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Original Research Article

# Predicting the potential distribution and habitat variables associated with pangolins in Nepal

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A B S T R A C T

Pangolins are highly-threatened due to illegal hunting and poaching, and by the loss, degradation, and fragmentation of their habitats. In Nepal, effective conservation actions for pangolins are scarce due to limited information on the distribution of pangolins in many areas of the country. To identify the nationwide distribution of pangolins in Nepal, and assess the environmental variables associated with their habitat, we conducted an extensive literature review to collate data from previous studies, canvassed information from key informant interviews and expert opinion, and conducted transect surveys and sign surveys. The occurrence of pangolins was recorded based on sightings and indirect signs (such as burrows, digs, tracks, and scats) along 115 belt transects of 500-m length with a fixed width of 50-m, and habitat parameters were surveyed using 347 quadrats of 10 m*10 m. Pangolin presence was confirmed from 61 out of 75 districts from the eastern to the far western parts of the country. The highest frequency of burrows (74%) was

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observed in the forested habitat constituting brown soil with medium texture (0.02−2 mm) within an elevation range of 500−1500 m above sea level. Logistic regression suggested that the occurrence of pangolin was highly influenced by ground cover and canopy cover of 50−75%, litter depth, and the distance to termite mounds and roads. We used 4136 occurrence GPS points of pangolin burrows that were compiled and collected from the literature review and field surveys in order to predict the potential habitat distribution of pangolin using maximum entropy algorithm (MaxEnt 3.4.1). The model predicted 15.2% (22,393 $km^2$) of the total land of Nepal as potentially suitable habitat for pangolin, with 38.3% (8574 $km^2$) of potential habitat in the eastern region, followed by 37.6% (8432 $km^2$) in the central and 24.1% (5,387 $km^2$) in the western regions. The results of this study present a national baseline for pangolin distribution and serve as an important document for developing and executing conservation actions and management plans for the long-term conservation of pangolins in Nepal.


## 1. Introduction

All eight extant species of pangolin, four in Asia (Manis sp.) and four in Africa, are considered globally threatened on the IUCN Red List of Threatened Species (IUCN, 2019). They are also listed in Appendix I in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2019). The best available information (collated in the Red List assessments) suggests that pangolin populations are declining throughout their range countries including in Nepal (IUCN, 2019), with the exception of Taiwan (Sun et al., 2019). Targeted, untargeted, and opportunistic illegal hunting and poaching takes place to supply markets for meat and scales in China and Vietnam (Wu and Ma, 2007; Pantel and Chin, 2009; Heinrich et al., 2017), despite pangolins being protected within many of their range countries in Asia and Africa by their respective national laws and acts (Challender and Waterman, 2017).

Out of four Asian pangolin species, the Chinese pangolin (*M. pentadactyla*) and Indian pangolin *(M. crassicaudata*) are found in Nepal (Baral and Shah, 2008; Jnawali et al., 2011; Thapa, 2014). Both species are at risk of extinction due to habitat loss and illegal trade for meat and traditional Chinese medicine (Challender et al., 2019; Mahmood et al., 2012). Within Nepal, pangolins are categorized as Endangered in “The Status of Nepal’s Mammals: National Red List Series” (Jnawali et al., 2011) and they also fall within the protected list of species under the National Parks and Wildlife Conservation (NPWC) Act 1973. Pangolins are widely distributed throughout Nepal however they are recorded mainly from within the protected areas of the country (Khatiwada et al., 2020). The Indian pangolin has been recorded from Bardia National Park and Suklaphanta National Park (Shrestha, 2003) as well as Banke National Park (Kaspal et al., 2016). According to the National Red list of Mammals of Nepal, the Indian pangolin has also been recorded in Chitwan National Park, whereas the Chinese pangolin has been recorded in Annapurna Conservation Area and Makalu Barun National Park (Jnawali et al., 2011). Presence of Chinese pangolin has also been confirmed from Shivapuri Nagarjun National Park (Gurung, 1996; Shrestha and Basnet, 2005; Bhandari, 2013) and Parsa National Park (Gopali, 2015).

Chinese and Indian pangolins use a wide range of habitats, including primary and secondary tropical/subtropical forests, bamboo forests, grasslands, agricultural fields, and some degraded habitats (Chao, 1989; Gurung, 1996; Baillie et al., 2014; Suwal, 2011; Katuwal et al., 2017). The information on habitat preferences in Nepal by previous studies are highly localized to a single habitat - tropical and subtropical habitat dominated by mixed and pine tree species. To date, no efforts have been placed on identifying potential habitats for pangolins. The main threat to pangolins is overexploitation, but the lack of quality information on ecology and population of these species has made pangolin conservation challenging. Therefore, we aimed to 1) map the species distribution by districts, 2) assess the important habitat features and their influences on pangolin occurrence, and 3) predict potential habitats across the country. We also provided suggestion to conservation actions in Nepal.

## 2. Material and methods

### 2.1. Study area

The study covered different physiographic zones of Nepal such as Middle Mountain, Hill, Siwalik, and lowland Tarai. The scope of this study spans throughout Nepal, however, the study excludes seven districts of High Mountain in the western part of the country (namely Dolpa, Humla, Jumla, Kalikot, Manang, Mugu, and Mustang) where pangolin populations are unlikely to exist due to their landscapes being characterized by snow, rock, boulders, and a shallow soil layer (<30 cm).

### *2.2. Literature review*

An extensive review of all available published and unpublished literature on pangolins in Nepal was conducted through searches at different universities, libraries, government and non-government agents, national and international journals, and daily newspapers. These documents were reviewed to acquire detailed information about the status, distribution, and threats of pangolins prior to selection of the districts (sites) for intensive field survey. These materials included Bachelor's and Master's degree dissertations, books, government and organizational project reports, newspaper articles, newsletters and pangolin seizure records in Division Forest Offices and Central Investigation Bureau in the country.

We conducted web searches for journals and proceedings of articles using Google Scholar and Web of Science. During the web searches, we used key words in English for pangolins (pangolin, Chinese pangolin, or Indian pangolin), and combined them with other relevant terms (status, distribution, habitat, threats, trade, conservation, poaching, hunting, seizures, rescued, in-situ, and ex-situ). Given the general lack of information on pangolins specifically, we also used more general terms to search for studies that may have information on pangolins (endangered species, small-sized mammals, burrowing mammals, and ant eaters).

### *2.3. Key informant interviews (KIIs)*

Key informant interviews (KIIs) were conducted during 2016–2019 through emails, telephone communication, and face-to-face interviews with the key persons in the Division Forests Offices, Sub-Division Forest Offices, Rural Development Committee/Municipalities, and Community Forest personnel, university professors, and experts working on pangolin research and wildlife conservationists. Altogether 110 people were interviewed to document the presence/absence, status and distribution of pangolins in their respective areas. The information collected from KIIs were verified through scales, burrows, and photographic evidence of live pangolins which were encountered and rescued. Information about the date and year of any encounters were collected along with their knowledge of pangolin ecology and behavior. We also conducted five expert meetings during this period and each meeting involved 15 to 25 participants. Besides the expert meetings, several consultations and discussions were organized with government officers from relevant wildlife sectors, professors, researchers, conservation stakeholders, and journalists to collect their opinions on pangolin presence, status, and distribution.

### *2.4. Transect and sign survey*

Transect and sign surveys were conducted to determine the presence of pangolins across the country. The districts for the study were systematically selected to represent different ecological zones; five districts in each zone (Tarai, Hill/Siwalik and Middle Mountain) extending from the eastern to the western parts of the country. The 15 selected districts varied topographically (Fig. 1) and most of the sites in the Tarai region had more than 75% of vegetation cover that included the tree cover and ground cover (bushes and grasses). The altitude of the survey sites ranged from 80 m to 3000 m above sea level, and varied in terms of their forested (tropical, sub-tropical and temperate forests with mixed, coniferous, and broad-leaved trees) or non-forested (shrubland, and agricultural land) habitat types.

