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POTENTIAL DISTRIBUTION OF THE ASIATIC BLACK BEAR IN KHANGCHENDZONGA NATIONAL PARK, SIKKIM EASTERN HIMALAYA USING MAXENT MODELING

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Abstract.
*Habitat assessments and mapping are major functional keys in the need of species conservation concern. The study aimed to understand the possible distribution of Asiatic Black bear (*Ursus thibetanus*) in the Khangchendzonga National Park. Sign survey, camera trapping, and trail monitoring were used to collect the presence-only data. In this analysis, we used Maximum Entropy Modeling and ArcGIS to determine the variable's contribution to the species distribution and presence. In total, 63 presence data were obtained, and out of 23 environmental variables we used only 15 different environmental variables due to multi collinearity. The ROC results show that variable consistency was excellent (mean AUC=0.941). The variables like Bio-14(Precipitation of driest month), Bio-2(Mean diurnal range (mean of monthly max temp - min temp)), Bio-13(Precipitation of wettest month), aspect and LULC were the critical factors for the distribution of U.thibetanus. The major distribution of* U. thibetanus *was found in the broadleaved, coniferous forest and grassland patches in the core area. The temperate zone is most preferred as compared to the sub-alpine and alpine zone by* U. thibetanus*. The distributional area accounts for 360.32km^2, representing 20.19% of the whole core area of Khangchendzonga National Park. Large areas of distribution were predicted outside of the core areas, i.e. buffer and transition areas of Khangchendzonga National Park. To have a deeper understanding of the animal's ecological needs and its potential distribution, the area outside of the park (Buffer zone and Transition zone) should also be taken into consideration for further studies. This study offers valuable findings and data which can be used in future research and conservation management plans in and around Khangchendzonga National Park to mitigate human-bear interaction.*

Key words: Distribution, Khangchendzonga National Park, MaxEnt Modeling, Ursus thibetanus*, Variables*

Background

Asiatic black bear (*Ursus thibetanus*) is widely distributed throughout its distributional ranges and recorded in 18 countries (Garshelis and Steinmetz 2016) from southeastern Iran to Japan, Russia, Korea to the Indo-China Himalayan region and in some parts of southeast Asia (Cowan 1972; Schaller 1977; Servheen 1990; Garshelis and Steinmetz 2016). In India, it is distributed throughout the Himalayan foothills from western Himalaya (Jammu and Kashmir, Ladhak, Himachal Pradesh, and Uttarakhand) to eastern Himalaya (all northeastern Himalayan state and some parts of North Bengal state (Sathyakumar and Choudhury 2007; Choudhury 2013). The Asiatic black bear mainly inhabits tropical, subtropical, temperate broadleaved, and conifer forests (Sunar et al. 2013). Due to their vigorous and opportunistic nature, they change their habitats, move to different habitats, and change their elevations seasonally in search of food (Izumiyama and Shiraishi 2004; Hwang et al. 2010; Koike et al. 2013) and may extend their presence up to 4300m above sea level (Sathyakumar and Choudhury 2007, Sathyakumar et al. 2011). The IUCN has included this species under the vulnerable species category due to the high number of poaching and hunting for meat, paws, skin, gall bladder, dam and roadways construction in their habitat, habitat loss, expansion of the agricultural field, and plantations practices (Garshelis and Steinmetz 2016; Basnett and Kumar 2021). In India, the population and distribution of Asiatic black bears are declining over the past decade, and it is protected under the Schedule I of Indian Wild Life (Protection) Act, 1972.

