

# Leopard (*Panthera pardus*) occupancy in the Chure range of Nepal.

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## Abstract

Conservation of large carnivores like leopards requires large and interconnected habitats. Despite the wide geographic range of the leopard globally, only 17% of their habitat is within protected areas. In Nepal, leopards are distributed widely across the country but their status is not adequately studied which compromised the necessary conservation attention for the species. This study carried out sign-based occupancy survey across the Chure (the Himalayan foothills) range (~19,000 km<sup>2</sup>) to understand the habitat occupancy of leopards along with the covariates affecting their presence. The model-averaged leopard occupancy in the Chure range was 0.5732 (0.0082 SD) with a detection probability of 0.2554 (0.1142 SE). The top model included wild boar, ruggedness, presence of livestock and human population density as covariates. The  $\beta$  coefficient estimate from the model indicated the wild boar was the primary covariate contributing positively to the leopard occupancy followed by the presence of livestock, ruggedness and human population density. The detection probability of leopard was higher outside the protected areas, less in the densely vegetated areas, and higher in the area where there is a presence of livestock. Enhanced law enforcement and mass awareness activities are necessary to reduce poaching/killing of wild ungulates and leopard in the Chure range and to increase leopard occupancy. In addition, maintaining a sufficient natural prey base can contribute to minimize the livestock depredation and hence, decrease the human-leopard conflict in the Chure range.

## Introduction

Common Leopard (*Panthera pardus*, called 'leopard' hereafter) is a widely distributed large carnivore adapted to a multitude of habitats, and tolerant to live in close proximity with humans (Myers, 1986; Nowell & Jackson 1996; Sunquist & Sunquist 2002; Athreya et al., 2016; Hunter et al., 2013). Despite their high adaptability, they require a large area for survival, thus, threatened by landscape fragmentation, prey depletion, poaching, conflict with humans and trophy hunting (Karanth, 1999; Cardillo et al., 2005; Kissui, 2008; Walston et al., 2010; Athreya et al., 2011; Raza et al., 2012; Strampelli, 2015; Jacobson et al., 2016). The leopard is now confined to 25–37% of its historical range (Cardillo et al., 2005; Jacobson et al., 2016) and listed as 'Vulnerable' in IUCN redlist (IUCN, 2020). Globally, only 17% of the leopard habitat lies inside the protected areas (PAs) (Jacobson et al., 2016). Intact PAs play a significant role for many large carnivores but for leopards, conservation cannot be ensured only in the PAs (Woodroffe & Ginsberg, 1998; Balme et al., 2010; Swanepoel et al., 2013; Strampelli, 2015).

The leopard habitat outside protected areas is rapidly declining and within PAs they face exploitative and interference competition with the socially dominant large carnivores such as tigers (*Panthera tigris*) and lions (*Panthera leo*) in most of their distribution range (Seidensticker, 1976; McDougal, 1988; Seidensticker et al.,

1990; Miquelle et al., 2005; Barber-Meyer et al., 2013; Miller et al., 2018). Among the mammalian carnivores, the less efficient competitors avoid the specialized competitors through spatial segregation by establishing the home range outside of the specialized competitors (Case & Gilpin, 1974; Major & Sherburne, 1987; Theberge & Wedeles, 1989; Robinson & Terborgh, 1995; Thornton et al., 2004; Atwood & Gese, 2010; Grassel et al., 2015).

In Southern lowlands and Himalayan foothills of Nepal, the leopards co-exist with tigers in the National Parks and Buffer Zone areas. The tiger populations in Nepal has almost doubled since 2010 through tiger focused conservation activities in and around the tiger bearing PAs (Thapa et al., 2017; DNPWC & DFSC, 2018). Thus, the increasing number of tigers may have pushed leopards to marginal habitats with some resource overlapping (Kafley et al., 2019; Lamichhane et al., 2019a). A large part of the Chure range falls outside the PAs. The forested areas of the Chure range adjoining the PAs provide habitat for dispersing or pushed out wildlife population including the leopards (Fig 1). Tigers are confined to protected areas and connected forest patches, and a large part of Chure is unoccupied by them. Thus, the Chure forest provides an opportunity for leopards to occupy a large area as apex predator. (DNPWC & DFSC, 2018). A recent study has highlighted its importance as key wildlife habitat (Thapa & Kelley 2017).