After the compilation of all the prior information acquired through the literature review, KIIs and expert opinion, we developed pangolin monitoring guidelines. The selected 45 field staff comprised of researchers and university graduates from different districts who already had some level of first-hand field experience of research on pangolins. In addition to their first-hand field experiences, the selected field staff were provided with theoretical and practical training on pangolin ecology and survey methods to refresh their knowledge on the identification of pangolin signs and habitat prior to the actual field surveys. The level of confidence of the field staff on identification of pangolin signs was assessed by test-visits to the habitat of pangolins. Nine of the previously studied and reported sites on the occurrence of pangolin presence in eastern (Sankhuwasabha), central (Dolakha, Kavre, Bhaktapur, Kathmandu, Sindhupalchowk) and western parts of the country (Banke, Bardia and Gorkha) were also resurveyed for verification of the reported previous evidence. An additional 12 unexplored districts from eastern (Siraha), central (Mahottari and Rautahat), and western parts of the country (Parabat, Rukum, Jajarkot, Kailali, Doti, Baitadi, Bajang, Bajura and Darchula) were newly surveyed along the elevational gradients. A total of 60 people including 45 trained biologists and 15 local people conducted approximately 7200 h (60 persons $\times$ 15 day $\times$ 8 hrs.) of surveys.

Pangolins are difficult to monitor due to their elusive and nocturnal nature and burrow-dwelling behavior (Willcox et al., 2019). Indirect signs (especially burrows) were considered as an effective indicator of the pangolin occurrence in an area (Wilson and Delahay, 2001). Transects survey (Supplementary Figure: A1 a, b) and burrow counts are used commonly for studying burrowing species (Ingram et al., 2019).

From the location of a burrow (active/old) or any other evidence of pangolin presence (digs/footprints/scats), a belt transect of 500-m was laid with fixed width of 50-m (25-m on each side). A minimum distance of 200-m was maintained between adjacent transects to avoid overlapping of sampling areas. We deployed a total of 115 belt transects within the selected survey districts according to the topography and environmental gradient of the survey area. However, the number of transects varied in different parts of the country due to the topographical barriers and presence/absence of pangolin evidence. We laid three transects in each site to cover large sample area.

Based on the structure of pangolin burrows, burrow entrances and the surrounding vegetation (herbs), we searched for both active/fresh and old burrows of pangolins along each transect. Other indirect signs such as digs, footprints and scats were

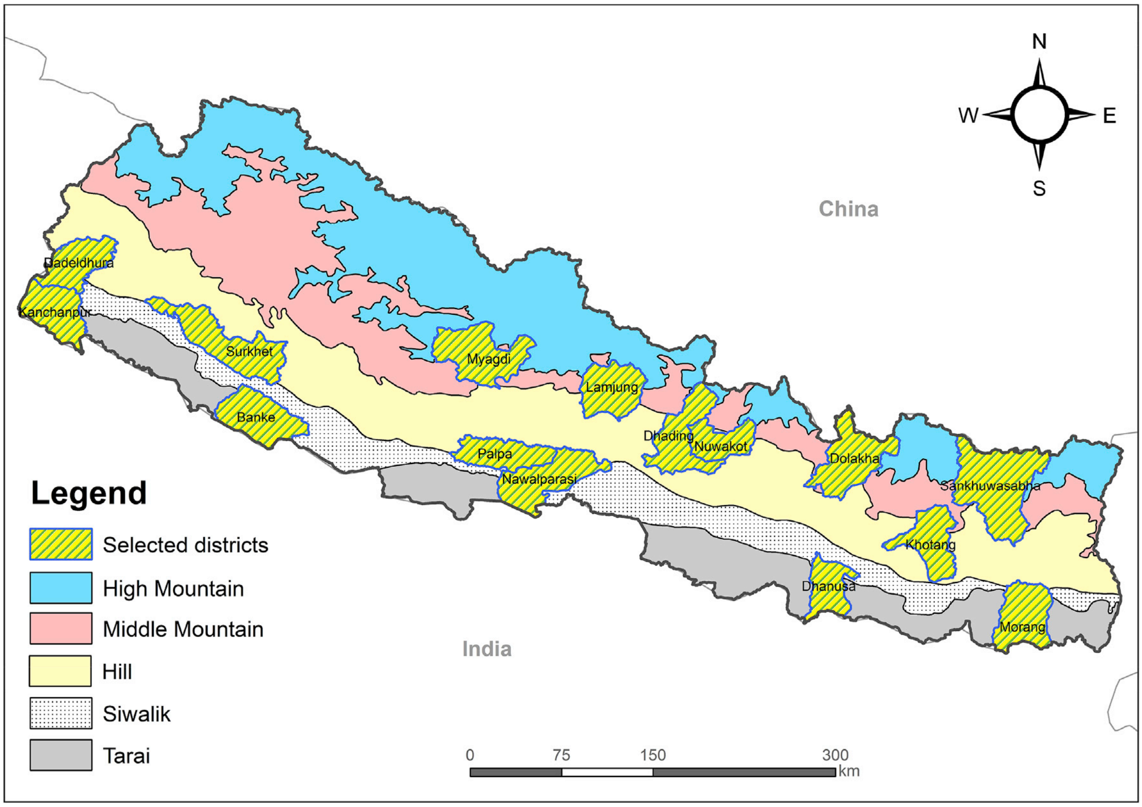


**Fig. 1.** Selected survey districts in different ecological zones in Nepal.

also recorded (Suwal, 2011; DNPWC, 2019) (Supplementary Table: A1). Upon encountering evidence of pangolin occurrence during the transect surveys (Supplementary Figure: A2 a, b, c, d, e, f, g, h), the location of the evidence was recorded using a GPS receiver (Garmin eTrex 10). Around each detected burrow, a 10 m × 10 m quadrat (N = 347) was laid to assess the habitat, geographic and proximity variables (Supplementary Table: A2).

### 2.5. Pangolin habitat preference and distribution mapping

The data from the literature, KIIs and surveys were collated and analyzed to establish the distribution range of pangolins, and their relationships with habitat variables. Based on the GPS coordinates, the distribution map of pangolin's habitat was prepared using ArcGIS 10.6 (ESRI, 2016). We tested 13 habitat variables (forested/non-forested habitat, canopy cover, ground cover, litter depth, soil color, soil texture, elevation, slope, aspect, distance to water, road, settlement and termite mound) (Supplementary Table: A2) and selected a minimum adequate model in a logistic regression. Model selection was conducted using a backward selection approach using Akaike Information Criteria (AIC) to select the model and Pseudo- $R^2$ values were calculated using a Hosmer-Lemeshow test. All statistical analyses were carried out using R (R Development Core Team, 2019).

The Maximum entropy algorithm (MaxEnt 3.4.1), a bioclimatic modeling approach for presence-only data (Elith et al., 2006, 2011; Wisz et al., 2008), was used to predict pangolin's potential habitat due to its flexibility with sparse or noisy input information and good predictive performance (Phillips et al., 2006; Phillips and Dudik, 2008). A total of 4136 presence records were compiled from literatures and field surveys (Supplementary Figure: A5). MaxEnt automatically removes multiple occurrences within a grid of 1 km × 1 km. For MaxEnt modeling, we included an additional 19 bioclimatic raster layers, which were downloaded from the WorldClim database (www.worldclim.com) (Supplementary Table: A4) at a 30 arc sec (~1 km) spatial resolution (Hijmans et al., 2005). To remove multi-collinearity, variables having correlation values > 0.7 were excluded in the model building. Eight bioclimatic variables (i.e., annual mean temperature, mean diurnal range, isothermality, mean temperature of coldest quarter, annual precipitation, precipitation of driest month, precipitation seasonality and precipitation of driest quarter) and 4 topographic variables (i.e., slope, aspect, elevation and land cover) were selected to develop the prediction model. Aspect and slope were derived from elevation data of WorldClim which have similar resolution with climate variables.

