Effectiveness of non-lethal predator deterrents to reduce livestock losses to leopard attacks within a multiple-use landscape of Himalaya

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Lethal measures are widely adopted by local communities and governments to manage human-wildlife conflicts. Such measures lead to large scale decline of carnivore populations globally with trophic cascades on ecosystems. Mitigating human-carnivore conflicts through non-lethal measures will protect endangered predators and secure livelihoods. However, information on effectiveness of such measures are extremely limited and hence cannot be applied in developing scientific evidence based policies. Further to develop human-carnivore coexistence models it is important for local community members, biologists and wildlife managers to actively participate in conservation programs. We evaluated the response of a non-lethal visual deterrent (fox lights) to deter leopard attacks on livestock within a multiple-use landscape of western Himalaya through community engagement. We monitored 16 experimental sites and 17 control sites within 27 villages and recorded data on livestock depredation by leopards between April 2017 to April 2018. A multivariate analysis was conducted to determine the influence of landscape predictors and animal husbandry practices on livestock depredation by leopards within vicinity of human settlements. We found that visual deterrents discouraged common leopards to predate on livestock (cows and goats). We also demonstrated that community based conservation initiatives are successful in mitigating human-carnivore conflicts within large natural ecosystems. Depredation was most likely to occur near settlements with tree, shrub cover and presence of domestic dogs. We suggest developing site specific coexistence strategies and adopting non-lethal measures to safeguard carnivores, livestock and humans within shared landscapes.

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Abstract

Lethal measures are widely adopted by local communities and governments to manage human-wildlife conflicts. Such measures lead to large scale decline of carnivore populations globally with trophic cascades on ecosystems. Mitigating human-carnivore conflicts through non-lethal measures will protect endangered predators and secure livelihoods. However, information on effectiveness of such measures are extremely limited and hence cannot be applied in developing scientific evidence based policies. Further to develop human-carnivore coexistence models it is important for local community members, biologists and wildlife managers to actively participate in conservation programs. We evaluated the response of a non-lethal visual deterrent (fox lights) to deter leopard attacks on livestock within a multiple-use landscape of western Himalaya through community engagement. We monitored 16 experimental sites and 17 control sites within 27 villages and recorded data on livestock depredation by leopards between April 2017 to April 2018. A multivariate analysis was conducted to determine the influence of landscape predictors and animal husbandry practices on livestock depredation by leopards within vicinity of human settlements. We found that visual deterrents discouraged common leopards to predate on livestock (cows and goats). We also demonstrated that community based conservation initiatives are successful in mitigating human-carnivore conflicts within large natural ecosystems. Depredation was most likely to occur near settlements with tree, shrub cover and presence of domestic dogs. We suggest developing site specific coexistence strategies and adopting non-lethal measures to safeguard carnivores, livestock and humans within shared landscapes.

Keywords: Carnivore, conflict, community, leopard, livestock, livelihood, mitigation

Introduction

Large carnivores are apex predators and help regulate structure and functioning of ecosystems. Decline in populations of apex predators have resulted in degradation of ecological systems, loss of biodiversity and ecosystem services globally (Ripple et al., 2014). Considering the present rates of human population growth, protected areas are not sufficient enough to provide refuge to viable population of large carnivores. Decline in wild prey and anthropogenic impacts degrade, fragment natural ecosystems forcing large carnivores to share space and resources with humans within larger heterogeneous landscapes (Chapron et al., 2014). As a consequence, large carnivores kill livestock and occasionally attack humans. Economic incentives from wildlife tourism benefit government, private agencies but local community members often share the disproportionate costs of coexistence with large carnivores through livestock losses (Dickman, 2010). Marginal livestock owners who own few livestock are at considerable risk from livestock depredation by large carnivores and such economic losses induce drastic retaliation. Livestock depredation is thus regarded as the stimuli of human-carnivore conflicts globally (Inskip & Zimmermann, 2009). Frequent and persistent negative interactions generate antagonism against large carnivores through real or perceived impacts on human wellbeing, safety and livelihoods (Kansky & Knight, 2014).

Local community members resort to retaliatory killings through poisoning of livestock carcass, bush meat, snaring, spearing, electrocution and shooting of large carnivores (Inskip et al., 2016; Hazzah et al., 2017). Human-carnivore conflicts also impact the overall ecosystem such as scavengers, birds of prey who die after consuming poisoned meat (Ogada, 2014). Hence effective mitigation measures are urgently required to ensure conservation of large carnivores and ensure functioning of health ecosystems. Lethal control has been widely adopted as the ultimate mitigation strategy to manage human-large carnivore conflicts and has been implemented both legally (Chapron et al., 2014) and illegally (Eklund et al., 2017). Government agencies have often advocated culling for certain populations of large carnivores or suggested targeted killing of problem individuals (Inskip & Zimmermann, 2009). Non-lethal methods that protect human property, secure livelihoods have the potential to maintain balance between conservation of large predators and humans especially within shared landscapes (Eeden et al., 2017). Such methods are diverse and includes audio, visual deterrents, physical barriers, financial incentives, livestock guardian animals, better animal husbandry practices, compensation and sterilization programs. However, non-lethal methods provide the desired benefits only when local community takes ownership of the problem and participate in timely implementation of the mitigation measures (Eklund et al., 2017).

Human-carnivore conflicts are severe in Asia with a diversity of large carnivores (tiger, common leopard, snow leopard, black bear, brown bear, wolf, wild dog). Size of protected areas are small in this region with a rapid rise in human, livestock populations and encroachment of wildlife habitats, expansion of agricultural farms. Within such multiple-use anthropogenic landscapes large carnivores share space and resources with humans and occur in close proximity to settlements (Naha et al., 2016; Naha et al., 2018). Amongst this diversity of large carnivores, human-leopard conflicts are a serious conservation problem with the major hotspot being India. With only 5% of India's geographical area under the protected area network, leopards co-occur with humans within agro-pastoral, forested landscapes (Karanth et al., 2009). Such anthropogenic landscapes are often devoid of wild prey and leopards frequently kill livestock and domestic dogs. Livestock depredation is the major conservation problem for the species and attacks on humans also occur as a consequence of leopard presence near settlements or due to specific human behaviour and activity. Livestock are a direct representation for the agro-pastoral societies and loss to large carnivores represents a substantial threat to human welfare and livelihoods in rural India. A series of recent studies have also documented a rise in human-leopard conflicts in India and have examined various aspects such as nature of human-leopard relations, movement behaviour, diet, extent of self-reported livestock loss and attacks on humans (Ghosal et al., 2013; Odden et al., 2014; Miller et al., 2016; Naha et al., 2018). Some of the prominent factors influencing human-leopard conflicts are landscape features, season, time of day, availability of wild prey, livestock herd size and type of livestock. Apart from these factors, human-carnivore conflicts are often a consequence of both human and carnivore behaviour. Inadequate animal husbandry practices, location of grazing pastures close to protected areas or forested habitats and lack of animal shelters also impact the extent of predation on livestock (Sangay & Vernes, 2008, Tamang & Baral, 2008, Khorozyan et al., 2015; Miller et al., 2016).