Although, Chure range has a potential of being key wildlife habitat for leopards and other associated wildlife, with increasing human pressure, the fragile Chure range has high deforestation rate (FRA/DFRS, 2014) which may limit the abundance and distribution of wildlife (GoN-RCTM, 2017). In addition, there is no comprehensive study on the status and distribution of wildlife in the Chure range. We carried out this study as a part of faunal diversity assessment in Chure range (~19,000km<sup>2</sup>) to understand the distribution and occupancy of leopards. This study provides information on leopard occupancy and associated covariates in Chure range of Nepal with far reaching implications for the conservation of leopards in the human dominated landscapes of Nepal and elsewhere.

## Materials and methods

### Study Area

The study was carried out in the Chure range (18,982 km<sup>2</sup>) of Nepal. Chure is the young mountain range and consists of fragile sedimentary rocks such as mudstones, shale, sandstones, siltstones and conglomerates (Pokharel, 2013). It extends from east to west in southern Nepal touching all the seven provinces (Fig 1). Chure has monsoon dominated sub-tropical climate. The average maximum and minimum temperature of this range lie between 15.8<sup>o</sup>C to 31.8<sup>o</sup>C. The mean annual precipitation is between 1400mm to 2000mm (GoN-RCTM, 2017; FRA/DFRS, 2014). The Chure range has highly rugged terrain and the altitudinal variation ranges from 120m to ~2000m. There are over 160 river systems with a different origin that flows through this range (Chaudhary & Subedi 2019; GoN-RCTM, 2017; FRA/DFRS, 2014).

A large part of the Chure range (>70%) is forested. The Chure range consists of 23.4% of the forest and 3.5% of other woodland covers of Nepal (FRA/DFRS, 2014). This range is important for biodiversity and represents 3 ecoregions, 9 forest types, 8 Important Plant Areas (IPAs), 14 Important Bird Areas (IBAs), and six protected areas (FRA/DFRS, 2014). This range acts as a water reservoir for the Terai region towards the south. The government of Nepal has initiated the conservation of this range via President Chure-Terai Madhesh Conservation Development Board. The central and western part of Chure falls in the Terai Arc Landscape (TAL) which is a globally significant the landscape for biodiversity (MoFSC, 2015) and serves as an important habitat for endangered and threatened wildlife including tiger, greater one-horned rhino (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus*), leopard, gaur (*Bos gaurus*), sloth bear (*Melursus ursinus*), pangolins (*Manis crassicaudata* and *M. pentadactyla*), and hyaena (*Hyaena hyaena*). Ungulates such as wild boar (*Sus scrofa*), barking deer (*Muntiacus vaginalis*), sambar (*Rusa unicolor*), chital (*Axis axis*) and three primates rhesus monkey (*Macaca mulata*), Asamese monkey (*Macaca assamensis*) and Terai grey langur (*Semnopithecus hector*) serve as prey species for a range of carnivores including the leopards.

Chure is the home for 14% of Nepal's human population and only 14% of the Chure area is suitable for

cultivation (SAWTEE, 2016). The majority of the people depend on subsistence farming for food crops and animal husbandry is an integral part of their farm. Livestock grazing is widespread across the Chure forests. Deforestation, unplanned road construction, agricultural practices on the steep slopes, drying of the water resources, lowering of the water table and climate change are affecting this range (Chaudhary & Subedi, 2019; GoN-RCTM, 2017; Bhandari et al., 2016; FRA/DFRS, 2014; Pokharel, 2013).

### Study Design

The Chure range was divided into 4 blocks (size ~2,200–6,400 km<sup>2</sup>) for easy organization of the survey. Each block was further divided into grids of size 10 X 10 km<sup>2</sup> and surveyed in two to three shifts successively. Biologists and experienced wildlife technicians with over a decade long field experience of wildlife conducted the survey in the field. The survey team was trained on survey protocols and wildlife sign identification before starting the survey to ensure the quality of the data. Out of 322 grids cells in the entire Chure range, 223 were surveyed which falls in the forested areas. The grids were further divided into 16 sub-grids of 2.5 X 2.5 km<sup>2</sup> (n=3,568). The survey was conducted between 2016 and 2018. We could not cover the entire Chure range in a single year due to the large area and limited human resources available. We carried out the survey in the same season (post-monsoon) to avoid the potential bias from surveys in different years.