The model output was converted into a binary map using the logistic threshold methods which maximizes the sum of the sensitivity and specificity (Liu et al., 2013). We tested the model predictive ability with twenty-fold cross-validations and comparisons based on the Area Under Curve (AUC) of the Receiver Operator Characteristics (ROC) curve. Then, we selected the training and tested AUC above 0.75 which indicates a reasonable to high model discrimination ability and good model performance (Elith et al., 2006) (Supplementary Figure: A6). The imported data was reclassified into three classes of habitat suitability: low (0.22–0.50), moderate (0.50–0.75), and high (>0.75) by omitting the values below the threshold as unsuitable habitat (Shrestha and Bawa, 2014; Thapa et al., 2018).

## 3. Results

### 3.1. Distribution, abundance and GIS mapping

A total of 77 pieces of literature were reviewed comprising project reports (N = 14), journal articles (N = 22), relevant books (N = 8), dissertations (N = 19), newspaper articles describing seizures, confiscations, and rescue and release cases (N = 14). Together with Key Informant Interviews (KIIs), and transect and sign surveys, pangolin presence was confirmed in 61 districts (81%), except in the north-western districts, across the country. Out of the 61 districts, pangolins have only been previously recorded in 28 districts (37%).

Two wild live Chinese pangolins were encountered in eastern Nepal (Khotang) during the field visits and another Chinese pangolins were caught live by local people in Bhaktapur and Kathmandu districts which were safely released back into the nearby community forests of respective districts in collaboration with forest staffs, local conservationists and Community Forest User Groups (Supplementary Figure: A2 j, k).

Chinese pangolin was confirmed from 24 districts mostly situated in the eastern and central parts of the country; eastern (Saptari, Jhapa, Ilam, Dhankuta, Panchthar, Terathum. Khotang, Taplejung, Sankhuwasabha, and Solukhumbu), central (Makwanpur, Sindhuli, Ramechhap, Bhaktapur, Kathmandu, Lalitpur, Kavrepalanchok, Dhading, Dolakha, and Sindhupalchok) and western (Palpa, Baglung, Lamjung and Gorkha). The confirmed locations ranged from Tarai to Middle Mountain respectively. The study found evidence of both Chinese and Indian pangolins in central (Chitwan and Parsa) and western parts (Kanchanpur, Banke, Bardia and Surkhet) of the country whereas Indian pangolin was also recorded in other districts in the central (Bara) region and western Tarai (Kailali) region. For the remaining 29 districts with a pangolin presence record, we could not identify the exact species (Fig. 2).

A total of 1063 burrows of single entrance were recorded during the field surveys in this study, spanning across the eastern (N = 701), central (N = 186), and western (N = 176) parts of Nepal. The highest number of burrows were reported from eastern Nepal in Sankhuwasabha (n = 355 burrows) and Khotang (n = 294 burrows) districts. The fewest number of burrows were recorded in the western part of the country; Dadeldhura, Nawalparasi, Surkhet and Myagdi (Fig. 3).

The average encounter rate of burrows was 18.5 burrows/km, and differed by ecological regions with the highest rate in Middle Mountain (32.3 burrows/km) followed by Hill and Siwalik (16.6 burrows/km). Geographically, the encounter rate of burrows was highest in eastern part (45.2 burrows/km), followed by the central (10.3 burrows/km) and western part (7.3 burrows/km) (Table 1). Other signs such as scratches (N = 68), digs (N = 13) and footprints (N = 6) were also recorded along with burrows in different parts of country.

### 3.2. Habitat features and influencing variables

Forests with mixed vegetation of different tree species dominanted by *Shorea robusta, Schima wallichii, Castanopsis indica,* and *Alnus nepalensis* were the main habitat type where the majority of the pangolin burrows (74%) were recorded. The highest number of pangolin burrows (48% burrows) were found in areas with 50–75% canopy cover and ground cover. Similarly, more burrows were observed in brown soil (46%) and medium texture soil (0.02–2 mm; 69%). Furthermore, burrows were distributed mainly in an altitude range of 500–1500 m with slope ranging from 30 to 50° (Supplementary Figure: A3 a, b; A4 a, b).

Out of 13 habitat variables, eight variables were selected in the minimum adequate model using a logistic regression where seven variables were found to be statistically significant i.e. ground cover (50–70%), litter depth, distance to termite mound (=<300 m), canopy cover, habitat type, distance to road and slope (Fig. 4). Probability of pangolin occurrence was found to have weak effect above 75% and below 50% of canopy cover, and decreased with the habitat type moving from the forest to non-forest habitat (shrubland, and agricultural land) (Table 2).

Pseudo $R^2$ values (Hosmer-Lemeshow $R^2 = 0.221$, Cox and Snell $R^2 = 0.262$, Nagelkerke $R^2 = 0.351$, McFadden $R^2 = 0.588$).

### 3.3. MaxEnt prediction modelling of the potential habitat

The validity of the model for the current distribution of pangolins was high (AUC = 0.917), indicating the selected variables described the distribution of pangolins in the country. The model predicted 62 districts of the country as the potentially suitable habitat for pangolins. The total predicted area of current suitable habitat for pangolin is 22,393 $km^2$ (*ca* 15.2%) in Nepal. Among the total predicted area, only 2940 $km^2$ (*ca* 17.0% of the total predicted area) lies inside the Protected Area system of Nepal. The model predicted that the eastern part as a potential habitat with 8574 $km^2$ area (*ca* 38.2%), followed by the central part with 8432 $km^2$ (*ca* 37.7%) and western part with 5,387 $km^2$ area (*ca* 24.1%) (Fig. 5).