The habitat is the physical and biological spaces (Krebs 1985; Jones 1987) for survival, reproduction, and population development of organisms (Block and Brennan, 1993). Assessing the species distribution and habitat assessment plays an important role in the wildlife conservation and management strategies (Schank et al. 2017; Bai et al. 2018). Species distribution modeling (SDMs) and ecological niche modeling (ENMs) is widely used model in the terrestrial, freshwater and aquatic environments to understand the species distribution (Chefaoui et al. 2005; Elith and Leathwick 2009). The SDM aimed to estimate the possible presence of the species (Schank et al. 2017). So far, many methods and models have been introduced in the field of ecology to understand the species distribution (Elith et al. 2011; Haghani et al. 2016), and most of them are sensitive to the size of the sample (Wisz et al. 2008). Due to great potential in species occurrence, selection, and distribution of habitat based on the points of presence-only data Maximum Entropy Model(MaxEnt) has become a popular SDM in wildlife conservation (Phillips et al. 2006; Haghani et al. 2016; Chettri et al. 2018). MaxEnt modeling became more predictive and accurate even in limited presence data and small sample size (Hernandez et al. 2006; Phillips et al. 2006; Phillips and Dudik, 2008) and requires only species presence data (Phillips et al. 2006; Chettri and Bodala 2017; Thapa et al. 2018).

Only one study was carried out by Bashir et al. (2018) on the *U. thibetanus* in the Khangchendzonga landscape. Besides, this study still lacks in the potential distribution of *U.thibetanus* in Sikkim and moreover from Khangchendzonga National Park and its surroundings. Based on *U. thibetanus* status, we used MaxEnt modeling (Phillips et al. 2006) to assess the potential distribution and seasonal habitat selection of ABB in the Khangchendzonga National Park. This study may update species existence, conservation status, and a lead to understand the Human-Bear conflicts in the region.

Materials and Methods

Study area

We carried out our study in Khangchendzonga National Park, Sikkim (27°42′N 88°08′E), which was established in 1997 to protect wild flora and fauna as well as local religious values towards the mighty 'Khangchendzonga' peak (8,586 meters). The study was extoled to the UNESCO World Heritage Site list in July 2016, becoming the first 'Mixed Heritage' site of India (O'Neill 2017). The park covers an area of 849.5 km^2 (328.0 sq mi), and it is India's highest National Park, ranging from 1,829m to over 8,550m. The KNP is widely spread in the west and north dis-

