Factors affecting livestock depredation by snow leopards (*Panthera uncia)* in the Himalayan region of Nepal

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Abstract

The snow leopard (*Panthera uncia*) found in central Asia is classified as vulnerable species by the International Union for Conservation of Nature (IUCN). Every year, ~~remarkable~~large number of livestock are killed by snow leopards in Nepal, leading to economic loss to local communities and making human-snow leopard conflict a major threat to snow leopard conservation ~~including economic loss to local communities~~. We conducted formal and informal stakeholder's ~~discussion~~interviews to gather information related to livestock depredation with the aim to map the attack sites by the snow leopard. These sites were further validated by district forest office staffs to ~~check the biasness~~assess sources of bias, if any of villagers and herders on it. Attack sites ~~of more~~older than 3 years were removed from the survey ~~and~~. We found ~~a total of~~ 109 attack sites ~~from past 3 years~~ and visited all the sites for geo location purpose (GPS points of all unique sites were taken). We maintained at least a 100 m distance between attack locations to ensure that each attack location wa~~i~~s unique, which resulted in 86 unique locations ~~out of 109 collected~~. A total of 235 km2 was assessed during this study. Using Maximum Entropy (MaxEnt) modeling, ~~this study reveals~~we found that distance to livestock sheds, distance to paths, aspect, and distance to roads we~~a~~re major contributing factors to the snow leopard's attacks. We identified 13.64 km2 as risk zone for livestock depredation from snow leopards in the study area. Furthermore, s~~S~~now leopards preferred~~r~~ to attack livestock near livestock shelters, far from human paths and at moderate distance from motor roads. ~~The probability of an attack on livestock is highest at western aspect.~~ These identified attack zones should be managed both for snow leopard conservation and livestock protection in order to balance human livelihoods while protecting snow leopards and their habitats.

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~~The snow leopard found in central Asia is classified as vulnerable species by the International Union for Conservation of Nature (IUCN). Every year, livestock are killed by snow leopards in Nepal, making human-snow leopard conflict a major threat to snow leopard conservation as well as causing economic harm to local communities. We prepared the list of herders in the study area, and then conducted a workshop of 5-8 herders and 3-5 villagers to gather information related to livestock depredation and finally mapping the attack sites. These sites were further validated by district forest office staffs to check the biasness, if any of villagers and herders. Attack sites of more than 3 years were removed from the survey and found a total of 109 attack sites from past 3 years and visited all the sites for geo location purpose (GPS points of all unique sites were taken). We maintained at least a 100 m distance between attack locations to ensure that each attack location was unique, resulting in 86 unique locations out of 109 collected. A total of 235 km^2 was assessed during this study. This study identified key variables contributing to snow leopard attacks on livestock in eastern Manang district, Nepal using Maximum Entropy (MaxEnt) modeling. We identified 13.64 km^2 as at risk for livestock depredation from snow leopards in the study area. The distance to livestock sheds, distance to paths, aspect, and distance to roads are the most important variables when modeling risk zones associated with snow leopard depredation. Snow leopards prefer to attack livestock near livestock shelters and at far from human paths and at moderate distance from motor roads. The probability of an attack on livestock is highest at western aspect. These identified attack zones should be managed both for snow leopard conservation and livestock protection in order to achieve optimal results for Nepalese communities and wildlife.~~

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Keywords: Conflict, snow leopard, livestock depredation, modeling, wildlife management

Introduction

The snow leopard (*Panthera uncia*) is a wild carnivore native to 12 countries in central Asia (China, Bhutan, Nepal, India, Pakistan, Afghanistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, Russia, and Mongolia) (McCarthy et al., 2017). The home range of this species is 124-207 km^2 ~~-~~(Johansson et al., 2016) but estimated at 11-37 km^2 in Nepal’s Himalaya (Jackson; 1996). In Qilianshan National Nature Reserve, China, the density of snow leopard is 3.31 individuals per 100 km^2 (Alexander et al., 2015)~~. ~~Nepal has extremely variable population density; for example Langu valley has 10-12 animals per 100 km^2 and Manang has 5-7 animals per 100 km^2 (DNPWC, 2017). The primary prey targeted by snow leopards include wild species such as blue sheep (*Pseudois nayaur*) and marmots (*Marmota caudate*) as well as domesticated livestock such as yak (*Bos grunniens*) and sheep (*Ovis* spp.) (Aryal et al., 2014; Weiskopf et al., 2016). Snow leopards co-exist with other Himalayan carnivores, such as red fox (*Vulpes vulpes*), grey wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*) and dhole (*Cuonal pinus*) (Alexander et al., 2016a; Bocci et al., 2017). Male snow leopards represent a greater threat to livestock than females (Chetri et al., 2017). While there are several studies characterizing snow leopards, their habits and habitats, there is a need for ~~greater~~more localized information to improve conservation management practices~~, which is somehow provided by this study~~.~~.~~