Pauri Garhwal district in western Himalaya has a history of human-leopard conflicts (Goyal et al., 2007) with over 160 persons injured in leopard attacks between 2006-2016. Livestock rearing is a major profession of the rural populations and losses to leopard attacks have often led to retaliatory killings. A total of 125 leopards were killed by local community members or shot dead by the district administration between 1990-2005 (Goyal et al., 2007). Due to rural-urban migration, the region has also seen several villages being abandoned providing an opportunity for large carnivores (common leopards, black bears) to recolonize such areas previously used by humans (Naha et al., 2018). Livestock are owned by individual families who takes care of the animals and keep them within enclosures at night. Such livestock enclosures or night shelters are made of locally available stones, mud and wood and are usually located adjacent to their houses. Leopards kill livestock in grazing lands near the villages (during day) and at night shelters. Apart from making noise by beating empty canisters and some lights, villagers do not have any ways to protect their livestock from predation by leopards. Through this study, we evaluate efficacy of a non-lethal visual predator deterrent (fox lights) to reduce livestock losses to leopard attacks. This is the first scientific experiment on leopard deterrence and evaluation of such a method to reduce livestock depredation in South Asia.

Depending on the size and spread of the village, fox lights were mounted at specific vantage points, at the periphery of a cluster of houses. The lights are solar-powered that flicker at random time intervals automatically during nights. These lights mimic movement or activity of local community members at the vantage points within the village. We tested the efficacy of these lights at two different spatial scales and collected data on livestock depredation by common leopard from experimental sites (n=16) and control sites (n=17) for a period of one year. We hypothesize that fox lights will reduce frequency of livestock losses due to fatal leopard attacks during night. We define a fatal attack leading to death to one or more heads of livestock (cattle, goats, sheep). Specifically, we examine 1) Effectiveness of fox lights in deterring leopard attacks on livestock 2) Identify landscape features and animal husbandry practices which increase vulnerability of livestock to leopard attacks.

Study Area

The study was conducted within Pauri Garhwal district in Uttarakhand state, India that falls within the western Himalaya. Two protected areas, viz. Rajaji and Corbett National Parks (Tiger Reserves) fall partially within this district. This is predominantly a mountainous district with an area of 5444 km^2 and is part of the lesser, middle Himalaya. The elevation range lies between 295–3100 m (Fig. 1). Based on the Forest survey of India report (FSI 2017), the region has a forest cover of 64% with majority being moderate dense forest followed by scrublands and open forests. The region is a landscape matrix of forests, scrubland, agricultural areas and human settlements. Average rainfall in the district range between 218-235 cm. Human population density is moderate i.e. 110 persons per km^2 (Census of India, 2011). Due to outmigration, 331 villages were abandoned and the district recorded an annual growth rate of -1.4 percent between 2001–2011 (Census of India, 2011). Livelihood opportunities are limited with the major professions being livestock farming, agriculture and cottage industries. Livestock density of this region is 58 per km^2 (http://ahd.uk.gov.in/files/census/Livestock_Census_2012_Uttarakhand_Districtwise.pdf, accessed on April 2020) whereas the major mammalian fauna is common leopard (*Panthera pardus*), Bengal tiger (*Panthera tigris tigris*), Asiatic black bear (*Ursus thibetanus*), barking deer (*Muntiacus muntjak*), goral (*Nemorhaedus goral*), sambar (*Rusa unicolor*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*) and common langur (*Semnopithecus entellus*) (Goyal et al., 2007).

Data collection

We adopted a participatory approach to create awareness about nature of leopard attacks and adoption of non-lethal predator deterrents by the local community members. Participatory approaches have often been regarded as effective means to alleviate human-carnivore conflicts and implement specific interventions (Treves et al., 2009). We conducted a series of conservation awareness workshops (N = 30) from March 2017 to March 2018 targeting local community members about the possible non-lethal interventions to reduce livestock predation by leopard. Community members (N = 80) who agreed to cooperate with our research team or were nominated by the village heads, were identified from this group and recognised as regional guardians. We selected 27 villages for conducting this experiment. All the community members were briefed about the nature, design of the experiment and use of visual predator deterrents. Selection of the experimental and control sites were done in consultation with the local forest staff, village heads and examination of compensation records regarding livestock losses to leopard attacks in the past two years. A total of (N = 16) locations were selected from 10 villages for setting up the predator deterrents. We selected another (N = 17) locations from the remaining 17 villages as control sites (Fig. 2). Three to four regional guardians were responsible for managing an experimental unit. The regional guardians were aware whether their village was part of the experiment or control site and reported any incident of malfunctioning within 4-6 hours. Our experimental and control sites were spatially spread out to prevent any regional or local variable affecting performance of the treatments. The experiments were conducted during the period April 2018 and April 2019.

The regional guardians assisted our research team in setting up the deterrents at specific vantage points within the village such as ridgelines, rooftops, animal trails and pasture lands (Fig. 3A & Fig. 3B). We installed two visual deterrents (fox lights) at two corners of an imaginary circle (50 m radius) surrounding a cluster of houses/livestock enclosures within a village. The lights were installed high enough or mounted on iron rods in order to make it visible for leopards depending on the surrounding vegetation and topography. The lights randomly emitted three different coloured flashlights and were automatically activated at dusk (after light reduced following sunset). Lights get deactivated at dawn depending on the intensity of natural light. To prevent habituation by leopards, all lights within the experimental sites were switched off randomly three days a week. This random pattern was decided by the regional guardians. To confirm visitation by leopards within the vicinity of the experimental and control sites, we regularly sampled trails (N = 27) and recorded presence of leopard pugmarks, scrape marks, scats within 50 and 500m radius of the imaginary circle. We also consulted the regional guardians and verified presence of leopard signs and livestock predation events during the experimental period. Data on livestock depredation by leopards were collected from the experimental and control sites during the study period. We also recorded data for seven socioecological variables within a 50-m circle of the experimental and control sites. The socio-ecological variables include: number of households, total number of people, condition of livestock enclosure, number of livestock, total number of guard/domestic dogs, vegetation cover (percentage of herb, shrub, tree and barren land) and altitude (Appendix 1).

Data preparation and analysis

To explore effect of ecological predictors, we generated individual buffer of 500m radii around each site using Arc GIS 10.3.3. For each of these circles, we generated information for a total of six predictor variables based on their ecological importance such as landscape features (area of non-forest, open forest, moderate dense forest, dense forest), topographic features (altitude) and nightlight. We were also interested in examining broader seasonal patterns of depredation (dry and wet) and not just for individual months, hence the experimental period was divided into 2 primary seasons (Dry – April-June, November-March, Wet – July-October).

Landscape features- We hypothesized that predation risk by leopard will be higher in sites with moderate to dense forests/vegetation cover. We calculated landscape variables for each site, i.e., area under different land-use types from Forest type map of India (FSI, 2017).