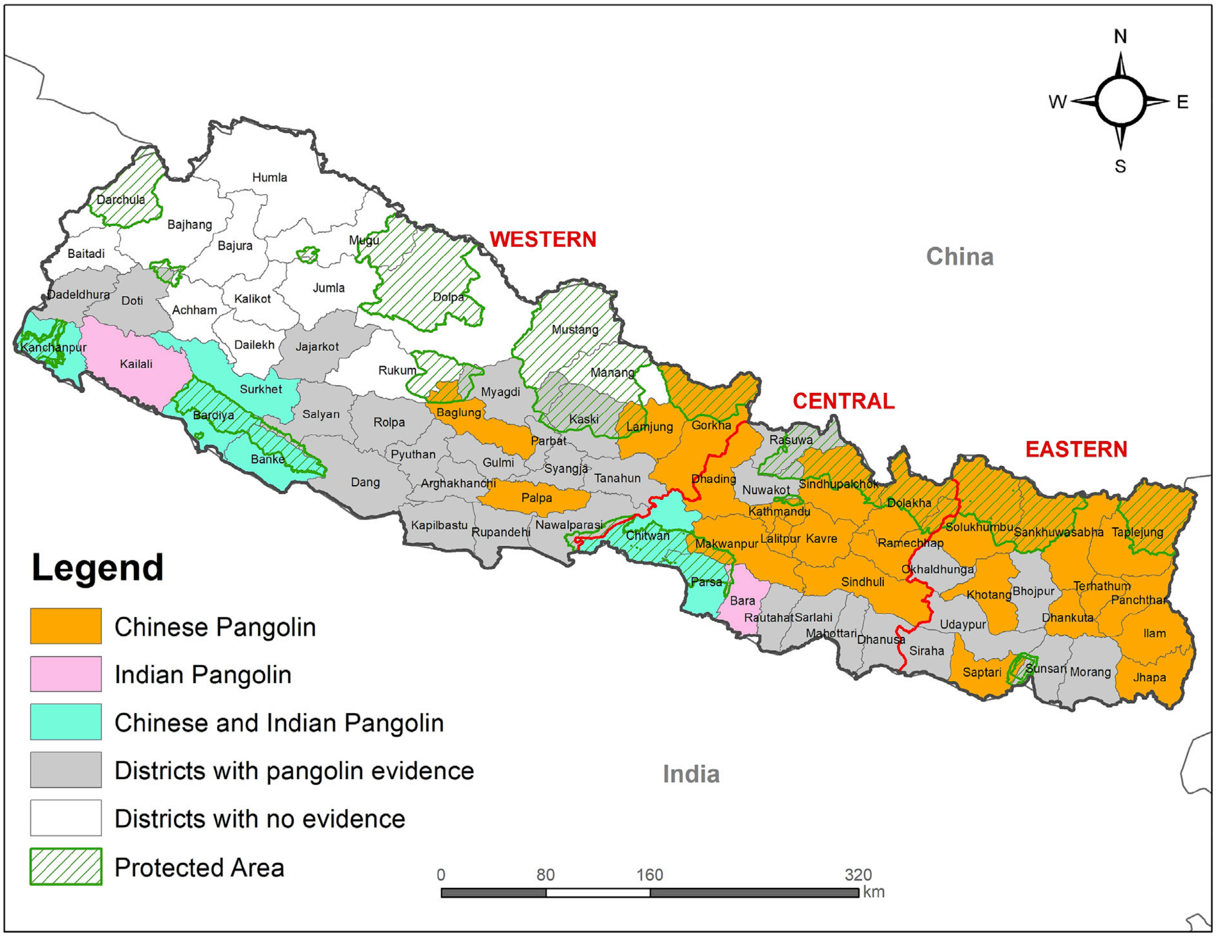


**Fig. 2.** Map depicting distribution of pangolin in Nepal by district based on the mixed methods used.

Among the 19 bioclimatic variables used for the habitat prediction, elevation (25.2%), precipitation of driest quarter (19.1%), isothermality (17.2%), annual precipitation (12.8%) and precipitation of driest month (11.7%) were the main contributing environmental predictors which contributed 86% for the prediction of the pangolin's habitat (Supplementary Figure: A7). The predicted habitat of pangolin ranged between 132 m up to 2704 m in elevation where the highest suitability class of habitat peaked at 1150 m (Supplementary Figure: A8). Low suitability habitat was found below 500 m and above 1750 m.

## 4. Discussion

This study addressed the lack of understanding of the distribution of pangolins throughout Nepal. Before 2000, the presence of pangolins was recorded only from 13 districts of Nepal, mostly in the central and eastern districts (Hodgson, 1836; Shrestha, 1981; Corbet and Hill, 1992; Suwal and Verheugt, 1995; Gurung, 1996). Pangolin presence was confirmed in a further 10 districts between 2000 and 2017 (Shrestha and Basnet, 2005; Kaspal, 2008; Suwal, 2011; Bhandari, 2013; Karki, 2015; Khatri-Chhetri, 2013, 2015; Khatiwada, 2014; Thapa et al., 2014; Katuwal et al., 2015; Gopali, 2015; Karki and dissertation, 2015; Dhakal, 2016; Khadgi, 2016; Acharya, 2016; Sapkota, 2016; Katuwal et al., 2017). The current study, however, could not find any evidence of pangolin presence to support the previous reports of pangolin from Baglung district (Shrestha, 1981; Jnawali et al., 2011). Additionally, the local people in Achham, Dailekh, and Rukum reported to have encountered pangolins 15–20 years ago, mentioning that they have neither seen a live pangolin nor a pangolin burrows in the districts recently. This anecdotal information suggests that pangolins may have greatly declined or even already extirpated in these areas.

Whilst pangolins and their habitats receive some level of protection inside Protected Areas, our predictive models of their habitat suggest that most of the pangolin habitats exist outside the Protected Areas. Furthermore, field surveys indicated that deforestation caused by forest fire, as well as for developing roads, mining, cattle grazing, logging and building construction has caused degradation and loss of pangolin habitat, which is a similar issue in other pangolin range states (China, India,

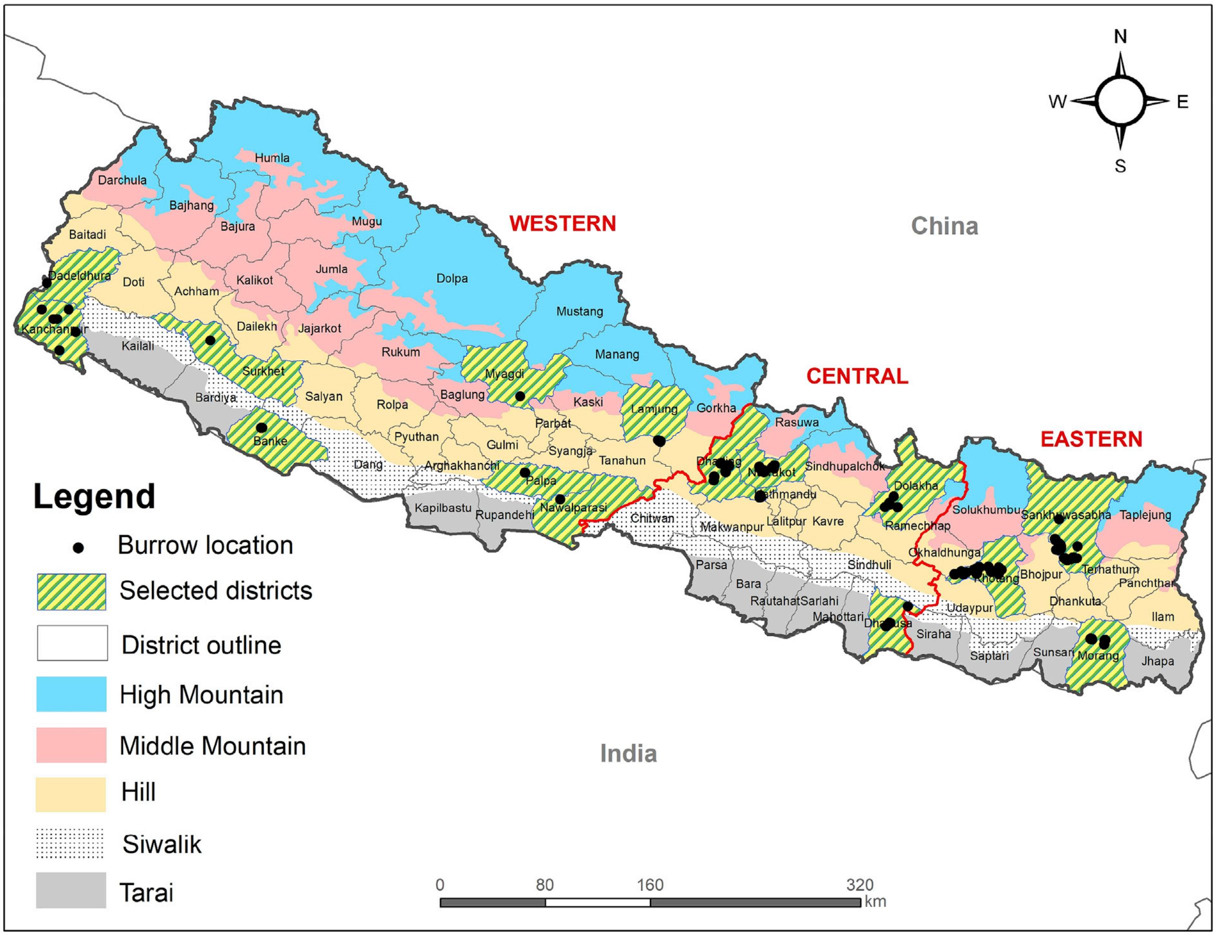


**Fig. 3.** Map depicting districts with confirmed presence of pangolin with burrow locations.

**Table 1**
Relative abundance of pangolin in different parts of Nepal; Total count (N), Mean, Standard Deviation (SD), Minimum (min), Maximum (max).