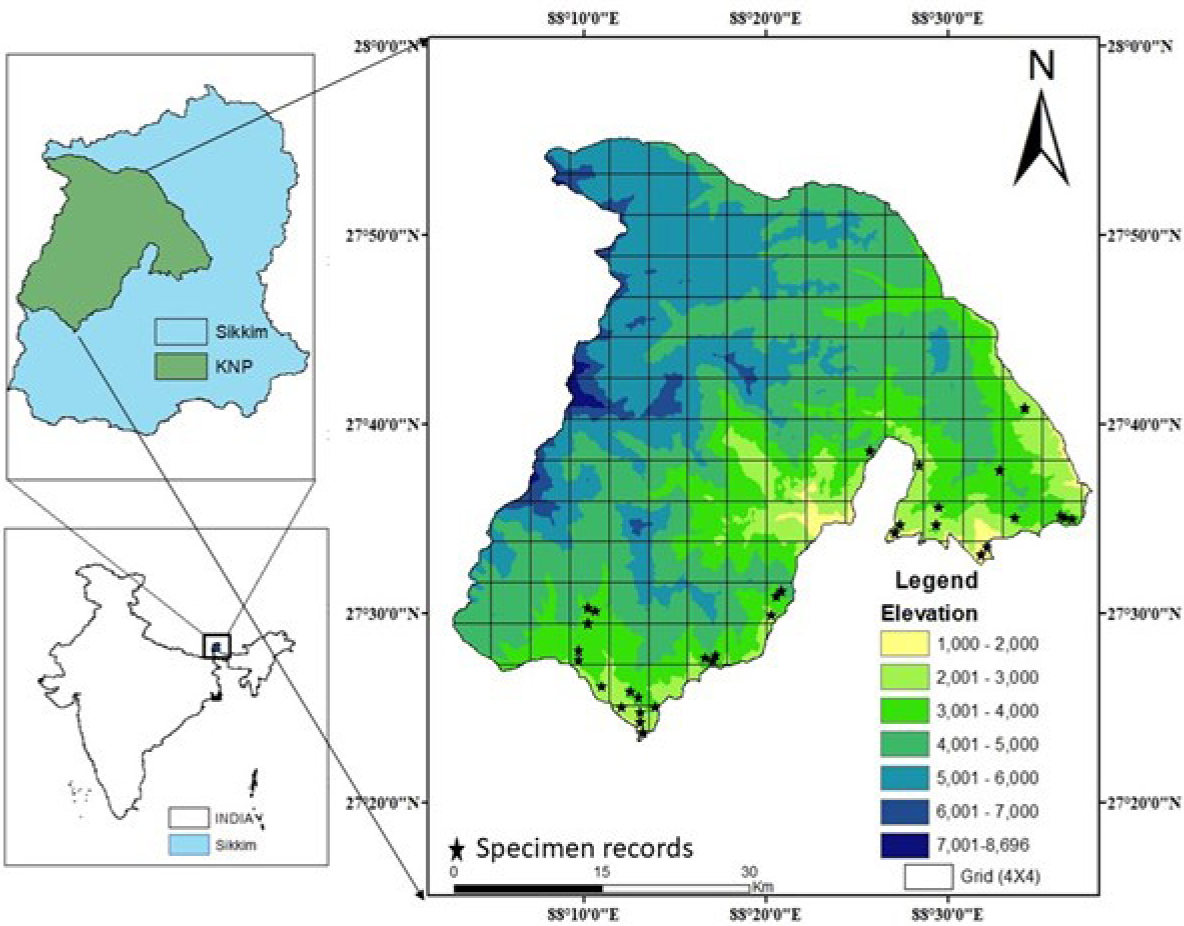

Figure 1. Map of study area with presence records of *U. thibetanus* in Khangchendzonga National Park.

trict of Sikkim as well as a small portion in the south district. International boundaries comprise of Tibet Autonomous Region (TAR) on the northern side, Nepal on the Western side, and West Bengal, an Indian state on the southern side (Fig. 1.). The average annual rainfall is around 3000 mm, and temperature varies from 15° to -20° respectively (Tambe 2007). Most of the park is covered with snow throughout the year has many isolated terrains. The study area's dominant vegetation includes *Castanopsis hystrix, Arundinaria* spp, *Machilus* spp, *Rhododendron* spp. *Symplocos* spp, *Michelia excelsa*, *Quercus lamellosa*, varieties of bamboo species, alpine scrubs, medicinal plants, herbs, and meadows. These areas KNP supports many rare and endangered faunal diversity like *Panthera pardus*, *Uncia uncia*, *Ursus thibetanus*, C*apricornis thar*, *Moschus leucogaster Naemorhedus goral*, *Semnopithecus schistaceus* and *Ailurus fulgens* (Tambe 2007). This area is recognized as a global biodiversity hotspot Myers et al. (2000) and the Global 200 Ecoregions (Olson et al. 2001). Most of the field research work was carried out near different trekking trails, pre-designed or permeant samples, and camping sites owing to its challenging terrain and remoteness.

Species survey and camera trapping

The study was carried out in the year 2017-2019 in Khangchendzonga National Park. We used two different types of data collection methods in the study. Secondary data was collected from various literature reviews, internet sources, forest department, and verbal discussion with local villagers at very onsets. Secondly, for primary data collection of *U. thibetanus* sign surveys were done in different transect lines, trekking trails, and extensive use of camera trapping. Sign data collections include sighting alive or dead bear, pugmarks, claw marks, scats, etc. The study area was divided into a grid of 96 squares of 4X4 km (Fig.1). We selected the transect sample, and the camera traps location was selected based on primary data, secondary data, and experience local guides. We used Cuddeback 1309 IR Plus and Cuddeback IR trail infrared cameras were set according to O'Brien et al. (2003); Thapa et al. (2013) in the core area of KNP. We selected 25 camera-trap locations in 12 different pre-designed transects on the presence of *U. thibetanus* data. A total of 121 cameras were installed in the various grids for 22 -25 days, with a total effective effort of 3,025 trap nights. All cameras were operational 24 hrs per day, and a single camera photo of *U. thibetanus* was counted as a presence. Garmin (Etrex 10x GPS) GPS was used to record the locations of direct and indirect sightings as well as the location of camera traps. The camera trap site was visited weekly by the field guide to monitoring the camera traps.