1. Human presence- We hypothesized that leopards would avoid killing livestock in areas with increased human presence. We extracted night light values using the 1,000-m spatial resolution night-time visible light data of India.
2. Altitude- Considering that carnivores prefer to kill livestock in areas with gradient in altitude, we hypothesized that predation risk by leopards will be higher in elevated regions. We extracted the mean altitude value for each site (control and experiment) based on 90-m spatial resolution digital elevation maps.

Once data were compiled, we prepared master tables for the 2 spatial scales (50 and 500-m radius circles) (Table 1, Table 2). We did Pearson correlation and omitted all correlated variables ≥ 0.70 (Dormann et al., 2007) using R version 3.4.0. We prepared both binary and count statistic data for the number of livestock predation events recorded within a site. We assigned 0 to sites that had no attacks. We used generalized linear models (GLMs) with poisson structures and logit-link function to quantify effect of predictor variables (habitat, human presence, altitude) for 500m radius circles and vegetation cover (altitude and proportion of shrub, herb, tree and barren land) for 50m radius circles and modelled probability of livestock predation by leopard. For the poisson structure our response variable was the number of livestock killed by leopards at night within each individual cluster during the experimental period. We used presence of fox light within a site as a factor in the analysis.

Livestock husbandry

To model livestock losses as a function of animal husbandry practices, we used the same response variable used for identifying landscape predictors of predation risk within a fine scale of 50-m circle. We used generalized linear models (GLMs) with a binomial error structure and logit link function and considered sociological variables (household size, number of houses), animal husbandry practices (condition of livestock enclosure, number of livestock, number of guard dogs), location (village name) and presence of fox lights. We used location/village name and presence of fox lights (presence of fox light: 1, absence of foxlight: 2) as categorical factors in the analysis. To determine the condition of livestock enclosure we considered strength of the construction materials in the following order (categorical: branches-1, wooden poles-2, stone walled-3, cemented-4).

We used a priori candidate models and ranked them based on AIC, AICc values. Models with the lowest AIC values were considered the best or dominant model (Burnham & Anderson, 2002) and the output (coefficients and estimates) explained the probability of livestock predation by leopards within IHR. We also used likelihood-ratio test (LRT) with ‘lrtest’ link function to test significance of predictor variables. LRT test is used to assess the goodness of fit of two competing statistical models based on the ratio of their likelihoods (Glover & Dixon, 2004).

We checked for diurnal livestock attacks after installation of the lights between experimental and control sites using chi-square test in R version 3.4.0. We also used chi-square test to check for presence of leopard signs, effectiveness of fox lights in deterring attacks, difference in temporal, seasonal patterns and type of livestock killed between experimental and control sites. Since data was not normally distributed, we also compared predictor variables between the experimental and control sites using Wilcoxon Signed-Rank Test in R 3.4.0. Statistical significance was $P <= 0.05$ for all analyses. All spatial analyses were performed with Arc GIS 10.3.3 and R 3.4.0.

Results

Livestock depredation within control and experimental sites

We confirmed presence of leopards within the vicinity of the experimental and control sites through trail walks (43 leopard signs i.e. pugmarks) and secondary information (4 sightings and 19 signs i.e. pugmarks) from regional guardians during the study period. A total of 105 livestock were killed by leopards within 10 villages of the Pauri Garhwal district during the study period. We found that the presence of fox lights reduced the number of livestock depredation by leopards. We recorded 36 (34%) and 69 (66%) livestock kills within experimental and control sites respectively (χ^2=10.24, df =1, p = 0.001). About 33 cases (92%) of the total livestock kills within experimental sites occurred outside livestock enclosures. Out of the total 105 livestock kills, 63 (60%) occurred during daylight and the remaining occurred during night (χ^2=4, df =1, p = 0.04). Within experimental sites, 25 (70%) of the predation events occurred during day and the remaining occurred during night (χ^2=16, df =1, p = 6.334e-05). Within control sites, 38 (55%) livestock kills occurred during day and the remaining occurred during night (χ^2=1, df =1, p = 0.317).

About 47% of the livestock killed were goats, 37% were cows and the rest were calves (χ^2=16.24, df =1, p = 0.0002). Livestock predation was higher (56% during the dry season when compared to the wet season (χ^2=1.44, df =1, p = 0.230). An average of 26 livestock, range (3-120) were present within a cluster of 50-m circle. The average elevation of experimental and control sites was 1533 m, range (1086-1823). The average number of people staying within a cluster was estimated to be 17 members (range 5-30) whereas the average number of houses was 7 (range 1-18). Households possessed an average of 1 guard dog (range 0-4). The minimum and maximum distance of livestock kills from the centre of clusters were estimated to be 27 and 574 m respectively. About 42% of the livestock enclosures were made of wooden poles, 36% branches, 12% stones and rest were cemented. Wilcoxon signed rank sum test results indicate that none of the predictor variables differed significantly between experimental and control sites.

Influence of landscape predictors on livestock depredation by leopards

The proportion of barren land cover was negatively correlated (-0.75) with proportion of shrub cover, hence we removed barren land cover from the analysis. On a fine scale, the proportion of tree cover was the best predictor of livestock depredation by leopard (Supplementary Table S1). Leopards were most likely to kill livestock in areas with closed habitats i.e. with increasing tree cover (estimate 0.0359, CI 0.0724-0.0005). Stepwise deletion method and likelihood ratio test results suggest that there was significant difference between competing models 1 and 3 and 3 and 5 with shrub and tree cover being the significant variables (Table 3).

On a coarser scale of 500-m radius, there were no significant landscape predictors of leopard attacks on livestock (Supplementary Table S2). The effect of scrubland, moderate dense forest and very dense forest displayed a weak positive relationship with probability of livestock depredation but these were not statistically significant (scrub: estimate 3.02E-06, CI 8.60E-06-2.57E-06, moderate dense forest: estimate, 9.45E-07 CI 4.19E-06-2.30E-06, very dense forest: estimate, 1.57E-07 CI 3.34E-06 -3.03E-06). Stepwise deletion method and likelihood ratio test results suggest that there were no significant variables between competing models (Table 4).

Livestock husbandry

The top model indicates that nocturnal livestock depredation events had a positive relationship with the number of household (estimate 0.795, CI 1.617-0.028) and number of guard dogs (estimate 2.378, CI 5.036-0.279) present within a 50-m circle of human settlements (Supplementary Table S3). Likelihood of a depredation event within a 50-m cluster was higher in sites with houses and domestic guard dogs. Each cluster had presence of at least 1 dog (61%, N = 33range) whereas the average number of households was 7 (range 1-18). The likelihood of livestock depredation was lower with presence of fox lights though it was not significant. Stepwise deletion method and likelihood ratio test results suggest that there was significant difference between two competing models 2 and 3 and 3 and 4 with number of livestock and enclosure type being the significant variables (Table 5).