A 2km long random walking transect with four segments of 500m was surveyed within a sub-grid which was used as a replicate. We targeted the existing trails and dirt roads (where possible) to minimize the likelihood of false absences. We recorded the presence/absence of the tracks, fresh droppings, and other signs (feeding sign, territory marking etc.) to detect the presence of large and medium-sized mammal species at each segment in the standard data format as sample covariates. Similarly, the human pressure as looping, encroachment and livestock presence was recorded in each segment.

### Occupancy modeling

We used program PRESENCE (2.12.33) to obtain the occupancy of leopards (MacKenzie et al., 2002). The naïve occupancy was calculated by dividing the no. of grids with species present/total number of grids surveyed in the block. The leopards can travel greater than the size of our replicate (2km) per day, hence the detection of the sign in successive spatial replicates violates the statistical independence required by the standard occupancy model (MacKenzie et al., 2017). The spatial correlation model (Hines et al., 2010) accounts for this correlation in the detection using the Markov spatial dependence approach. For the degree of dependence between the replicated samples, the model uses replicate level occupancy parameters ‘ $\theta_0$ ’ and ‘ $\theta_1$ ’, where ‘ $\theta_0$ ’= Pr (leopard presence in a replicate/grid occupied and which was absent in the previous replicate) and ‘ $\theta_1$ ’= Pr (leopard presence in a replicate/ grid occupied and was present in the previous replicate). We also checked the performance of the standard occupancy model (MacKenzie et al., 2002) and spatial correlation model (Hines et al., 2010) without adding any covariates in our data. We compared these models based on the Akaike Information Criterion (AIC) value as our no. of grids (>200) and replicates were adequate (replicate=16) (Burnham & Anderson, 2002). It clearly showed the correlation in sign detection on 2km long replicates. The AIC value for the spatial correlation model was less than the standard occupancy model indicating better performance by the former model (Supplementary file 1). Hence, all other analysis was performed using this model.

The sample covariates collected from the field survey included prey species, PS= (Barking Deer, Wild boar, Chital, and Rhesus), human disturbance (HD= looping, human encroachment), and livestock presence (L). We separated the wild boar (W) from other prey species because many studies reported leopards avoiding the wild boar (Karanth & Sunquist, 1995; Ramakrishnan et al., 1999) and we wanted to know how wild boar affects the presence of a leopard. Moreover, the occurrence of wild boar was the most widespread among the prey species.

The site covariates were management regime (IO = inside or outside of the national park), vegetation cover measured as NDVI- Normalized Difference Vegetation Index (N), terrain ruggedness index (R), and human population density (PD). If a grid falls more than half inside the national park or buffer zone, it was coded as ‘1’ and ‘0’ if it falls outside. The human population density was obtained from the Gridded

Population of the World Version 4 (GPWv4) (CIESIN, 2018) and NDVI (2018) was obtained from the 250m resolution Medium Resolution Imaging Spectroradiometer (MODIS) satellite images of 2019 (Didan et al., 2015) available at <https://earthexplorer.usgs.gov>. Similarly, the terrain ruggedness index for each grid was calculated using 90m ASTER DEM (Fujusunda et al., 2005) in Arc GIS 10.1. We also included a sampling effort (SE) as a covariate that affects the detection probability. Before adding the covariates in our analysis, we tested the Spearman correlation coefficient ( $r$ ) using PAST version (4.0) (Hammer et al., 2001). If  $|r| \geq 0.7$  between covariates, one of the covariate is dropped off. Here, the correlation between the covariates of human disturbance (lopping and encroachment) and livestock were more than 0.7 (Supplementary file 3). Because of the contribution of livestock in leopard’s diet, we selected livestock and removed human disturbance to obtain the final model (Kshetry et al., 2018; Reynaert, 2018; Kandel et al. 2020). The data were prepared in an excel sheet via creating detection history for the leopard and their prey and livestock detection across all the grids, having 16 replicates each. On each replicate, the detection of the species was coded 1 and non-detection was coded 0. The site covariates were constant in each grid and we applied z-transformation to normalize the site covariate data. We defined the global model as follow:

Global  $[(\Psi) (\text{IO, R, N, PD, PS, W, L}), \vartheta_0 (\cdot), \vartheta_1 (\cdot), \text{Pt} (\text{SE, IO, R, N, L})]$ .

We identified the suitable covariates on the basis of ecological importance, a recommendation from previous studies, and simplest explanation of model (parsimony). We used a constant model for replicate level occupancy parameters ( $\vartheta_0$  and  $\vartheta_1$ ) (Karanth et al., 2011).