| | Ecological Regions N (Mean ± SD) (min-max) | | | |
|---|---|---|---|---|
| Variables | Tarai (5 Districts) | Hill and Siwalik (6 Districts) | Middle Mountain (4 Districts) | Total |
| No. of Transects | 28 (5.6 ± 1.5) (3–7) | 53 (8.8 ± 4.1) (4–14) | 34 (8.5 ± 3) (5–11) | 115 |
| Length of Transects (km) | 14 (2.8 ± 0.8) (1.5–3.5) | 26.5 (4.4 ± 2.1) (2–7) | 17 (4.3 ± 1.5) (2.5–5.5) | 57.5 |
| Total no. of Burrows | 75 (15 ± 20.8) (2–52) | 439 (73.2 ± 15.3) (2–294) | 549 (137.3 ± 7.1) (3–355) | 1063 |
| Burrows/km | 5.4 | 16.6 | 32.3 | 18.5 |
| | Geographical Regions N (Mean ± SD) (min-max) | | | |
| Variables | Eastern (3 Districts) | Central (4 Districts) | Western (8 Districts) | Total |
| No. of Transects | 31 (10.3 ± 3.1) (7–13) | 36 (9 ± 3.6) (6–14) | 48 (6 ± 2.5) (3–11) | 115 |
| Length of Transects (km) | 15.5 (5.2 ± 1.5) (3.5–6.5) | 18 (4.5 ± 1.8) (3–7) | 24 (3 ± 1.3) (1.5–5.5) | 57.5 |
| Total no. of Burrows | 701 (233.7 ± 160.3) (14.9–64.6) | 186 (46.5 ± 43.1) (8–107) | 176 (22 ± 50.2) (2–146) | 1063 |
| Burrows/km | 45.2 | 10.3 | 7.3 | 18.5 |

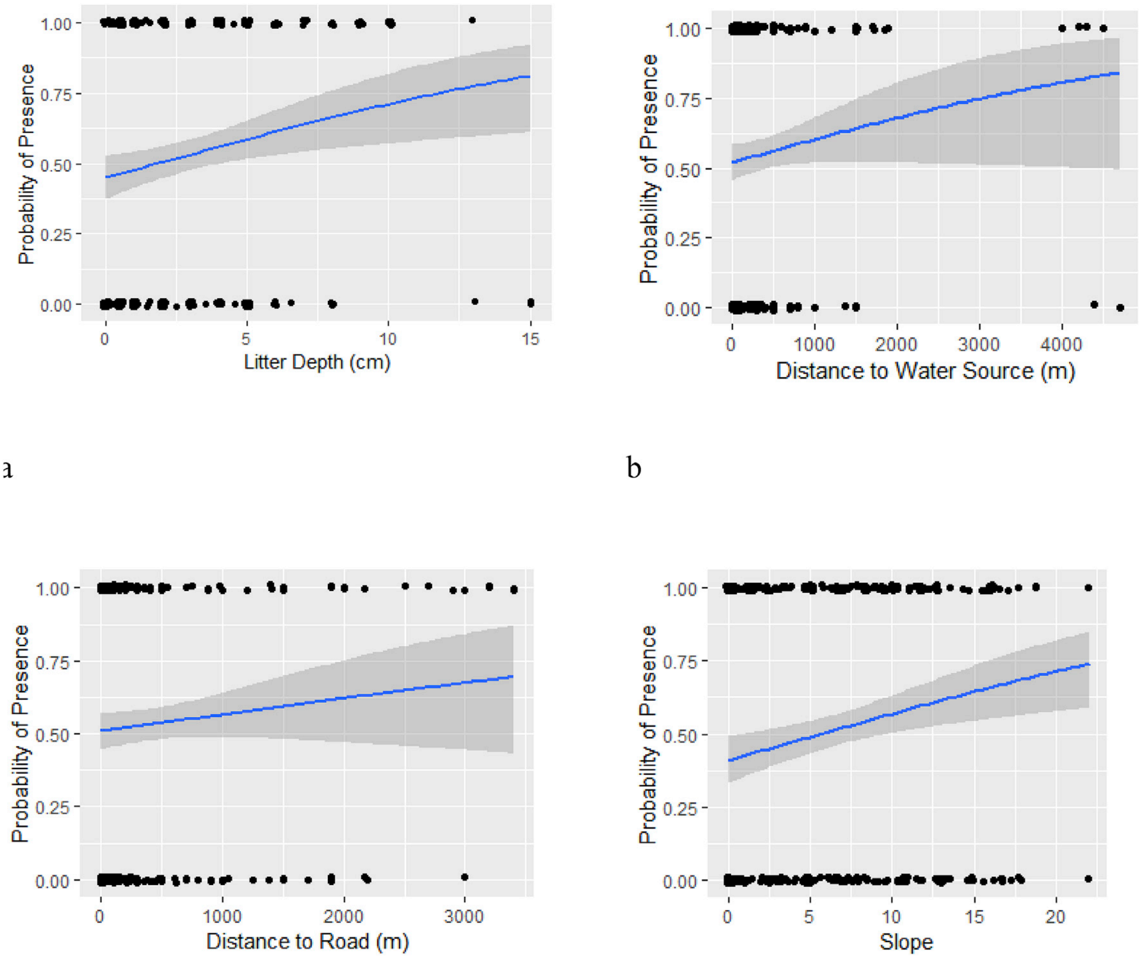


**Fig. 4.** Factors affecting the distribution of pangolins (a–d).

**Table 2**
The coefficients and respective odds ratios, z-score, p values and confidence intervals for the minimal adequate model for presence/absence of pangolins.

| Coefficient | Odds Ratio | z Score | p-value | exp (Lo CI) | exp (Up CI) |
|---|---|---|---|---|---|
| Intercept | 0.211 | −2.604 | 0.009 | 0.066 | 0.681 |
| Canopy Cover (%) 25-50 | 0.932 | −0.161 | 0.872 | 0.396 | 2.192 |
| **Canopy Cover (%) 50–75** | **0.200** | **−2.287** | **0.022** | **0.050** | **0.794** |
| Canopy Cover (%) 75-100 | 0.142 | −1.582 | 0.114 | 0.013 | 1.595 |
| Ground Cover (%) 25-50 | 1.272 | 0.561 | 0.575 | 0.550 | 2.943 |
| **Ground Cover (%) 50–75** | **6.274** | **3.109** | **0.002** | **1.972** | **19.963** |
| Ground Cover (%) 75-100 | 0.605 | −0.731 | 0.465 | 0.157 | 2.331 |
| **Litter Depth (cm)** | **1.296** | **2.946** | **0.003** | **1.091** | **1.540** |
| **Habitat Type (Non- forest)** | **0.420** | **−2.031** | **0.042** | **0.182** | **0.970** |
| **Distance to Road (m)** | **1.001** | **2.366** | **0.018** | **1.000** | **1.001** |
| Distance to Water Source (m) | 1.001 | 1.791 | 0.073 | 1.000 | 1.001 |
| **Distance to Termite Mound (=<300m)** | **3.815** | **3.142** | **0.002** | **1.655** | **8.793** |
| **Slope ($^0$)** | **1.069** | **1.997** | **0.046** | **1.001** | **1.142** |

[*Note: Confidence Intervals are in exponential scale*].