Discussion

Our study provides evidence based results to manage large carnivores within human dominated landscapes and highlights effectiveness of non-lethal deterrents to reduce livestock depredation. This study is the first known experiment testing the effectiveness of non-lethal visual deterrents in reducing livestock losses to common leopards in South Asia. We found that flashlight devices deterred predation by leopards on livestock. Significant decline in livestock depredation by leopard in sites with predator deterrents support the hypothesis that fox lights reduce the number of livestock losses to nocturnal leopard attacks within villages in the western Himalaya. Probability of livestock killing by leopard around a cluster of houses within a village increased with presence of domestic dogs, tree and shrub cover. Predation on livestock is the stimuli for human-carnivore conflicts globally and such events have to be addressed effectively to ensure survival of large carnivores within human-dominated landscapes. Considering the outcome of our work, there is immense potential for adopting non-lethal visual deterrents through community based conservation programs and reduce livestock losses to leopards across heterogeneous landscapes of Asia.

Our results demonstrate that landscape predictors and animal husbandry practices are both important predictors of livestock depredation by leopards within a fine scale of 50-m radius around village settlements. The proportion of dense vegetation (shrub and tree) cover within a fine scale was positively related to livestock depredation in the vicinity of human settlements. Previous studies have documented that at a fine scale large carnivores use dense vegetation cover to hunt prey (Inskip & Zimmerman, 2009). Human settlements surrounded by closed habitats, i.e. tree and shrub cover had higher risk of depredation than settlements within open habitats. These high risk areas could be favourable for leopards who are basically stalk, ambush predators and rely on stealth to hunt domestic prey (Jacobson et al., 2016). A study conducted in eastern Himalaya documented that risk of leopard killing livestock increased with forest cover (Garcia et al., 2016).

Our results also suggest that livestock killing were diurnal in nature which is contrary to previous findings from western and eastern Himalaya i.e. Pakistan and Bhutan where they were nocturnal (Sangay & Vernes, 2008; Qamar et al., 2010). Radio-telemetry studies in Nepal and India have documented leopards to be nocturnal (Odden & Wegge, 2005; Odden et al., 2014) but our results suggest diurnal activity peaks within human dominated mountainous landscapes. Cheetahs and lions in eastern Africa (Broekhuis et al., 2014, Lesilau et al., 2018) and tigers in Sundarban delta (Naha et al., 2016) have also been reported to exhibit diurnal activity peaks and are believed to be the major driver of human-carnivore conflicts. Leopards probably prefer to kill wild prey at night whereas livestock killing is diurnal due to the availability, poor or unsupervised grazing practices, and ease of catching domestic prey.

Improving condition of animal enclosures, use of livestock guardians (herders and trained dogs), visual, auditory deterrents and lethal control of predators have been identified as the major interventions which have effectively reduced livestock losses (Eeden et al., 2017, Miller et al., 2016, Eklund et al., 2017). Visual deterrents have been documented to effectively protect livestock against lions (Lesilau et al., 2018) and pumas (Ohrens et al., 2019) and our results also support such findings. However, not all visual deterrents are effective as scarecrows have failed to prevent livestock losses to leopard attacks in Africa (Broekhuis et al., 2017). An interesting finding of our study was that presence of domestic guard dogs increased the probability of livestock predation by leopard. Several studies have highlighted the importance of livestock guardian dogs in deterring carnivore attacks such as with cheetah, lion, wolves, bears and hyena (Khorozyan & Waltart, 2019). However, there is also evidence that lack of proper training in dogs can lead to ineffective protection of livestock against carnivore attacks (Khorozyan, 2017). Dogs present within our study site were not trained to deter carnivore attacks and hence were not effective in reducing livestock depredation. Leopards are behaviourally flexible and have adapted to living in close proximity of humans in South Asia. Hence they could also be habituated to the presence of domestic dogs and don't consider them as a deterrent. Wild prey availability is also low and domestic, feral dogs have been reported to be a major prey of leopard within anthropogenic landscapes of India (Jacobson et al., 2016). Hence, presence of untrained dogs could be an attractant than a deterrent for leopard attacks on livestock and humans. Domestic dogs are also reservoir of diseases such as canine distemper virus (CDV), rabies and are responsible for massive decline of large carnivores (Lembo et al., 2010). They might also hunt wild prey and compete with smaller predators affecting overall biodiversity of an ecosystem (Home et al., 2018). Hence, removal of dogs within immediate vicinity of human settlements will reduce the likelihood of attacks on livestock and also improve functioning of the overall ecosystem in western Himalaya.

Animal husbandry also influenced the probability of livestock depredation by leopards. The number of houses, livestock present and condition of enclosure within a cluster increased the likelihood of attacks. Fortified and improved enclosures have been largely documented to be effective in reducing livestock losses to multiple predators such as wolves, pumas, spotted hyenas and lions in Europe, South America and Africa. Yet such measures have not provided success in deterring leopard attacks on livestock in Africa (Eklund et al., 2017). Several studies have documented that herd size in a village is directly proportional to the number of predator attacks (Von Bommell et al., 2007, Woodroffe, 2007). Similarly, within our study site number of livestock present within a cluster of settlements were an attractant for leopards and hence was positively related to the likelihood of attack. Number of houses within a cluster indicate availability of domestic dogs and livestock and hence accounted for higher probability of leopard attacks within our study site.

It is important to reduce livestock losses but perceived risk towards large predators are also influenced by a combination of several social, cultural variables (Dickman, 2010). Such variables should also be prioritized when developing community based conservation programs and promote tolerance towards large carnivores. Community based conservation programs are successful when local members are directly involved and take ownership of the project. We demonstrate that it is possible to overcome challenges within a natural ecosystem such as a village society by having moderate control over recruitment of participants and recognizing community leaders. By adopting a community based conflict mitigation approach we have been successful in reducing human-leopard conflicts and promote tolerance within a human-dominated Himalayan region. Similar success stories such as the "Lion Guardians" project in east Africa (Hazzah et al., 2014), snow leopard community based conservation programs in India (Vannelli et al., 2019) and Tiger Team initiative in Bangladesh Sundarbans (Inskip et al., 2016) have demonstrated considerable success in improving human-predator relations and created pathways of coexistence within developing regions of the world.

Rising anthropogenic impacts affect survival of large carnivores globally and hence they are forced to occupy heterogeneous shared landscapes where persecution due to real or perceived threats to human interests or livelihoods are high. To maintain coexistence within such shared landscapes, it is essential to develop conservation models which can balance human livelihoods, reduce financial losses to predators as well preserve biodiversity. We provide rigorous scientific evidence that non-lethal interventions are effective in reducing predation on livestock within multiple-use landscapes of South Asia. Although, there might be differences within natural and social systems our community based approach has the potential to reduce livestock losses to similar large bodied carnivores such as jaguars, hyenas, cheetah, tigers, snow leopards, wild dogs, wolves and bears. By reducing financial loss, we can ensure survival of large carnivores and preserve functionality of natural ecosystems. Such measures will have cascading effects on the larger human society through flow of ecosystem services, increased wildlife tourism based livelihoods and improved human-wellbeing, safety.