Human-snow leopard conflict, especially related to~~concerning~~ livestock depredation, represents a major threat to snow leopards (Li et al., 2013; Mijiddorj et al., 2018; Suryawanshi et al., 2013; Ud Din et al., 2017; Wegge et al., 2012). Livestock grazing in snow leopard habitat has been seen to be a serious conservation threat to this species (Ghoshal et al., 2017; Khanal et al., 2018; Sharma et al., 2015). One of the main stressors of snow leopard poaching was found to be retaliatory killing as a consequence of livestock depredation (Maheshwari and Niraj, 2018). Another important factor influencing snow leopard poaching is the illegal trade

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of the body parts and pelts (Hussain, 2003), which is also on the rise (Li and Lu, 2014). Furthermore, impacts of climate change have ~~been~~ emerged as a primary threat to snow leopards; ~~reductions~~~~shrinkages to~~ their habitats are expected to shrink throughout their range (Aryal et al., 2016; Li et al., 2016).

Mitigating human-snow leopard conflict through community engagement is one of the major objectives of the snow leopard conservation action plan for Nepal (2017-2021) (DNPWC, 2017). Research has shown that visitors are willing to pay for snow leopard conservation in the Annapurna Conservation Area in Nepal (Schutgens et al., 2018) but more research is needed on snow leopard interactions with human activities to better understand the influence of snow leopards on livestock herding practices and vice-versa (Alexander et al., 2016b).

This study was conducted to identify the major factors affecting the risk of livestock depredation from snow leopards. We also identified the potential snow leopard attack risk zone within the study area. We hypothesized that anthropogenic variables are more ~~highly~~ correlated with livestock depredation risk from snow leopards than environmental and topographic factors.

Materials and methods

Study area

The study was conducted in the southeastern part of Manang District, Nepal covering a total area of 235 km^2 which is the jurisdiction of the District Forest Office (Now, Division Forest Office) (**Figure 1**). We chose extent of study area by making 3 km buffering from livestock sheds. ~~It is assumed that~~ According to the herders, -livestock travel for grazing up to 3 km and some of them travel in valley, rocks and glacier too. Further, the glacier around the attack zone is not permanent which allows seasonal grazing of livestock. Alongside, in rocky area small

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livestock like ~~Himalayan~~ goat and sheep roam easily, thus considered in the buffer. ~~.~~The study area is rich in faunal and floral diversity. During the study, we recorded Himalayan pine (*Pinus wallichiana)*, east Himalayan fir *(Abies spectabilis)*, Himalayan birch *(Betula utilis)*, yew *(Taxus baccata)*, figwort *(Picrorhiza scrophulariiflora)*, marsh orchid *(Dactylorhiza hatagirea)*, caterpillar fungus *(Ophiocordyceps sinensis)*, felworts *(Swertia chirata)*, love apple *(Paris polyphylla)*, sunpati *(Rhododendron anthopogon)*, sea buckthorn *(Hippophae* spp.), lokta *(Daphne bholua)*, lily *(Lilium nepalense)*, black juniper *(Juniperus indica)* as the major plant species in the study area. Snow leopard (*Panthera uncia)*, musk deer (*Moschus moschiferus)*, common leopard *(Panthera pardus)*, impeyan pheasant *(Lophophorus impejanus)*, Himalayan goral *(Naemorhedus goral)*, wolf *(Canis lupus)*, Asiatic black bear *(Ursus thibetanus)*, barking deer *(Muntiacus muntjac)*, gray langur *(Semnopithecus schistaceus)* are the major wild animals found in the study area.