We also could not ignore the possibilities that some of the covariates or other unknown factors influencing the leopard presence contribute to variation in the leopard abundance and hence influence the replicate level detectability (Pt). To address this, our occupancy model focused on identifying the suitable covariate model structure for Pt from sample effort (SE), management type (IO), ruggedness (R), vegetation cover (N), and livestock (L). Then the suitable model structure of Pt was kept constant and  $\Psi$  was varied for the top covariate model structure on grid level occupancy. We identified top competitive models that fit the data well with  $\Delta \text{AIC} < 2$ . From these top competitive models, we estimated the grid specific occupancy rate, the total fraction of Chure occupied by the leopard, replicate level occupancy parameters ( $\vartheta_0$  and  $\vartheta_1$ ) and other parameters using the model averaging. We applied the parametric bootstrapping to the untransformed  $\beta$  parameter from the top models via simulating 1000 random deviate to obtain the standard deviation of the mean (MacKenzie et al., 2017, StatDisk 13: Triola Stats, <https://www.triolastats.com/>).

## Results

A total survey effort of 3,244 km transect walk was carried out to record signs of leopard, their prey, and human disturbances. The leopard signs were detected from 70 grids with a naïve occupancy of 0.31. Wild boars were the most abundant among the prey species with records from 104 grids (48%). They were present in 49% of the grids where leopards were detected. Other prey species combined (chital, sambar, rhesus, barking deer) were present in 111 grids (52%). Lopping and encroachment were recorded on 97 grids (45%) whereas livestock was found in 117 grids (55%).

The detection probability was negatively influenced by the location of the grid (inside the protected areas) and vegetation cover (NDVI) whereas positively influenced by the presence of the livestock (Table 1, 3). The top model obtained after model averaging (table 2,3) for the occupancy included wild boar (WB), human population density (PD), ruggedness (R) and livestock (L). The model-averaged leopard occupancy ( $\Psi$ ) in Chure was 0.5732 (0.0082 SD) with the detection probability 0.2554 (0.1142). The  $\beta$  coefficient estimate indicated that the leopard occupancy was highly influenced by the presence of the livestock and the wild boar (Table 2, 3).

[Table 1,2,3,4]

## Discussion

This is the first comprehensive survey of leopard occupancy covering the entire Chure range (18982 km<sup>2</sup>) of Nepal. We found the spatial replicate model performed better than the standard occupancy model

(supplementary 1). Our result showed that more than half of the Chure range was occupied by leopards. The leopard occupancy was primarily associated with the presence of wild boar (one of the prey species), human population density, terrain ruggedness and the presence of livestock. The detection probability of the leopard was higher outside the protected areas, less in the densely vegetated areas and higher in the areas with the presence of livestock.

The reliability of the occupancy is dependent on the detection probability of the leopard sign on the replicates (Hines et al., 2010). The value of naïve estimate occupancy (0.31) through the conventional presence-absence approach created biased in the actual occupancy because it did not consider the false absences (Fig 3). The prior consideration of leopard home range, their behaviour, the prior identification of associated covariates while designing the survey, and formation of the representative global model has helped us to obtain robust detection function and explain the pattern of leopard occupancy as well as associated environmental and ecological factors (Karanth et al., 2011).

In our result, the probability of leopard presence on 1<sup>st</sup> level replicate was more than the probability of leopard presence in a replicate occupied and which was absent in the previous replicate ( $\vartheta_0$ ). Similarly, the leopard presence on a replicate was higher when the previous replicate was occupied ( $\vartheta_1$ ) by the leopard. The result was consistent to Barber-Meyer et al., 2013.