Environmental variables and Model

A total of 23 environmental variables were used as a predictor to understand the present distribution of *U. thibetanus* on the presence datasets. In detail, we used 19 environmental variables downloaded from https://www.worldclim.org. The spatial resolution of 30 seconds (~1 km^2) was used with a spatial resolution of about 1 km^2. Topography parameters as elevation, aspect, and slope, was extracted using ArcGIS 10.3.3. Biological parameters like NVDI, VI were downloaded from https://www.earthdata.nasa.gov. The digital elevation model (DEM) was downloaded from https://earthexplorer.usgs.gov. Land use and land cover (LULC) data were obtained from https://daac.ornl.gov. All the environmental variables were continuous except LULC, aspect and slope are categorical, and they are outlined in Table. 1. The MaxEnt software (version 3.4.4. https://biodiversityinformatics.amnh.org/open_source/MaxEnt) was used based on presence data only Phillips et al. (2006) because MaxEnt is better when the data are presence mode only with a few presence data (Bosso et al. 2013; Abdelaal et al. 2019). We used ArcGIS 10.3.3 to convert downloaded environmental variables into an ASCII format and *U. thibetanus* presence point (CVS DOT format) into raster data. The different setting was used during the analysis like the maximum number of background points was fixed at 10,000 and replicated run types was cross-validate. The maximum iterations were fixed at 500, and an automatic limiting feature was selected. We kept the threshold rule in 10% percentile training presence with random test percentage at 25. All the environmental variables were in ASCII file format with the exact spatial resolution (30m). Each variable was kept in the logistic output format. 80% of the data set were used as the training and 20% test data points. The presence data was divided into two sets, 75% for training and 25% for testing the model. The higher the value of ACU, the closer to the 1 the performance will be better (Phillips et al. 2006). The significant level of AUC verified by receiver operating characteristic (ROC) values was divided into 5 groups, i.e., 0.5–0.6 poor, 0.7–0.8 fair, 0.8–0.9 normal, 0.8–0.9,

Table 1. Bioclim and environmental variables used including altitude, aspect, slope and LULC for the potential distribution of *U. thibetanus*.

SN	CODE	Variable	Description	Temporal scale	Unit
1	BIO-1	Annual mean temperature	Continuous	Annual	(°C)
2	BIO-2	Mean diurnal range (mean of monthly (max temp - min temp))	Continuous	Variation	(°C)
3	BIO-3	Isothermality (P2/P7) (*100)	Continuous	Variation	(°C)
4	BIO-4	Temperature seasonality (standard deviation *100)	Continuous	Variation	(°C)
5	BIO-5	Max temperature of warmest month	Continuous	Month	(°C)
6	BIO-6	Min temperature of coldest month	Continuous	month	(°C)
7	BIO-7	Temperature annual range (P5–P6)	Continuous	Annual	(°C)
8	BIO-8	Mean temperature of wettest quarter	Continuous	Quarter	(°C)
9	BIO-9	Mean temperature of driest quarter	Continuous	Quarter	(°C)
10	BIO-10	Mean temperature of warmest quarter	Continuous	Quarter	(°C)
11	BIO-11	Mean temperature of coldest quarter	Continuous	Quarter	(°C)
12	BIO-12	Annual precipitation	Continuous	Annual	(mm)
13	BIO-13	Precipitation of wettest month	Continuous	Month	(mm)
14	BIO-14	Precipitation of driest month	Continuous	Month	(mm)
15	BIO-15	Precipitation seasonality (coefficient of variation)	Continuous	Variation	(mm)
16	BIO-16	Precipitation of wettest quarter	Continuous	Quarter	(mm)
17	BIO-17	Precipitation of driest quarter	Continuous	Quarter	(mm)
18	BIO-18	Precipitation of warmest quarter	Continuous	Quarter	(mm)
19	BIO-19	Precipitation of coldest quarter	Continuous	Quarter	(mm)
20	ELEVATION	Numeric ranges	Continuous		(m)
21	SLOPE	Derived from Elevation	Categorical: 0-11.52,11.52-27.45, 27.45, 34.57, 34.57-41.69, 41.69-49.48, 49.48-59.31, 59.31-8643		(%)
22	ASPECT	Derived from Elevation	Categorical: Flat; North-22.5; Northeast- 22.5-67.5; East- 67.5-112.5; Southwest-112.5-157.5; South-157.5-202.5; South-west-202.5-247.5; West-2.47.5-292.5; Northwest 292.5-337.5; North-33.5-360		°(deg)
23	LULC		Categorical: Cropland, Mixed Forest, Barren Land, Water Bodies, Grassland, Evergreen Broadleaf forest, Snow and Ice		