Insert Figure-1 around here

Plot design and data collection

Firstly, we visited all possible risk zones[1] for the livestock depredation by snow leopard in the study area between April and June, 2018. We prepared the list of herders in the study area, and then conducted a workshop[2] of 5-8 herders and 3-5 villagers[3] to gather information related to livestock depredation by snow leopard and finally mapped the attack sites. Workshop with herders were conducted at livestock sheds and workshops with villagers were conducted at villages. These sites were further validated by district forest office (now division forest office) staffs to check the biasness, if any. The study area is the habitat of common leopard and Asiatic

[1] Possible risk zones were identified based on proximity to shed, grazing/browsing pastures of livestock, grazing area where herders are normally absent
[2] A total of 17 workshops were conducted and participants were replicated in some workshops
[3] Only villagers who received the compensation for livestock depredation were considered for workshops to make sure that participants know the real information about attack sites

black bear as well; however, they use lower elevation than snow leopard and there is no habitat overlap[4] in livestock attack zone. This was further confirmed by local herders, villagers and the forest staffs who regularly patrol there. Wolf generally hunt on pack (with group). Due to hunting patterns, information provided by herders and villagers, and verification by forest staffs, we confirmed that we collected locations attacked by snow leopard, not by other carnivores. A total of 109 attack sites ~~from past~~in the last 3 years were visited to record geo location (GPS points of all unique sites were taken). We maintained at least a 100 m distance between attack locations to ensure that each attack location is unique, resulting in 86 unique locations out of 109 collected.

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Environmental variables

Topographical variables

Geographic factors are responsible for the spatial distribution of the snow leopard (Wolf and Ale, 2009). These geographic variables were used to model the habitat of this species and other Himalayan carnivores in Nepal (Aryal et al., 2016; Bista et al., 2018; Panthi, 2018). A Digital Elevation Model (DEM) with 30 m resolution was downloaded from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). Slope and aspect were calculated from the DEM using ArcGIS software (Table 1).

Vegetative variables

As the snow leopards are carnivores, their diet primarily consists of wild and domesticated herbivores (Aryal et al., 2014; Wegge et al., 2012; Weiskopf et al., 2016), making vegetative variables important to consider (Andersen et al., 2000). Therefore, forest cover of Global Forest Change (GFC) http://earthenginepartners.appspot.com/science-2013-global-forest) was used

[4] Most of the attack zones are around 4000 m of altitude

as a vegetative variable (Hansen et al., 2013). We also included Enhanced Vegetation Index (EVI) to model the potential attack risk of snow leopards. We downloaded EVI time series images from 2015, 2016, and 2017 from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor from the USGS. Then, we used Environment for Visualizing Images (ENVI) software to smooth the data by using an adaptive Savitzky-Golay filter in TIMESAT (Jönsson and Eklundh, 2004), which reduced the cloud effect and allowed us to obtain mean, maximum, minimum and standard deviation of EVI.

Anthropogenic variables

Large numbers of livestock are killed in Nepal due to the proximity of human settlements to the natural range of snow leopards (Aryal et al., 2014; Wegge et al., 2012). Assessing anthropogenic factors leading to livestock predation by snow leopards is critical as these are the variables that represent the greatest degree of control from humans and would allow for achieving the stated goals of snow leopard conservation and decreased livestock mortality from depredation. During field data collection, human activities were documented in snow leopard habitat. We obtained the shape file of motor roads and paths inside the study area from Geofabrik (https://www.geofabrik.de/data/shapefiles.html). The locations of livestock ~~shelters~~shelter within snow leopard habitat were collected during field work. Distance raster files of livestock shelters, footpaths, and motor roads were created using ArcGIS. We downloaded land cover and land use from the International Centre for Integrated Mountain Development (Uddin et al., 2015) and included them in the model.