Human-leopard conflicts are a major threat to survival of leopards outside protected areas in Asia and Africa. Successful implementation of conservation programs will need a coordinated effort from all multiple agencies, which includes (local communities, wildlife staff, police, civil administration, animal husbandry, agriculturists, veterinarians, conservationists etc.). To ensure such coordination a common platform has to developed to allow interaction and exchange of knowledge amongst all such groups to manage conflicts. Local community members should be encouraged by the forest and wildlife departments and non-governmental organizations to participate in leopard conservation and conflict management initiatives. Retaliatory killings will reduce once community members take ownership of the problem and benefit economically from conserving leopard within human-dominated landscapes. Livestock farmers should not be encouraged to raise or keep guardian dogs solely as protection from large predators. Dogs are responsible for killing endangered wildlife, act as reservoirs of zoonotic diseases, replace natural scavengers and act as attractants for large predators which will further aggravate the problem. Livestock should be herded by an experienced person and owners can be encouraged to advocate livestock insurance programs, construct predator proof enclosures/corrals and use sophisticated predator deterrents. The wildlife departments, non-governmental organizations and district administrations can help provide technical and financial support to establish such mitigation programs. Research on evidence based interventions to reduce human-carnivore conflicts within multi-predator systems have to be further enhanced by the scientific community. Future studies should be taken up to understand the behavioural response and habituation of this technique to leopards in deterring attacks on livestock within multiple-use landscapes.

Conclusions

Despite the effectiveness of fox lights in deterring leopard attacks on livestock in western Himalaya, we do not guarantee successful replication of this experimental work within other regions. Conflict mitigation measures which might work at a particular place might not be successful elsewhere due to uncertainty in animal behaviour, environmental and social factors. Majority of the predator deterrent experiments are usually not successful as long term solutions to reduce livestock depredation by large carnivores. We could however demonstrate that fox lights if used with a certain level of randomness are effective to deter attacks on livestock for a time period of one year. Given the positive effect of these flash lights to reduce livestock depredation at night, we recommend adopting better animal husbandry practices to reduce economic losses to leopard attacks during the day.

Additional Information and Declarations

Competing Interests

The authors declare there are no competing interests.

Author contributions

Dipanjan Naha conceived and designed the experiment, analysed the data and authored drafts of the paper.

Pooja Chaudhary collected data, did preliminary data analysis and approved the final draft.

Gaurav Sonkar collected data, did preliminary data analysis and approved the final draft.

Sambandam Sathyakumar supervised the project, authored or reviewed drafts of the paper, approved the final draft.

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References

Broekhuis, F., Grünewälder, S., McNutt, J. W., & Macdonald, D. W. (2014). Optimal hunting conditions drive circalunar behavior of a diurnal carnivore. *Behavioral Ecology*, *25*(5), 1268–1275. https://doi.org/10.1093/beheco/aru122

Broekhuis, F., Cushman, S. A., & Elliot, N. B. (2017). Identification of human–carnivore conflict hotspots to prioritize mitigation efforts. *Ecology and Evolution*, *7*(24), 10630–10639. https://doi.org/10.1002/ece3.3565

Burnham, K.P., Anderson, D.R. (2002). *Model selection and multimodel inference: A practical information-theoretic approach*. Springer- Verlag. https://link.springer.com/book/10.1007%2F978-1-4757-2917-7

Chapron, G., Kaczensky, P., Linnell, J. D. C., Von Arx, M., Huber, D., Andrén, H., López-Bao, J. V., Adamec, M., Álvares, F., Anders, O., Balečiauskas, L., Balys, V., Bedõ, P., Bego, F., Blanco, J. C., Breitenmoser, U., Brøseth, H., Bufka, L., Bunikyte, R., … Boitani, L. (2014). Recovery of large carnivores in Europe's modern human-dominated landscapes. *Science*, *346*(6216), 1517–1519. https://doi.org/10.1126/science.1257553

Dickman, A. J. (2010). Complexities of conflict: The importance of considering social factors for effectively resolving human-wildlife conflict. *Animal Conservation*, *13*(5), 458–466. https://doi.org/10.1111/j.1469-1795.2010.00368.x

Dormann, FC., McPherson, MJ., B. Araújo, M., Bivand, R., Bolliger, J., Carl, G., G. Davies, R., Hirzel, A., Jetz, W., Daniel Kissling, W., Kühn, I., Ohlemüller, R., R. Peres-Neto, P., Reineking, B., Schröder, B., M. Schurr, F., & Wilson, R. (2007). Methods to account for spatial autocorrelation in the analysis of species distributional data: A review. *Ecography*, *30*(5), 609–628. https://doi.org/10.1111/j.2007.0906-7590.05171.x

Eklund, A., López-Bao, J. V., Tourani, M., Chapron, G., & Frank, J. (2017). Limited evidence on the effectiveness of interventions to reduce livestock predation by large carnivores. *Scientific Reports*, *7*(1), 1–9. https://doi.org/10.1038/s41598-017-02323-w

Ghosal, S., Athreya, V. R., Linnell, J. D. C., & Vedeld, P. O. (2013). An ontological crisis? A review of large felid conservation in India. *Biodiversity and Conservation*, *22*(11), 2665–2681. https://doi.org/10.1007/s10531-013-0549-6

Glover, S., & Dixon, P. (2004). Likelihood ratios: A simple and flexible statistic for empirical psychologists. *Psychonomic Bulletin and Review*, *11*(5), 791–806. https://doi.org/10.3758/BF03196706

Goyal, S.P., Chauhan, D, S., Yumnam, B. (2007). *Status and ecology of Leopard in Pauri Garhwal: Ranging patterns and reproductive biology of leopard (Panthera pardus) in Pauri Garhwal Himalaya*.

Hazzah, L., Dolrenry, S., Naughton, L., Edwards, C. T. T., Mwebi, O., Kearney, F., & Frank, L. (2014). Efficacy of two lion conservation programs in Maasailand, Kenya. *Conservation Biology*, *28*(3), 851–860. https://doi.org/10.1111/cobi.12244

Hazzah, L., Bath, A., Dolrenry, S., Dickman, A., & Frank, L. (2017). From attitudes to actions: Predictors of lion killing by maasai warriors. *PLoS ONE*, *12*(1), 1–13. https://doi.org/10.1371/journal.pone.0170796

Home, C., Bhatnagar, Y. V., & Vanak, A. T. (2018). Canine Conundrum: domestic dogs as an invasive species and their impacts on wildlife in India. *Animal Conservation*, *21*(4), 275–282. https://doi.org/10.1111/acv.12389

India state of Forest Report. (2017). *Uttarakhand-Isfr-2017.Pdf*.