and excellent with 0.9–1.0 (Bai et al. 2018; Chettri and Badola 2017; Jiang et al., 2016). The map obtained from MaxEnt had a logistic format providing the possible distribution of *U. thibetanus* according to a 0–1 scale. The distribution map generated in MaxEnt was imported in ArcGIS 10.3.3 for further analysis.

Results and Discussion

Pearson`s coefficient test was conducted among all 23 environmental variables to confirm the influence of autocorrelation and multi collinearity. In the results, environmental variables including Bio-1 (Annual mean temperature), Bio-7 (Temperature annual range), Bio-8(Mean temperature of wettest quarter), Bio-9 (Mean temperature of driest quarter), Bio-10 (Mean temperature of warmest quarter), Bio-11 (Mean temperature of coldest quarter), Bio-12 (Annual precipitation), and Bio-18 (Precipitation of warmest quarter) were eliminated from MaxEnt modeling due to the collinearity which may lead to false ecological assumptions in the modeling. The following table (Table 2) gives valuations of relative contributions of the environmental variables to the MaxEnt model. The result indicated that the model’s performance was very good and appropriate for

Table 2. The contribution of different environmental variables in MaxEnt model.

Variable	Percent contribution (%)	Permutation importance (%)
bio-14	43.8	6.7
bio-2	20	16.1
bio-13	8.2	46.8
aspect	8	4.6
lulc	6.6	2
bio-15	5.9	11.5
bio-6	3.2	4.6
bio-3	2.9	2.3
bio-5	0.6	0
bio-19	0.3	0
altitude	0.2	4.7
bio-4	0.1	0.4
slope	0.1	0
bio-17	0.1	0

Table 3. Cumulative and logistic thresholds and Training omission rates used in MaxEnt modeling.

Cumulative threshold	Logistic threshold	Description	Fractional predicted area	Training omission rate
1.000	0.017	Fixed cumulative value 1	0.509	0.000
5.000	0.082	Fixed cumulative value 5	0.287	0.000
10.000	0.170	Fixed cumulative value 10	0.205	0.013
5.518	0.091	Minimum training presence	0.274	0.000
16.736	0.276	10 percentile training presence	0.151	0.090
19.843	0.319	Equal training sensitivity and specificity	0.134	0.128
11.133	0.189	Maximum training sensitivity plus specificity	0.193	0.013
5.096	0.083	Balance training omission, predicted area and threshold value	0.285	0.000
8.205	0.141	Equate entropy of thresholded and original distributions	0.227	0.013

monitoring the effectiveness of a niche model. All the variables were calculated and arranged from higher to the lower contribution (Table 2). As a result, the current distribution of *U. thibetanus*, as defined by the variables chosen, is perfect. The highest contributor is Bio:14-Precipitation of driest month(43.8%), Bio:2-Mean diurnal range(20%), Bio:13- Precipitation of wettest month (8.2%), Aspect (8%), and LULC(6.6%), respectively (Table 2). Considering the Premutation importance the bio- 13 variable had the highest impact on the habitat model, and it contributed for 46.8% while bio-2, bio 15 and bio-1 respectively contribute for 16.1%, 11.5% and 6.7%.

The ROC results showed a high level of predictive values with an AUC of training gain of 0.941 and an AUC test gain of 0.914, indicating that the predictions obtained from the MaxEnt model were excellent (Fig.2). The high value of random prediction AUC is good, and the model lower than 0.5 shows that the model is not suitable for all variables (Fig.2). The Jackknife evaluation indicate that the precipitation, temperature, and forest type were major influencing factor in the distribution of *U. thibetanus* (Fig.2).