Bhutan, Bangladesh, Pakistan, Sri Lanka; Wu et al., 2020), except in Taiwan where the species are regularly monitored and conservation actions are conducted by conservation stakeholders including local communities and the government of Taiwan (Pei, 2010). Thus, community based conservation, extensive conservation awareness programs, and capacity building training for the relevant stakeholders (e.g. Protect Area and Forestry staff, local communities) are needed for the long-term conservation of the species (DNPWC, 2018).

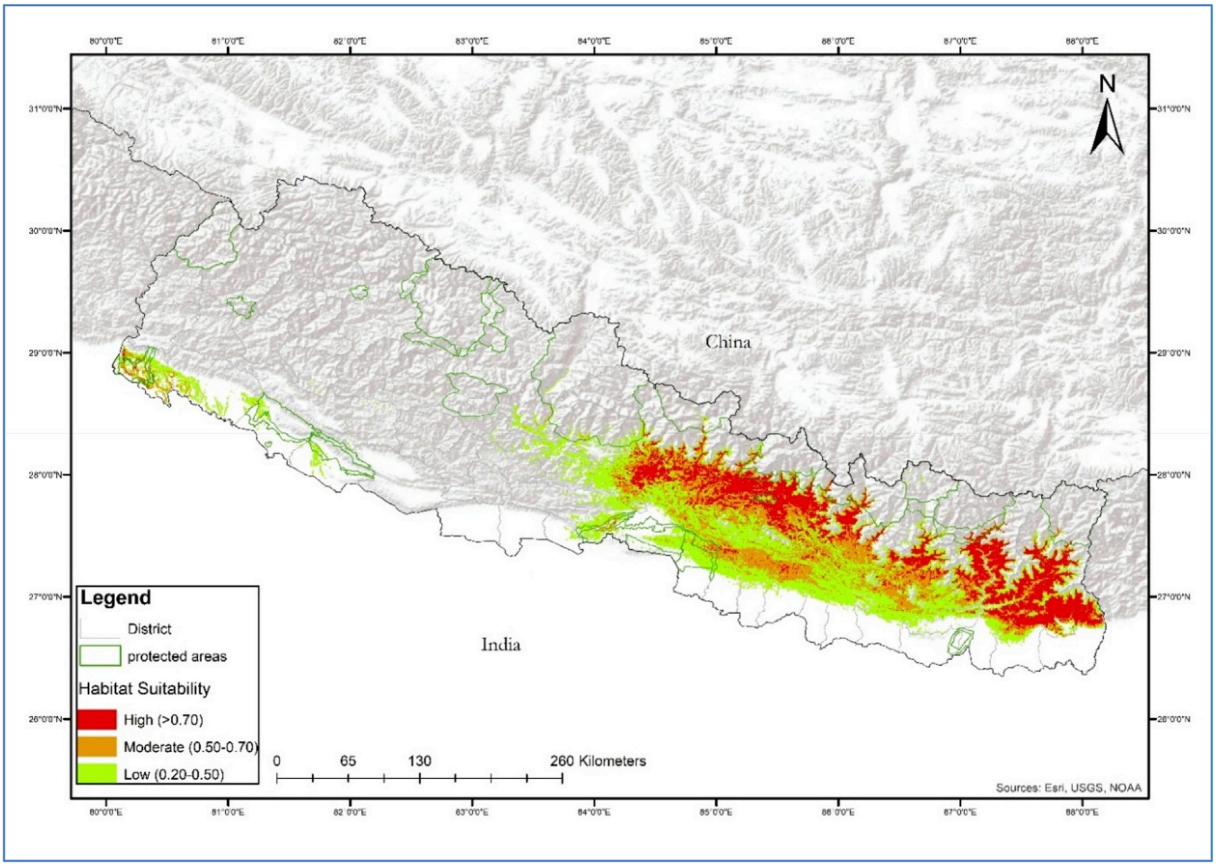


**Fig. 5.** Predicted suitable habitat of pangolins in Nepal.

This study found that pangolins were distributed throughout the country and mostly in the human dominated landscape from the eastern to the western part of the country. Despite of the highest elevation, burrows recorded for the occurrence of Chinese pangolin was 3000 m above sea level which was located in Taplejung district in the eastern part of Nepal (Wu et al., 2020). This study found the maximum occurrence of Chinese pangolin within the range from 1500–1844 (Supplementary Table: A3) meters above sea level which supports the previous studies in Nepal (Suwal, 2011; Katuwal et al., 2017) and in Bhutan from where the species has been recorded within an elevation range of 1300–1700 m above sea level (Dorji, 2017). However, in China the species has been recorded from 760–1500 m above sea level (Wu et al., 2004) and in Taiwan, the occurrence of the species has been limited to a lower elevation range of 200–1000 m above sea level (Sun et al., 2019). Chinese pangolins have also been recorded in the tropical and subtropical mixed-type forests and agricultural land in Nepal (Gurung, 1996; Suwal, 2011) and in mixed evergreen and dry deciduous forest in Bangladesh (Trageser et al., 2017).

Regarding the Indian pangolin, this study recorded the species mostly in the tropical Tarai region and also in the sub-tropical forest of the western part (Surkhet district) of the country at an elevation of 675 m above sea level. Our results are similar to those of Mahmood et al. (2017) from Pakistan, where the species was recorded at a maximum elevation of 880 m above sea level in the sub-tropical scrub and sub-tropical deciduous forests. In Sri Lanka, the species was recorded up to an elevation range of 200–400 m (Karawita et al., 2018). The predicted habitat for both species of pangolin ranged between 132 m up to 2704 m in elevation where the highest suitability class of habitat peaked at 1150 m. Lower suitability habitat was found below 500 m and above 1750 m which indicated that the hilly region provided more suitable habitat for pangolins in Nepal.

The greatest occurrence of pangolins was observed between 30 and 50° slope in Nepal which was similar to a study in China where the Chinese pangolins were observed between the slope of 30–40° (Wu et al., 2004), and in Bhutan where they were recorded between 25 and 45° slope (Dorji, 2017). In Sri Lanka, the Indian Pangolin was found at higher slopes of 45–60° (Karawita et al., 2018). It can be inferred that pangolins prefer areas with medium canopy cover (50–75%), rather than forests that are too dense or too sparse. In addition, the study showed weaker significant relationships among pangolin occurrences and canopy cover, habitat type, distance to road, and slope. However, we could not assess seasonal variation and influence of micro habitats due to the short duration of the study. Therefore, further studies are needed to investigate microhabitat preferences, seasonal variation, and the possible impacts of climate change on the species distribution, habitat, and prey availability to understand the spatial ecology of the species and contribute to the pangolin conservation.

The occurrence of pangolins was confirmed based majority on burrow presence, however, the exact species of pangolin could not be confirmed on the burrow evidence alone. This study therefore jointly addressed the distribution of both species and also predicted the potential habitat for both. The MaxEnt modeling on pangolin distribution and potential suitable habitat depicts only 15.2% of Nepal's total land as potentially suitable habitat for pangolins where 5.8% lies in eastern part of the country followed by 5.7% in central and 3.7% in the western part. Among the selected geographic variables, elevation was the most influential variable in predicting suitable habitat for the pangolins which supports the previous studies (Suwal, 2011; Thapa et al., 2014). In Nepal, the varying elevational range contributes to diverse weather and climatic conditions, temperature, rainfall and vegetation patterns; herbs, shrubs, and trees which could influence the activities of burrowing mammals like pangolins. Therefore, the hilly region with less dense and diverse forests along with appropriate climate, rainfall, availability of food and less human disturbance could provide more suitable habitat for the pangolins. For this reason, community-based conservation programs need to be given priority to aid the conservation of the species.

This study demonstrated the potential distribution of pangolin habitat in Nepal using field-based species-presence data across the country along with bioclimatic and topographic variables. However, the actual suitable habitat is likely to be lesser than the model-predicted habitat because climatic variables are not the only determinants of habitat suitability. This study provides opportunities for further research and conservation actions, facilitates the establishment of pangolin sanctuaries in suitable habitat areas, and helps in the development of pangolin conservation strategy plans and policies in Nepal.