The probability of leopard occurrence in the Chure range in Terai Arc Landscape (TAL) (between Parsa National Park (PNP) in the east and Shuklaphanta National Park (ShNP) in the west (Fig 1, 2) was higher. Within TAL, there are 5 national parks with source populations of leopards. Leopards are highly adaptable in terms of foraging strategy and flexible for habitat selection in the rugged Chure area (Balme et al., 2007; Dutta et al., 2013). Similarly, all 5 national parks are the home for tiger, the apex carnivore. The tiger focused conservation activities in these protected areas has increased their number nearly twice since 2010 (DNPWC & DFSC, 2018). The increasing number of tigers in these national parks may have pushed leopards to the adjacent Chure range (Odden et al., 2010; Thapa & Kelly, 2017; Lamichhane et al., 2019a). Compared to protected areas, the Chure forests outside has a lower density of prey (Shrestha, 2004). Leopard probably avoids interspecific encounters with tigers by choosing these marginal areas (Woodroffe & Ginsberg, 1998; Lamichhane et al., 2019a). Besides the TAL area, in the eastern part of Nepal, there is only a small protected area, i.e. Koshi Tappu Wildlife Reserve (area: 175 sq km) which touches a small portion of the Chure range in the north (Fig 1). Due to this, the wildlife conservation activities are low in the eastern part. Similarly, the average forest cover in the central, western, and far-western grid of the Chure range is greater than the eastern grid. It may have reduced the prey availability and subsequently reduced the leopard occupancy in the eastern part compared to the TAL area. Hence, this study of leopard occupancy distribution helps wildlife managers and policymakers to guide for identifying locations to focus on leopard conservation in the Chure range.

Our results did not correspond to earlier findings that the leopards avoid wild boars (Eisenberg & Lockhart, 1972; Ramakrishnan et al., 1999; Hayward et al., 2006). In our study, it positively influenced the leopard occupancy in the Chure range. The leopard consuming wild boar as a diet was also observed by (Kandel et al., 2020) in the Kamdi forest corridor of the western part of the Chure range. The wild boar occurred in almost half of the surveyed grids in the Chure range, the highest among the mammal species surveyed. Leopard and wild boar co-occurred in 49 (22%) grids. (Karanth, 1999) also reported the occurrence of the leopard proportional to the wild boar. Our study showed the importance of wild boar as prey species on the occurrence of leopard. Some previous studies excluded prey species in their analysis which could have biased the result (Gavashelishvili & Lukarevskiy, 2008; Maharjan et al., 2017).

We also used other prey species (Barking Deer, Rhesus, and Chital) as covariates but their influence in the model was weak. Scarcity of prey other than wild boar in the Chure range could be the reason for this. The opportunistically placed camera traps along with this survey also photographed poachers with guns in various locations. It indicates the widespread hunting of wild prey species which have probably contributed to reducing the prey abundance.

The positive influence of the ruggedness index on leopard occupancy indicates the extensive use of rugged Chure hills by leopards. The rugged terrain provides an opportunity for ambush predators to hunt (Sharma et al., 2015). Leopards are excellent climbers and rugged terrain probably does not limit their movements/use of the habitat. Generally flat and less rugged areas are occupied by human settlements and the rugged hills are still covered with forest providing habitat for leopards, their prey and other wildlife. However, we didn't find the relation between vegetation cover (NDVI) and leopard occupancy. Instead, the detection probability was inversely related to NDVI. In intact forests (high NDVI value) generally, there are fewer and less visible animal trails. Detecting the leopard sign in such a forest is comparatively difficult which reduces the detection probability. The survey was conducted in the post-monsoon season, the time the leaves start shading from the deciduous trees. The fallen leaves covering the forest floor also reduces the chances of detecting the leopard sign in densely vegetated areas.

We found the positive influence of human population density and livestock on leopard occupancy. It indicates that leopards can persist in the highly modified landscape with high human population density. The findings correspond to (Athreya et al., 2013, 2016; Kuhn, 2014). The majority of the Nepalese rural community is based on agriculture and livestock is an integral part of their farm (Lamichhane et al., 2019b). Thus, livestock can be used as a proxy of human pressure in this landscape. Livestock was present in ~55% of the surveyed grid and leopard occurred in 19% of the grids with livestock presence. It increases the chances of livestock encounters by leopards. Leopards may be depending potentially for their diet in the livestock (Kandel et al., 2020).

Leopards are specialized solitary hunters primarily hunting wild ungulates, but also kill livestock if opportunity arises (Treves & Karanth, 2003; Kandel et al., 2020). In the presence of the sufficient natural prey base, leopards tend to avoid livestock (Kolowski & Holekamp, 2006). We do not have the data on the density of prey in the Chure range but the low detection of prey signs (except the wild boar) indicates their low abundance (Smallwood & Fitzhugh 1995; Stander, 1998). In absence of enough wild prey leopards shift to livestock for diet (Khorozyan et al., 2015) which is also observed in our study with the positive influence of the livestock on leopard occupancy. So, this opportunistic predator may have followed the optimal foraging theory to minimize their search time, encounter rates and the energy cost to capture prey (Sunquist & Sunquist, 1989; Lamichhane & Jha, 2015). It indicates the possibilities of human-leopard conflict in the Chure range. We suggest that maintaining a sufficient natural prey base can contribute to minimize the livestock depredation and hence, decrease the human-leopard conflict in the Chure range. Similarly, the detection of the leopard sign was higher in the Chure range that falls outside the protected areas. It may be because the vegetation cover (NDVI) inside the national park is high in comparison to the outside area which reduces the chances of leopard sign detection.