Jackknife results show that major environmental variables like Bio-14 (Precipitation of driest month), Bio-2 (Mean diurnal range), Bio-13 (Precipitation of wettest month), Aspect, LULC, and Bio-15 Precipitation Seasonality (Coefficient of Variation) are key predictors in the distribution of *U. thibetanus* in the KNP. These variables show a higher gain of AUC in the MaxEnt model as compared to other variables (Table.2, Table3, Fig.2). The present study indi-

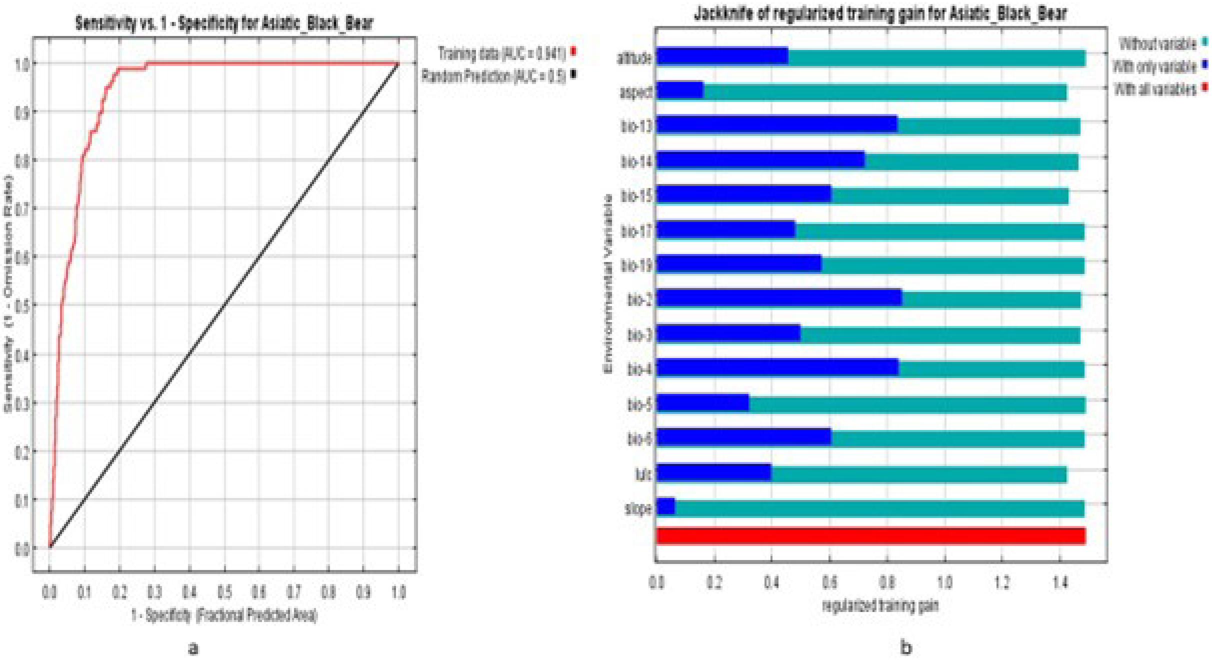

Figure 2. (a) ROC Verification of distribution of *U. thibetanus* in KNP, (b)Jackknife charts of variable in model predication for *U. thibetanus* MaxEnt model.

cates that the distribution of *U. thibetanus* may depend upon the rainfall, temperature, and vegetation type (Fig.3). The mean annual rainfall of the KNP is about 3000mm (Tambe 2007), whereas the distribution area of *U. thibetanus* itself receives 2500mm-3000mm. The maximum temperature varies from 15°-20° and the minimum temperature ranges from 30° - 0° in the KNP with 70% of humidity throughout the year. The present distribution area of *U. thibetanus* in the KNP shows temperature varies from maximum 20°to 3° and a minimum of 15° to 1°. Based on the temperature variables, the warmer the place in the KNP area the distribution probability of *U. thibetanus* increases. The present finding shows that the major distribution and habitat of *U. thibetanus* was found in the Temperate Forest, followed by the Subalpine and small range in Alpine areas (Fig.3). The *U. thibetanus* are omnivorous and highly depends on seasonal foods (Garshelis and Steinmetz 2016; Bashir et al. 2018; Basnett et al. 2021). Most distribution was seen in the evergreen broadleaf forest and grasslands area in the present study sites (Fig.3), like other studies (Sathyakumar et al. 2011; Sunar et al. 2012; Bashir et al. 2018). Present study shows that forest cover has been playing an important role in habitat selection and distribution of *U. thibetanus*. The highest distribution probability was observed in special-use forests and protected forests where a high percentage of forest cover present.