Inskip, C., Carter, N., Riley, S., Roberts, T., & MacMillan, D. (2016). Toward human-carnivore coexistence: Understanding tolerance for tigers in Bangladesh. *PLoS ONE*, *11*(1), 1–20. https://doi.org/10.1371/journal.pone.0145913

Inskip, C., & Zimmermann, A. (2009). Human-felid conflict: A review of patterns and priorities worldwide. *Oryx*, *43*(1), 18–34. https://doi.org/10.1017/S003060530899030X

Jacobson, A. P., Gerngross, P., Lemeris, 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*, *2016*(5), 1–28. https://doi.org/10.7717/peerj.1974

Kansky, R., & Knight, A. T. (2014). Key factors driving attitudes towards large mammals in conflict with humans. *Biological Conservation*, *179*, 93–105. https://doi.org/10.1016/j.biocon.2014.09.008

Karanth, K. K., Nichols, J. D., Hines, J. E., Karanth, K. U., & Christensen, N. L. (2009). Patterns and determinants of mammal species occurrence in India. *Journal of Applied Ecology*, *46*(6), 1189–1200. https://doi.org/10.1111/j.1365-2664.2009.01710.x

Khorozyan, I., Ghoddousi, A., Soofi, M., & Waltert, M. (2015). Big cats kill more livestock when wild prey reaches a minimum threshold. *Biological Conservation*, *192*(March 2019), 268–275. https://doi.org/10.1016/j.biocon.2015.09.031

Khorozyan, I., Soofi, M., Soufi, M., Hamidi, A. K., Ghoddousi, A., & Waltert, M. (2017). Effects of shepherds and dogs on livestock depredation by leopards (Panthera pardus) in north-eastern Iran. *PeerJ*, *2017*(2), 1–18. https://doi.org/10.7717/peerj.3049

Khorozyan, I., & Waltert, M. (2019). A framework of most effective practices in protecting human assets from predators. *Human Dimensions of Wildlife*, *24*(4), 380–394. https://doi.org/10.1080/10871209.2019.1619883

Lembo, T., Hampson, K., Kaare, M. T., Ernest, E., Knobel, D., Kazwala, R. R., Haydon, D. T., & Cleaveland, S. (2010). The feasibility of canine rabies elimination in Africa: Dispelling doubts with data. *PLoS Neglected Tropical Diseases*, *4*(2). https://doi.org/10.1371/journal.pntd.0000626

Lesilau, F., Fonck, M., Gatta, M., Musyoki, C., Zelfde, M. van t., Persoon, G. A., Musters, K. C. J. M., De Snoo, G. R., & De Iongh, H. H. (2018). Effectiveness of a LED flashlight technique in reducing livestock depredation by lions (Panthera leo) around Nairobi National Park, Kenya. *PLoS ONE*, *13*(1), 1–18. https://doi.org/10.1371/journal.pone.0190898

Miller, J. R. B., Jhala, Y. V., & Jena, J. (2016). Livestock losses and hotspots of attack from tigers and leopards in Kanha Tiger Reserve, Central India. *Regional Environmental Change*, *16* (July 2016), 17–29. https://doi.org/10.1007/s10113-015-0871-5

Naha, D., Jhala, Y. V., Qureshi, Q., Roy, M., Sankar, K., & Gopal, R. (2016). Ranging, activity and habitat use by tigers in the mangrove forests of the Sundarban. *PLoS ONE*, *11*(4), 1–16. https://doi.org/10.1371/journal.pone.0152119

Naha, D., Sathyakumar, S., & Rawat, G. S. (2018). Understanding drivers of human-leopard conflicts in the Indian Himalayan region: Spatio-Temporal patterns of conflicts and perception of local communities towards conserving large carnivores. *PLoS ONE*, *13*(10), 1–19. https://doi.org/10.1371/journal.pone.0204528

Odden, M., Athreya, V., Rattan, S., & Linnell, J. D. C. (2014). Adaptable neighbours: Movement patterns of GPS-collared leopards in human dominated landscapes in India. *PLoS ONE*, *9*(11). https://doi.org/10.1371/journal.pone.0112044

Ogada, D. L. (2014). The power of poison: Pesticide poisoning of Africa's wildlife. *Annals of the New York Academy of Sciences*, *1322*(1), 1–20. https://doi.org/10.1111/nyas.12405

Ohrens, O., Bonacic, C., & Treves, A. (2019). Non-lethal defense of livestock against predators: flashing lights deter puma attacks in Chile. *Frontiers in Ecology and the Environment*, *17*(1), 32–38. https://doi.org/10.1002/fee.1952

Ripple W, Estes J, Beschta R, Wilmers CC, Ritchie EG, Hebblewhite M, Berger J, Elmhagen B, Letnic M, Nelson MP+4 more. 2014. Status and ecological effects of the world's largest carnivores. *Science* 343(6167):1241484

Rostro-García, S., Tharchen, L., Abade, L., Astaras, C., Cushman, S. A., & Macdonald, D. W. (2016). Scale dependence of felid predation risk: identifying predictors of livestock kills by tiger and leopard in Bhutan. *Landscape Ecology*, *31*(6), 1277–1298. https://doi.org/10.1007/s10980-015-0335-9

Sangay, T., & Vernes, K. (2008). Human-wildlife conflict in the Kingdom of Bhutan: Patterns of livestock predation by large mammalian carnivores. *Biological Conservation*, *141*(5), 1272–1282. https://doi.org/10.1016/j.biocon.2008.02.027

Tamang, B., & Baral, N. (2008). Livestock depredation by large cats in Bardia National Park, Nepal: Implications for improving park-people relations. *International Journal of Biodiversity Science and Management*, *4*(1), 44–53. https://doi.org/10.1080/17451590809618182

Treves, A., Wallace, R. B., & White, S. (2009). Participatory planning of interventions to mitigate human-wildlife conflicts. *Conservation Biology*, *23*(6), 1577–1587. https://doi.org/10.1111/j.1523-1739.2009.01242.x

Van Bommel, L., Bij De Vaate, M. D., De Boer, W. F., & De Iongh, H. H. (2007). Factors affecting livestock predation by lions in Cameroon. *African Journal of Ecology*, *45*(4), 490–498. https://doi.org/10.1111/j.1365-2028.2007.00759.x

van Eeden, L. M., Crowther, M. S., Dickman, C. R., Macdonald, D. W., Ripple, W. J., Ritchie, E. G., & Newsome, T. M. (2018). Managing conflict between large carnivores and livestock. *Conservation Biology*, *32*(1), 26–34. https://doi.org/10.1111/cobi.12959

Vannelli, K., Hampton, M. P., Namgail, T., & Black, S. A. (2019). Community participation in ecotourism and its effect on local perceptions of snow leopard (Panthera uncia) conservation. *Human Dimensions of Wildlife*, *24*(2), 180–193. https://doi.org/10.1080/10871209.2019.1563929

Woodroffe, R., Frank, L. G., Lindsey, P. A., Ole Ranah, S. M. K., & Romañach, S. (2007). Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: A case-control study. *Biodiversity and Conservation*, *16*(4), 1245–1260. https://doi.org/10.1007/s10531-006-9124-8

Figure 1. Location of Pauri Garhwal District within India and Uttarakhand

Figure 2. Location of experimental (fox lights) and control site locations within Pauri Garhwal District

Figure 3A. Image of a fox light deployed by regional guardians and researchers at the periphery of human settlements within a village in the Himalaya

Figure 3B. Image of a fox light deployed by regional guardians and researchers at the periphery of human settlements within a village in the Himalaya

Table 1. Major predictor variables considered for regression analysis within a fine scale of 50-m radii of experimental and control sites in Pauri Garhwal, Uttarakhand, India

Table 2. Major predictor variables considered for regression analysis within a broader scale of 500-m radii of experimental and control sites in Pauri Garhwal, Uttarakhand, India

