conserv. Biol. 17, 1491–1499.
Wang, S.W., Macdonald, D.W., 2006. Livestock predation by carnivores in Jigme Singye Wangchuck National Park, Bhutan. Biol. Conserv. 129, 558–565.
Woodroffe, R., Ginsberg, J.R., 1998. Edge effects and the extinction of populations inside protected areas. Science 280, 2126–2128.