Our study finds that the presence of *U. thibetanus* is limited in the trekking trails, tourist halt areas, and some grazing pastures. The distribution and habitat use area are an abundance of hard mast trees like *Machilus* spp., *Symplocos* spp., *Quercus spp*. and vegetation like *Arundinaria* spp., *Arisema* spp., *Aconogonum molle* along with berries like *Rubus* spp. *Prunus* spp. and *Morus* spp. which is the major source of the *U. thibetanus* diet (Basnett et al. 2021). Our study's major finding is that the distribution and habitat of the *U. thibetanus* in the Khangchendzonga National Park and the surrounding areas directly depend on the vegetation of the areas. The present study shows the higher the rainfall in these areas, the distribution and density of *U. thibetanus* may be higher. The present study shows that the suitable habitat is confined from sub-tropical vegetation to tropical vegetation. The results indicated that distribution of *U. thibetanus* is restricted to lower elevations between 1800m-4000m.This restricted distribution may depend on the availability of food plants and hard mast trees in the regions.

We created a distribution map obtained from the MaxEnt model fit with the distributional map prepared by the IUCN experts. From the reclassified map of the potential distribution of *U. thibetanus* in KNP (Fig.3), the distribution area was divided

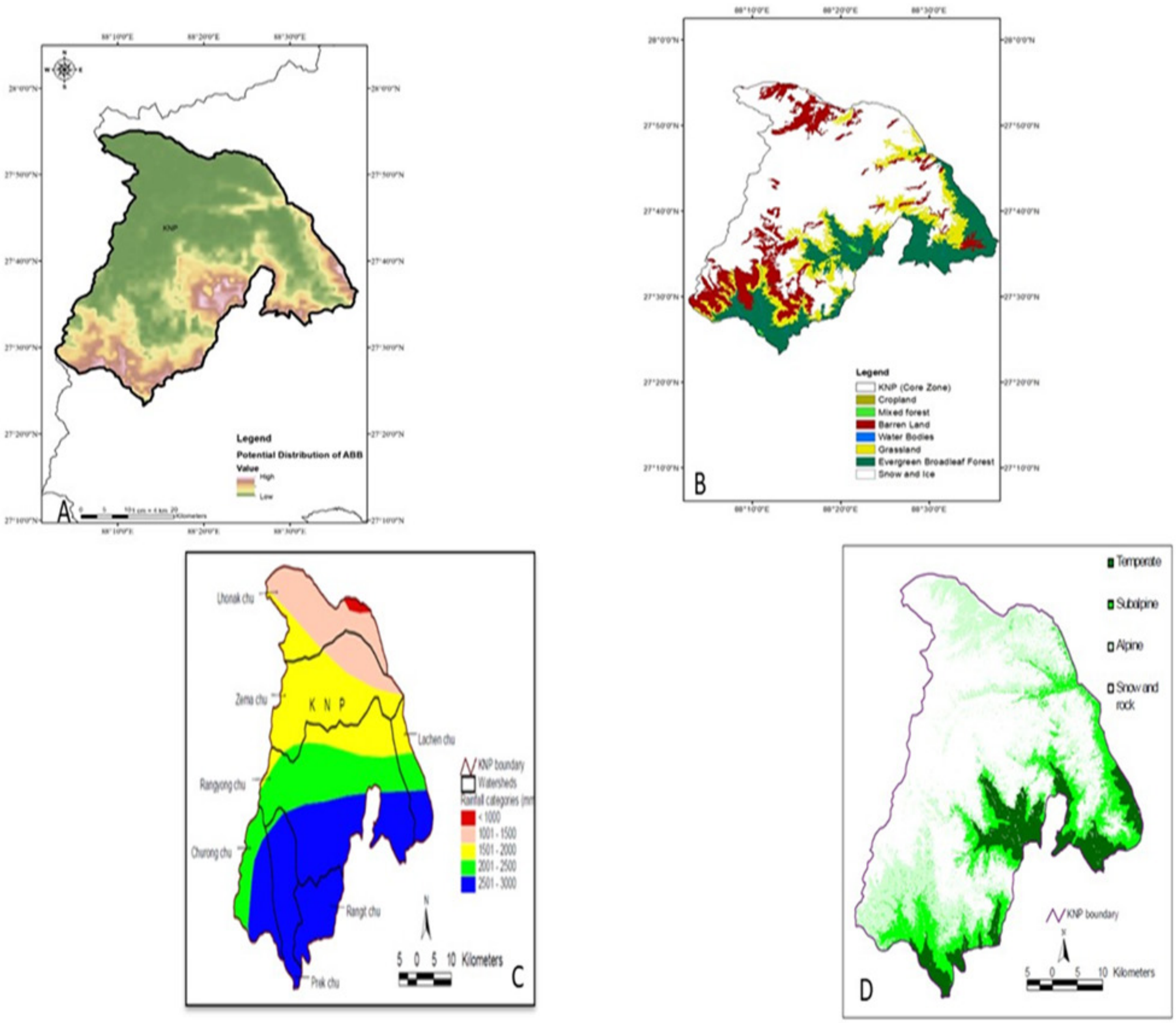

Figure 3. Relationship between potential distribution of *U.thibetanus* with vegetations, landscapes and rainfall of Khangchendzonga National Park. (A) Potential distribution of *U.thibetanus* in KNP (B) Vegetation of KNP, (C) Mean annual rainfall in KNP and (D) Different landscape zones in KNP. ** (C) and (D) Tambe 2007©.

into two categories suitable and unsuitable habitat for *U. thibetanus*. The model identified the area of highly suitable habitat for *U. thibetanus* in the KNP was 360.32km^2, and the unsuitable area was 1343.91km^2, accounting for 20.19% suitable area of the overall area of KNP (Fig.3.). The distribution of *U. thibetanus* in KNP was confined with altitudinal gradients, ranging from tropical region to alpine forest and scrubs region (1200m-4500m asl). Present study found that more than 64% of habitat is in sub-tropical forest