Table 3. Second-order Akaike Information criterion scores (AIC), (AICc), ΔAIC of generalized linear models with poisson structure predicting livestock depredation by common leopards in Pauri Garhwal within a fine scale of 50 m radius around human settlements

Table 4. Second-order Akaike Information criterion scores (AIC), (AICc), ΔAIC of generalized linear models with poisson structure predicting livestock depredation by common leopards in Pauri Garhwal within a coarser scale of 500 m radius around human settlements

Table 5. Second-order Akaike Information criterion scores (AIC), (AICc), ΔAIC of generalized linear models with binomial structure for influence of livestock husbandry on probability of livestock depredation by common leopards within a fine scale of 50 m radius around human settlements

Supplementary Table S1. Summary of the dominant generalized linear model with poisson structure for probability of livestock predation by leopard within a fine scale of 50 m radius around human settlements

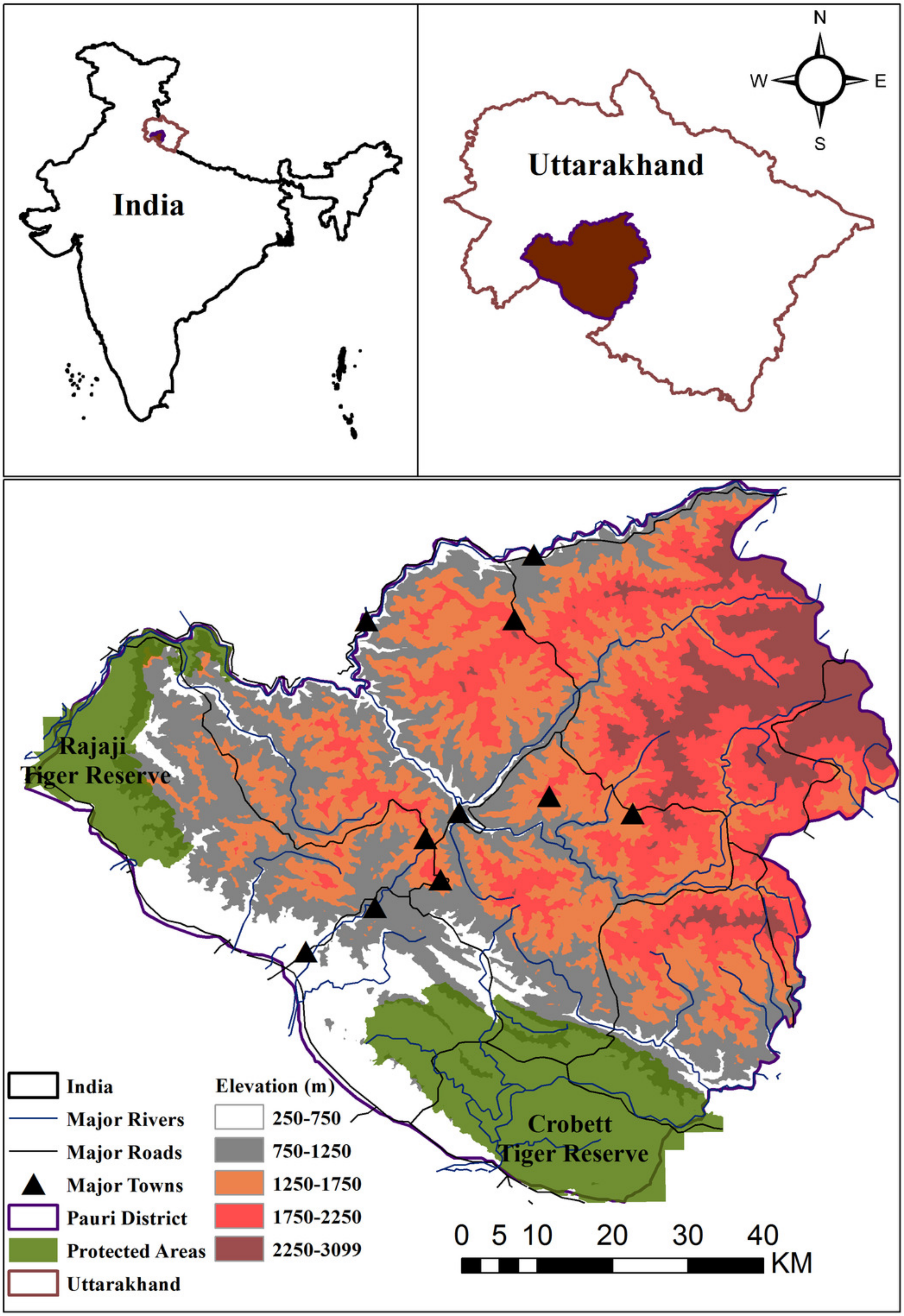
Supplementary Table S2. Summary of the dominant generalized linear model with poisson structure for probability of livestock predation by leopard within a coarser scale of 500 m radius around human settlements

Supplementary Table S3. Summary of the dominant generalized linear model with binomial structure for influence of livestock husbandry on probability of livestock predation by leopard within a fine scale of 50 m radius around human settlements

Appendix 1. Questionnaire sheet used for recording data on livestock depredation by common leopard during the experimental period

Figure 1

The map depicts protected areas, major roads, rivers, towns and elevation gradient within the Pauri Garhwal District


N
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Rajaji
Tiger Reserve
Crobett
Tiger Reserve
India
Major Rivers
Major Roads
Major Towns
Pauri District
Protected Areas
Uttarakhand
Elevation (m)
250-750
750-1250
1250-1750
1750-2250
2250-3099
0 5 10 20 30 40
KM

Figure 2

The map depicts location of experimental and control sites along with forest cover for the district