More than half of the Chure range is occupied by leopards. We identified wild boar, human population density, ruggedness and livestock presence as top covariates influencing their occupancy that would support the policymakers, researchers, and wildlife managers to search possibilities to increase the leopard occupancy in the range. The grid wise occupancy estimate provides insight to identify the area that needs conservation actions. The positive influence on the occupancy of leopard with the presence of wild boar and livestock has indicated the importance of wild ungulates and pointed the possibilities of human-leopard conflict. The activities focusing to increase the wild prey base in the Chure range through better protection would help to reduce the livestock depredation by leopards and their retaliatory killing.

Sign based occupancy survey is a suitable method for landscape-level studies of large-ranging species like leopards. We recommend carrying out an occupancy survey in the Chure range periodically to understand leopard status as done for tigers in TAL. In future research, the exploration of the livestock depredation and human-leopard conflict data add value to understanding the dynamics of the conflict.

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Table 1: Role of covariates in determining detection probability of leopard sign (Pt) on 2km long replicates, based on covariates for probability of occurrence of leopard from the global model, Global ( $\Psi$ )= IO, R, N, PD,PS,WB,L

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	D
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L)	844.33	0	0.5148	1	30	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(N)(L)(R)	846.04	1.71	0.2189	0.4253	31	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(N)(L)(SE)	846.19	1.86	0.2031	0.3946	31	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(N)	850.81	6.48	0.0202	0.0392	29	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(L)	851.35	7.02	0.0154	0.0299	29	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(N)(SE)	852.63	8.3	0.0081	0.0158	30	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(N)(R)	852.71	8.38	0.0078	0.0151	30	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)	853.75	9.42	0.0046	0.009	28	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(SE)	854.04	9.71	0.004	0.0078	29	7
psi(IO)(R)(N)(PD)(PS)(WB)(L), $\vartheta_0, \vartheta_1,p$ (IO)(R)	854.62	10.29	0.003	0.0058	29	7

Table 2: Role of covariates in determining probability of leopard occupancy in the Chure range, structured on Pt obtained from Table 1.

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	Deviance
psi(WB)(PD)(R)(L), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L),th0pi()	858.33	0	0.612	1	27	804.33
psi(WB)(PD)(R), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L),th0pi()	859.35	1.02	0.3675	0.6005	26	807.35
psi(WB)(PD)(L), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L),th0pi()	866.27	7.94	0.0116	0.0189	26	814.27
psi(WB)(PD), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L),th0pi()	867.94	9.61	0.005	0.0082	25	817.94
psi(WB)(R), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L),th0pi()	868.46	10.13	0.0039	0.0063	25	818.46
psi(WB)(L), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L),th0pi()	876.36	18.03	0.0001	0.0001	25	826.36

Table 3: Model-specific  $\beta$  coefficient estimates for covariates determining leopard occupancy in the Chure range.

$\beta$ coefficient estimates for covariates determining leopard occupancy $\Psi$ in Chure a	
Model	$\beta_0$ (SE( $\beta_0$ ))
psi(WB)(PD)(R)(L), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L)	-1.067920 (0.599866)
psi(WB)(PD)(R), $\vartheta_0,\vartheta_1,p$ (IO)(N)(L)	-1.073205 (0.601534)

Table 4: Estimated occupancy, other parameters, and variance

Pr (leopard presence on the 1st replicate, i.e ( $\vartheta_0$ (SE( $\vartheta_0$ )))	0.2168 (0.
Pr (leopard presence in a replicate/grid occupied and which was absent in the previous replicate, i.e. $\vartheta$ (SE( $\vartheta$ )))	0.1292 (0.
Pr (leopard presence in a replicate/ grid occupied and was present in the previous replicate, i.e. $\vartheta_1$ (SE( $\vartheta_1$ )))	0.4726 (0.
Pr (detecting leopard sign on a replicate/grid occupied, i.e. Pt (SE(Pt)))	0.2554 (0.
Pr (the total fraction of the area occupied by leopards in the Chure range, i.e. $\Psi$ (SE( $\Psi$ )))	0.5732 (0.
Naïve Occupancy of leopard from the traditional present/absent approach in the Chure range	0.31