followed by temperate forest and alpine and scrub forest 26% and 10% respectively. The major distribution and habitat are in the North and West district's core area, followed by the small portion of Sikkim's South district. It was observed that the watersheds area used by *U. thibetanus* showing 80% of distribution in these areas. Based on the study, the major area of distribution of *U. thibetanus* may be present in the buffer and transition zone of the Khangchendzonga National Park. In West and North Sikkim, the significant parts of the distribution and habitat of *U. thibetanus* come under these areas. In this scenario, the significant tourist influx into the core area may lead to shifting of habitat to less disturbance area or movement to lower gradient, especially human settlement areas, causing more human-bear interaction. More climatic modeling research studies are urgently needed to understand the potential distribution, habitat use, and human-bear conflict throughout the Khangchendzonga landscapes.

To achieve our research goal, we chose MaxEnt modelling in our study based on presence data. The present study's data was limited and called bias due to restricted habitat, rugged terrain, and inadequate resource availability and accessibility. Our study was restricted up to 4600m asl due to tough terrain and remoteness, but we tried to sample as many as possible. The present study provides only the potential distribution and habitat of *U. thibetanus* in the core area of KNP. Furthermore, in-depth research studies like species distribution, population densities, climatic factors affecting habitat selection (present and future scenario), and conservation-oriented studies should be initiated in three different zones: core zone, buffer zone, and transition zone. These studies provide the species distribution and habitat use and provide the knowledge and factors behind the Human-Bear conflict in the fringe villages of KNP. There is a need to identify natural corridors linking KNP to other protected areas of Sikkim to minimize the human-bear conflict. The Government should initiate long-term monitoring, conservation, and management program to tackle the present and future status of *U. thibetanus* in the Sikkim.

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