Insert table 1 around here

Modeling livestock depredation risk from snow leopards

We used MaxEnt software to model the livestock depredation risk from snow leopard in the study area. Geo-referenced presence points of livestock attacks by snow leopard and the environmental variables (**Table 1**) were used as input variables to the MaxEnt model to produce a predictive livestock depredation risk map (Elith et al., 2006; Phillips et al., 2017, 2006). The model was validated by the area under receiver-operator curve (AUC) (Pearce and Ferrier, 2000) and evaluated by True Skill Statistics (TSS) (Allouche et al., 2006). The multicollinearity between variables was less than 0.7, which is acceptable for modeling (Dormann et al., 2013). Seventy percent of the data were used to train the model and 30 % were used to validate the model. We used 10 replications, 1000 maximum iterations, and 1000 background points during the modeling using reference from Barbet-Massin et al. (2012). The threshold to maximize the sum of specificity and sensitivity was used to calculate TSS and to prepare the binary map from the continuous map (Liu et al., 2013).

Results

Snow leopard attack risk zone

We identified 13.64 km^2 as the potential risk zone for snow leopard attacks in the study area. The areas with the highest risk for snow leopard attacks were identified spatially using ArcGIS (**Figure 2**). The AUC and TSS of the model were 0.941+/-0.013 and 0.862+/-0.047, respectively. A threshold of 0.273 was used to prepare the risk map from the continuous probability map.

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The most important variables found in the model to determine snow leopard attack risks are distance to livestock sheds, distance to path, aspect, and distance to motor road (**Figure 3**). Other variables have less information to model the snow leopard attack risk. In **figure 3**, the regularized gain of the model without distance to livestock shed was less than that of the model using other single variables, therefore this is a more useful variable to the model. Similarly, the regularized gain of the models without distance to path, aspect and distance to road are less, which also demonstrates the high utility of these variables in modeling the snow leopard attack risk zone.

Insert Figure-3, around here

The regularized training gain of this figure explains how better the model distribution fits the presence data compared to a uniform distribution. “With all variables” indicates the outcomes of the model when all variables are used; “with only variable” denotes the effect of removing that single variable. “Without variable” denotes the result when only that variable is used (Phillips, 2017). See Table 1 for full variable names and descriptions.

Snow leopard attacks on livestock are much more likely at closer distances to the shed which is used to house the livestock (**Figure 4A)**. Livestock are prone to attack by snow leopards far from foot paths and at a moderate distance to motor roads (**Figure 4B, D**). At western aspect, the probability of snow leopard attacks on livestock is high in comparison to other aspect (**Figure 4C**). Our study area was small, the~~se kind of~~ relationships may be different in other ~~place~~regions or in case of a larger study area.

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Discussion

The southern and western sections of the study area are at the greatest risk of livestock depredation from snow leopards. A portion of the west side of the study area is situated inside the Annapurna Conservation Area (ACA) and other patches identified as risk zones are very near to the ACA, which likely indicates that snow leopards living in the ACA may come to these places to prey on livestock. We did not assess the proportion of the habitat used by snow leopard inside and outside the protected areas, however this study somehow supports the finding of Deguignet et al., (2014). Their study depicted that small proportion (14-19%) of the species ranges in protected areas and primarily share the landscape with livestock herders. These patches were also identified by the interviewed respondents too as the good areas for livestock grazing, which is further evidenced by the high occurrence of livestock shelters. We surveyed only 235 km^2, since the home range of this species is 124-207 km^2 (Johansson et al., 2016), the total area may have retain~~contain~~ed only 2-3 individuals. However, a study indicates that Manang has 5-7 animals per 100 km^2 (DNPWC, 2017), thus there might be more than 2-3 individuals in the study area.

Anthropogenic variables were identified as the most important factors influencing snow leopard attacks on livestock, and this finding is concurrent with existing literature. Multiple studies throughout the snow leopard's native range have recorded livestock depredation (Li et al., 2013; Mijiddorj et al., 2018; Suryawanshi et al., 2013; Ud Din et al., 2017; Wegge et al., 2012) and, in Nepal, the spatial distribution of snow leopard activities has been positively correlated with human activities (Wolf and Ale, 2009). Additionally, carnivore food requirement and spatial needs often conflict with human interest which is the major challenge for biodiversity conservation and maintaining the viable population (Treves and Karanth, 2003), this is supported by this study too. Previous research has shown that the presence of livestock does not negatively affect the occurrence of snow leopards. Alongside, presence of higher livestock in grazing areas may have affected the space used by wild prey which could have forced the snow leopard to prey on livestock, which is supported by Karimov et al., (2018). In fact, snow leopards continue to hunt in the areas close to livestock herding (Alexander et al., 2016; Rovero et al., 2018). The same finding was supported by the results of this study. Alongside, Johansson et al., (2015); identified that snow leopard preys on livestock mainly on stragglers and rugged areas where herders can't pay attention for livestock.