## 5. Conclusions

This is the first study conducted on pangolins in Nepal which extensively surveyed a large area to collect pangolin records and verified anecdotal information through field surveys. This study developed a database of pangolin presence records through reviewing historical reports along with first-hand information from many unexplored new areas. The study also assessed the important habitat-associated variables and their influences on pangolin occurrence and distribution. However, we could not consider the two species of pangolins in Nepal separately due to difficulties in identifying the species purely based on indirect signs. The causes of declining pangolin populations and the absence of pangolins in areas where they were previously reported indicates immediate need for conservation actions. In addition, the study predicted the potential habitat for pangolin in different regions across the country. Therefore, the results of this study are crucial for further research, in formulating conservation and management plans, and contributing to the long-term conservation of the species both in Nepal and in other range states around the world.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.gecco.2020.e01049.

## References

Acharya, S., 2016. Assessment of Conservation Threats and Habitat Management of Chinese Pangolin (*Manis Pentadactyla)* in Balthali VDC of Kavreplanchowk Nepal (B.Sc. Dissertation). Institute of Forestry, Tribhuvan University, Pokhara, Nepal.

Baillie, J., Challender, D., Kaspal, P., Khatiwada, A., Mohapatra, R., Nash, H., 2014. *Manis crassicaudata.* the IUCN red list of threatened species. Version 2014.3. www.iucnredlist.org.

Baral, H.S., Shah, K.B., 2008. Wild Mammals of Nepal. Himalayan Nature, Kathmandu.

Bhandari, N., 2013. Distribution, Habitat Utilization and Threats Assessment of Chinese Pangolin (*Manis Pentadactyla* Linnaeus, 1758) in Nagarjun Forest of Shivapuri Nagarjun National Park (M.Sc. dissertation). Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal.

Challender, D., Wu, S., Kaspal, P., Khatiwada, A., Ghose, A., Ching-Min Su, N., Laxmi Suwal, T., 2019. Manis pentadactyla. The IUCN red list of threatened species 2019. e. T12764A123585318. https://dx.doi.org/10.2305/IUCN.UK.

Challender, D., Waterman, C., 2017. Implementation of CITES Decision2 17.239 B) and 17.240 on Pangolins (Manis Spp.). Prepared by IUCN for the CITES Secretariat. SC69 Doc 57.

Chao, J., 1989. Studies on the Conservation of the Formosan Pangolin (*Manis Pentadactyla Pentadactyla*). I. General Biology and Current Status. Division of Forest Biology, Taiwan Forestry Research Institute. Printed by Council of Agriculture, Executive Yuan, Taiwan.

CITES, 2019. The CITES appendices. Appendices I, II & III (04/04/2017), 16. 26 July 2019. https://cites.org/sites/default/files/eng/app/2017/E-Appendices-2017-10-04.pdf.

Corbet, G.B., Hill, J.E., 1992. The Mammals of the Indomalayan Region: a Systematic Review. Natural History Museum publications, Oxford University Press, Oxford, UK.

Dhakal, S., 2016. Distribution and Conservation Status of Chinese Pangolin (Manis Pentadactyla Linnaeus, 1758) in Palungtar Municipality of Gorkha District, Western Nepal (B.Sc. dissertation). Kathmandu Forestry College, Tribhuvan University, Kathmandu, Nepal.

DNPWC, 2019. Pangolin Monitoring Guideline for Nepal. Department of National Parks and Wildlife Conservation, Ministry of Forests and Environment, Kathmandu, Nepal.

DNPWC, DoF., 2018. Pangolin Conservation Action Plan for Nepal (2018-2022). Department of National Parks and Wildlife Conservation and Department of Forests, Kathmandu, Nepal.

Dorji, D., 2017. Distribution, Habitat Use, Threats and Conservation of the Critically Endangered Chinese Pangolin (*Manis Pentadactyla*) in Samtse District, Bhutan. Rufford Small Grants, UK. Unpublished. https://www.rufford.org/projects/dago_dorji.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Zimmermann, N.E., 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29, 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x.

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y.E., Yates, C.J., 2011. A statistical explanation of MaxEnt for ecologists. Divers. Distrib. 17, 43–57. https://doi.org/10.1111/j.1472-4642.2010.00725.x.

ESRI, 2016. ArcGIS Desktop: Release 10.6. Environmental Systems Research Institute, Redlands, CA.

Gopali, R.A., 2015. A Study on Status, Distribution, Threat and Habitat Pattern of Pangolin (Manis sps.), in Parsa Wildlife Reserve (B.Sc. dissertation). Kathmandu Forestry College, Tribhuvan University, Kathmandu, Nepal.

Gurung, J.B., 1996. A pangolin survey in royal nagarjung forest in Kathmandu, Nepal. Tigerpaper 23 (2), 29–32.

Heinrich, S., Wittman, T.A., Ross, J.V., Shepherd, C.R., Challender, D.W.S., Cassey, P., 2017. The Global Trafficking of Pangolins: A Comprehensive Summary of Seizures and Trafficking Routes from 2010-2015. TRAFFIC, Southeast Asia Regional Office. Petaling Jaya, Selangor, Malaysia.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high-resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978. https://doi.org/10.1002/(ISSN)1097-0088.

Hodgson, B., 1836. Synoptical description of sundry new animals, enumerated in the catalogue of Nepalese mammals. J. Asiatic Soc. Bengal 5, 231–238. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1020.2433&rep=rep1&type=pdf.

Ingram, D.J., Willcox, D., Challender, D.W.S., 2019. Evaluation of applied methods to detect and monitor selected mammalian taxa and its application to pangolin conservation. Global Ecol. Conserv. 18 https://doi.org/10.1016/j.gecco.2019.e00632 e00632.

IUCN, 2019. The IUCN Red List of Threatened Species. Version 2019-2. 26 July 2019. https://www.iucnredlist.org.

Jnawali, S.R., Baral, H.S., Lee, S., Subedi, N., Acharya, K.P., Upadhyay, G.P., Pandey, M., Shrestha, R., Joshi, D., Lamichhane, B.R., Griffiths, J., Khatiwada, A., Amin, R., 2011. The Status of Nepal's Mammals: the National Red List Series. Department of National Parks and Wildlife Conservation, Kathmandu, Nepal.

Karawita, H., Perera, P., Gunawardane, P., Dayawansa, N., 2018. Habitat preference and den characterization of Indian Pangolin (*Manis crassicaudata*) in tropical lowland forested landscape of southwest SriLanka. PloS One 13 (11). https://doi.org/10.1371/journal.pone.0206082 e0206082.

Karki, N., 2015. Distribution and Conservation Status of Chinese Pangolin (Manis Pentadactyla Linnaeus, 1758) in Rani Community Forest, Makwanpur, Central Nepal (B.Sc. dissertation). Kathmandu University, Kathmandu, Nepal.

Kaspal, P., 2008. Status, Distribution, Habitat Utilization and Conservation of Chinese Pangolin (Manis Pentadactyla Linnaeus, 1758) in the Community Forest of Suryabinayak Range Post, Bhaktapur District (M.Sc. dissertation). Department of Environmental Science, Khwopa College, Bhaktapur, Nepal.

Kaspal, P., Shah, K.B., Baral, H.S., 2016. SAALAK (i.e. Pangolin). Himalayan Nature, Kathmandu, Nepal.

Katuwal, H.B., Neupane, K.R., Adhikari, D., Sharma, M., Thapa, S., 2015. Pangolins in eastern Nepal: trade and ethno-Medicinal importance. J. Threat. Taxa 7 (9), 7563–7567. https://doi.org/10.11609/JoTT.o4202.7563-7.