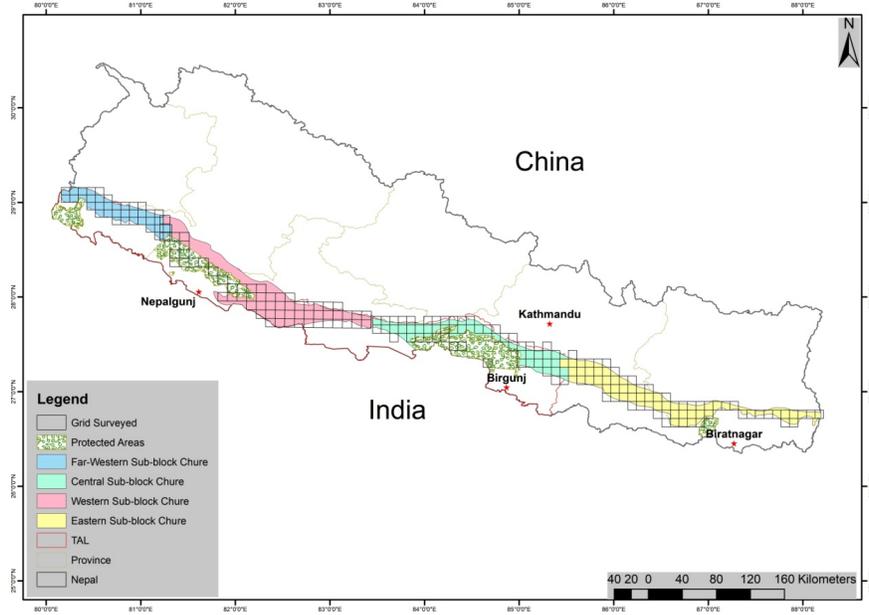


Figure 1: Study area

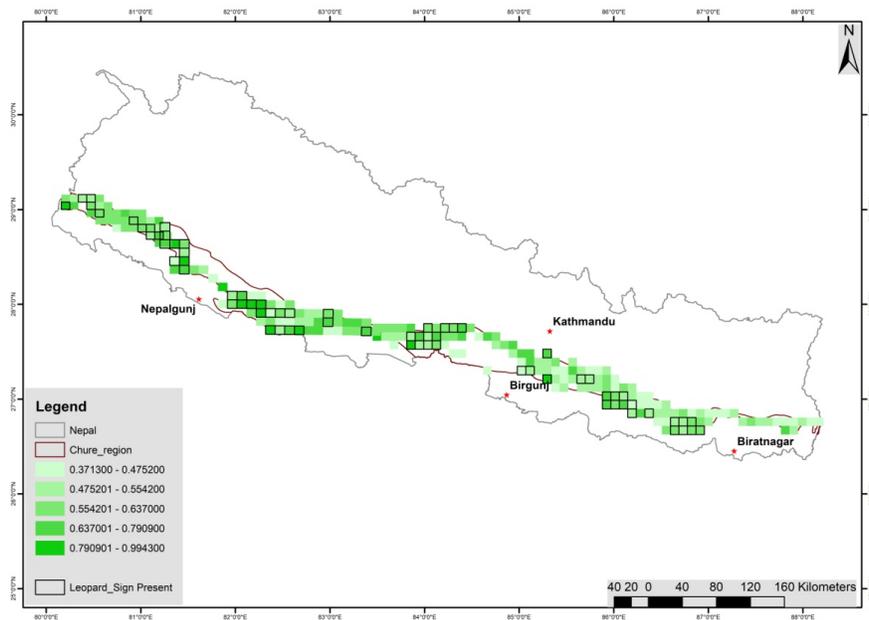


Figure 2: Probability of site occupancy of leopards in the Chure range.

**Declaration:**

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Author's Contribution: NS, BRL, RR, MD designed the research. BRL, SL, AG, SB, RPP, AP, SKT lead to collect the data. SL, BRL interpreted the data and wrote the manuscript. NS supervised the study.

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