Livestock predation by snow leopard is increased with livestock density (Suryawanshi et al., 2017). Similarly, our research shows that proximity to livestock shelters is the variable most closely associated with livestock depredation from snow leopards, which emphasizes the serious nature of human-snow leopard conflict. If snow leopards attack livestock far from livestock shelters, wildlife managers can restrict livestock from high risk areas and confine them to areas of relative safety using shelter. However, our findings indicate that the areas near to livestock shelter are at high risk of attack. Therefore, wildlife managers have to manage in such a way to allow for the co-existence of livestock and snow leopards in pastureland.

Our study also identified a higher likelihood of snow leopard attack far from foot trails and at a moderate distance from and motor roads. In the study area, there are many foot trails and a few motor roads. Generally, the foot trails and motor roads have a steady flow of traffic, resulting in few snow leopard attacks within direct proximity of foot trails and motor roads.

In order to achieve the goals of increasing conservation for snow leopards as well as decreasing livestock depredation and economic loss from snow leopard attacks, the findings from this research should be applied by herders in high risk zones. Given the high occurrence of attacks close to livestock shelters in the risk model, it is imperative that livestock herders utilize leopard-proof sheds and that vigilant care is given, even near the shelters. The data indicates~~ing~~

that leopards are deterred from attacks in close proximity to humans, as shown by the lack of fit in the model at close spatial scales to footpaths and motor roads, demonstrate the efficacy of human presence in deterring snow leopard attacks. Further research is needed to determine if these results are applicable in areas beyond that studied in this investigation as well as identifying other factors and tactics that decrease human-snow leopard conflict.

It is noteworthy that MaxEnt software only considers the presence of livestock depredation by snow leopards and is therefore limited~~ in~~ ~~that ~~because the risk model cannot account for the absence of livestock attacks. Additionally, although we maintained at least 100 m in distance between livestock attacks to ensure their uniqueness, we did not fully avoid spatial autocorrelation~~ in a scientific manner~~. The ~~scientific ~~statistical method~~s~~ to identify the minimum distance to deal with spatial autocorrelation may be useful for a more robust model. We have collected presence locations of attack sites based mainly on information provided by the herders and villagers, it may be biased and influence the result. Therefore, the probability of showing attack sites of their proximity may be higher. Furthermore, the snow leopard attack risk zone is also zone of livestock presence and livestock are vulnerable to snow leopard depredation in these zones. Finally, while the distribution range of snow leopards is extensive in the Manang d~~D~~istrict of Nepal, our study area is small and only represented a small portion of the large and heterogeneous district.

Conclusions

This study identified the risk zone of snow leopard attacks in the Manang District of Nepal. The southwestern part of the study area was found as the most vulnerable to snow leopard attacks. The distance to livestock shelters, distance to paths, aspect, and distance to roads are the most important variables in defining the risk of snow leopard attacks in the study area. Snow leopards prefer to attack livestock near livestock shelters and at moderate distances from roads. These identified risk patches should be managed to conserve both the snow leopard and to protect the livestock. The herders should be encouraged to protect their livestock through active caretaking, even in close proximity to livestock sheds, and keeping them in leopard proof sheds, which will result in less human-snow leopard conflict. Investigations of this nature should be conducted throughout the snow leopard's range to determine the factors affecting livestock depredation by snow leopards and to model snow leopard attack risk zones across its native range.

Acknowledgements

The study was conducted under the regular annual program of the Government of Nepal. We would like to acknowledge the Department of Forests in Nepal for allocating funding to this program. We would like to thank all of the staff of the District Forest office in Manang for their support during the entire study, especially during data collection, as well as the communities that participated in the study. We would like to thank Marcus E Taylor, Rajani Regmi and Shambhu Paudel for reviewing the l~~English~~anguage of the manuscript.

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