Katuwal, H.B., Sharma, H.P., Parajuli, K., 2017. Anthropogenic impacts on the occurrence of the critically endangered Chinese pangolin (*Manis pentadactyla*) in Nepal. J. Mammal. 98 (6), 1667–1673. https://doi.org/10.1093/jmammal/gyx114.

Khadgi, B., 2016. Distribution, Conservation Status and Habitat Analysis of Chinese Pangolin (Manis Pentadactyla Linnaeus, 1758) in Maimajuwa VDC, Ilam, Eastern Nepal (B.Sc. dissertation). School of Environment Science and Management, Kathmandu, Nepal.

Khatiwada, A.P., 2014. Conservation of Chinese Pangolin (Manis Pentadactyle Linnaeus, 1758) in the Eastern Himalayas of Nepal. EDGE Fellowship Programme. A report submitted to ZSL.

Khatiwada, A.P., Suwal, T.L., Wright, W., Roe, D., Kaspal, P., Thapa, S., Paudel, K., 2020. Pangolins Science, Society and Conservation; Chapter 25- Community Conservation in Nepal- opportunities and challenges for pangolin conservation, pp. 395–409. https://doi.org/10.1016/B978-0-12-815507-3.00025-3.

Khatri-Chhetri, A., 2015. Habitat Preferences and Illegal Trade of Chinese Pangolin (Manis Pentadactyla Linnaeus, 1758) in Kavrepalanchok District, Nepal (M.Sc. dissertation). Department of Environmental Science, Khowpa College, Bhaktapur, Nepal.

Khatri-Chhetri, A., 2013. Habitat Mapping and Conservation Threats of Chinese Pangolin (Manis Pentadactyla Linnaeus, 1758) in Kusadevi VDC of Kavrepalanchok District (B.Sc. dissertation). Institute of Forestry, Tribhuvan University, Hetauda, Nepal.

Liu, C., White, M., Newell, G., 2013. Selecting thresholds for the prediction of species occurrence with presence-only data. J. Biogeogr. 40 (4), 778–789. https://doi.org/10.1111/jbi.12058.

Mahmood, T., Akrim, F., Irshad, N., Hussain, R., Fatima, H., Andleeb, S., Aihetasham, A., 2017. Distribution and Illegal Killing of the Endangered Indian Pangolin *Manis Crassicaudata* on the Potohar Plateau, Pakistan. Oryx 1-6. https://doi.org/10.1017/S0030605317000023.

Mahmood, T., Hussain, R., Irshad, N., Akrim, F., Nadeem, M.S., 2012. Illegal mass killing of Indian pangolin (*Manis crassicaudata*) on potohar region, Pakistan. Pakistan J. Zool. 44 (5), 1457–1461. https://bit.ly/2k6oQST.

Pantel, S., Chin, S.Y., 2009. Proceedings of the Workshop on Trade and Conservation of Pangolins Native to South and Southeast Asia, 30 June – 2 July 2008. Singapore Zoo. TRAFFIC Southeast Asia.

Pei, K.J.C., 2010. Ecological Study and Population Monitoring for the Taiwanese Pangolin (*Manis Pentadactyla Pentadactyla*) in Luanshan Area, Taitung. Final Report. Taitung Forest District Office Consservation Research, Taitung, Taiwan, p. 37.

Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Model. 190, 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026.

Phillips, S.J., Dudik, M., 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31, 161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x.

R Development Core Team, 2019. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Sapkota, R., 2016. Habitat Preference and Burrowing Habits of Chinese Pangolin (M.Sc. dissertation). Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal.

Shrestha, B., Basnet, K., 2005. Indirect methods of identifying mammals: a case study from Shivapuri National park, Nepal. Ecoprint 12, 43–58. https://doi.org/10.3126/eco.v12i0.3196.

Shrestha, B.B., Bawa, K.S., 2014. Impact of climate change on potential distribution of Chinese caterpillar fungus (*Ophiocordyceps sinensis*) in Nepal Himalaya. PloS One 9. https://doi.org/10.1371/journal.pone.0106405 e106405.

Shrestha, T.K., 2003. Wildlife of Nepal: A Study of Renewable Resources of Nepal Himalayas. Steven Simpson Books, Norwich, UK.

Shrestha, T.K., 1981. Wildlife of Nepal. A Study of Renewal Resources of Nepal, Himalayas. Curriculum Development Center, Tribhuvan University, Kathmandu, Nepal.

Sun, N.C.M., Arora, B., Lin, J.S., Lin, W.C., Chi, M.J., Chen, C.C., Pei, C.J.C., 2019. Mortality and morbidity in wild Taiwanese pangolin (*Manis pentadactyla pentadactyla*). PloS One 14. https://doi.org/10.1371/journal.pone.0198230 e0198230.

Suwal, R.N., Verheugt, W.J.M., 1995. Enumeration of the mammals of Nepal. Euroconsult.

Suwal, T.L., 2011. Status, Distribution, Behaviour and Conservation of Pangolins in Private and Community Forest of Balthali in Kavreplanchowk, Nepal (M.Sc. dissertation). Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal.

Thapa, A., Wu, R., Hu, Y., Nie, Y., Singh, P.B., Khatiwada, J.R., Yan, L., Gu, X., Wei, F., 2018. Predicting the potential distribution of the endangered red panda across its entire range using MaxEnt modeling. Ecology and Evolution 8, 10542–10554. https://doi.org/10.1002/ece3.4526.

Thapa, P., Khatiwada, A.P., Nepali, S.C., Poudel, S., 2014. Distribution and conservation status of Chinese pangolin (*Manis pentadactyla* linnaeus, 1758) in nangkholyang VDC, Taplejung, eastern Nepal. Am J. Zool. Res. 2, 16–21. https://doi.org/10.12691/ajzr-2-1-3.

Thapa, S., 2014. A checklist of mammals of Nepal. J. Threat. Taxa 6 (8), 6061–6072. https://doi.org/10.11609/JoTT.o3511.6061-72.

Trageser, S.J., Ghose, A., Faisal, M., Mro, P., Mro, P., Rahman, S.C., 2017. Pangolin distribution and conservation status in Bangladesh. PloS One 12 (4). https://doi.org/10.1371/journal.pone.0175450 e0175450.

Willcox, D., Nash, H., Trageser, S., Kim, H.J., Hywood, L., Connelly, E., Godwill, I.I., Nyumu, J.K., Moumbolou, C.L.M., Ingram, D.J., Challender, D.W.S., 2019. Evaluating methods for the detection and ecological monitoring of pangolins (Pholidota: Manidae). Global Ecol. Conserv. 17 https://doi.org/10.1016/j.gecco.2019.e00539 e00539.

Wilson, G.J., Delahay, R.J., 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. Wildl. Res. 28 (2), 151–164. https://doi.org/10.1071/WR00033.

Wisz, M.S., Tamstorf, M.P., Madsen, J., Jespersen, M., 2008. Where might the western Svalbard tundra be vulnerable to pink-footed goose (*Anser brachyrhynchus*) population expansion? Clues from species distribution models. Divers. Distrib. 14, 26–37. https://doi.org/10.1111/j.1472-4642.2007.00408.x.

Wu, S., Ma, G., 2007. The Status and Conservation of Pangolins in China. TRAFFIC East Asia Newsletter.

Wu, S., Sun, N.C.-M., Zhang, F., Yu, Y., Ades, G., Suwal, T.L., Jiang, Z., 2020. Pangolins science, society and conservation; chapter 4 –Chinese pangolin Manis pentadatyla (Linnaeus,1758), 49–70. https://doi.org/10.1016/B978-0-12-815507-3.00004-6.

Wu, S.B., Ma, G.Z., Tang, M., Chen, H., Xu, Z., Liu, N.F., 2004. A preliminary study on burrow ecology of *Manis pentadactyla*. Chin. J. 15 (3), 401–407.