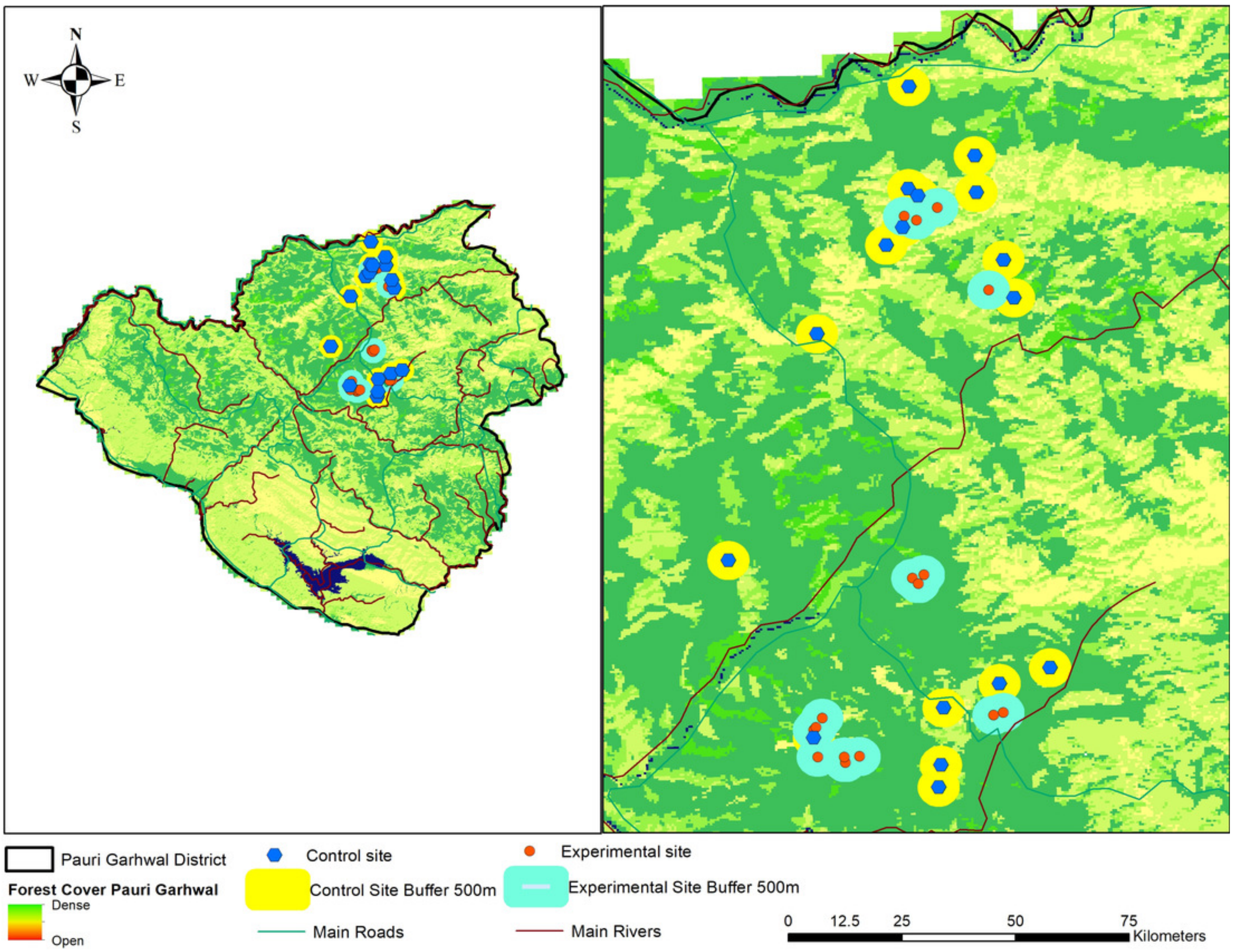

Figure 3

The image is of a fox light deployed at the edge of a human settlement in Pauri Garhwal

Figure 4

The image is of a fox light deployed on a vantage point (hilltop/edge of the settlement) to deter leopard attacks on livestock

Table 1(on next page)

1 Table 1. Major predictor variables considered for regression analysis within a fine scale of 50-
2 m radii of experimental and control sites in Pauri Garhwal

Type of variable	Predictor variable	Unit	Resolution	Source
Habitat (Landscape variables)	Proportion of herb cover	Percentage	50-m radii	Recorded during field survey
	Proportion of shrub cover	Percentage	50-m radii	Recorded during field survey
	Proportion of barren land cover	Percentage	50-m radii	Recorded during field survey
	Proportion of tree cover	Percentage	50-m radii	Recorded during field survey
Altitude	DEM	M	50-m radii	Recorded during field survey
Livestock husbandry practices	Number of household	Numeric	50-m radii	Recorded during field survey
	Number of people	Numeric	50-m radii	Recorded during field survey
	Number of livestock	Numeric	50-m radii	Recorded during field survey
	Enclosure type	Categorical	50-m radii	Recorded during field survey
	Number of domestic guard dogs	Numeric	50-m radii	Recorded during field survey
Livestock lost to leopard attacks	Number of livestock killed in forest patch	Numeric	Vicinity of village (500-m radii)	Recorded during field survey
	Number of livestock killed	Numeric	50-m radii	Recorded during field

	within enclosure			surveys

3

Table 2(on next page)

Table 2. Major predictor variables considered for regression analysis within a broader scale of 500-m radii of experimental and control sites in Pauri Garhwal

Type of variable	**Predictor variable**	**Unit**	**Resolution**	**Source**
Habitat (Landscape variables)	Area of non-forests	m^2	30 m	FSI, 2017
	Area of scrubland	m^2	30 m	FSI, 2017
	Area of moderate dense forests	m^2	30 m	FSI, 2017
	Area of very dense forests	m^2	30 m	FSI, 2017
	Area of open forest	m^2	30 m	FSI, 2017
Human presence and infrastructure	Night light	Radiance	500-m radii	Census India, 2011
Altitude	DEM	M	90 m	DEM

Table 3(on next page)

Table 3 Second-order Akaike Information criterion scores (AIC), (AICc), ΔAICc of generalized linear models with poisson structure predicting livestock depredation by common leopards in Pauri Garhwal within a fine scale of 50 m radius around human settlements

Model	**AIC**	**AICc**	**ΔAIC**
Proportion of scrub cover + Proportion of tree cover	97.759	98.586	0
Proportion of herb cover + Proportion of scrub cover + Proportion of tree cover	98.2	99.629	0.441
Proportion of herb cover + Proportion of tree cover	99.14	99.967	1.381
Altitude + Proportion of herb cover + Proportion of scrub cover + Proportion of tree cover	100.17	102.39	2.411
Proportion of herb cover + Proportion of scrub cover	100.72	101.546	2.961

Table 4(on next page)

Table 4 Second-order Akaike Information criterion scores (AIC), (AICc), ΔAICc of generalized linear models with poisson structure predicting livestock depredation by common leopards in Pauri Garhwal within a coarser scale of 500 m radius around human settlements

Model	**AIC**	**AICc**	**ΔAIC**
Area of scrub + Area of moderate dense forest + Area of very dense forest	102.6	104.031	0
Area of scrub + Area of open forest + Area of moderate dense forest + Area of very dense forest	104.58	106.797	1.98
Nightlight + Area of non-forest + Area of scrub + Area of open forest + Area of moderate dense forest + Area of very dense forest	106.37	110.845	3.77
Nightlight + Area of scrub + Area of open forest + Area of moderate dense forest + Area of very dense forest	106.42	110.896	3.82
Altitude+ Nightlight + Area of non-forest + Area of scrub + Area of open forest + Area of moderate dense forest + Area of very dense forest	107.47	113.467	4.87

Table 5(on next page)

Table 5 Second-order Akaike Information criterion scores (AIC), (AICc), ΔAICc of generalized linear models with binomial structure for influence of livestock husbandry on probability of livestock depredation by common leopards within a fine scale of 50 m radius around human settlements

Model	**AIC**	**AICc**	**ΔAIC**
Deterrent + Number of household + Enclosure type + Number of livestock + Number of domestic guard dog	30.964	36.964	0
Deterrent + Number of household + Number of people + Enclosure type + Number of livestock + Number of domestic guard dog	31.281	39.107	0.317
Deterrent + Number of household + Enclosure type + Number of domestic guard dog	32.573	37.053	1.609
Deterrent + Number of household + Number of domestic guard dog	39.122	40.550	8.158
Deterrent + Number of domestic guard dog	39.576	40.403	8.612