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***Research Article***

# ECOLOGICAL NICHE MODELLING OF HIMALAYAN LANGUR (*Semnopithecus entellus*) IN SOUTHERN FLANK OF THE HIMALAYA

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## ABSTRACT

The species and subspecies status of various populations of the Himalayan langur (*Semnopithecus entellus*) have been disputed in many literatures. Before delineating the taxonomic boundaries, it is important to identify the potential distribution areas of extant populations of the species. Ecological niche modeling (ENM) can be coupled with the systematic survey of species presence to identify the species' potential distribution range. Therefore, we did extensive survey and population census of the Himalayan langur across three major river basins (Koshi, Gandaki and Karnali) of Nepal and analyzed the population patterns. In addition, we also modelled the ecological niche of the species by using maximum entropy (MaxEnt) algorithm. We counted a total of 559 individuals from 33 troops that accounted the average troop size of 16.94 (±8.39) individuals. Within Nepal territory, the highest population of langurs was observed from the Gandaki River basin followed by the Karnali River basin. We revealed that Himalayan langurs have a wide range of altitudinal (49 m - 4190 m above sea level) distributions from Bhutan to Kashmir across southern flank of the Himalaya. We warrant for the detail distribution assessment and taxonomic analysis of Himalayan langurs using ecological, morphological and genetic variables.

**Keywords:** Colobines, Ecological niche, River basins, Nepal Himalaya, Population

## INTRODUCTION

Colobine monkeys are distributed in sub-Saharan African forests and all over the South and Southeast Asia (Fashing 2007). The extant colobine species belong to 10 genera in two subtribes- the African Colobina and the Asian Presbytina. The later includes seven genera, namely *Pygathrix, Rhinopithecus, Nasalis, Simias, Presbytis, Trachypithecus* and *Semnopithecus* (Wang *et al.* 2013). The evidences obtained from the fossil records support the divergence between ancestral African colobines and Asian colobines occurred between 10 - 13 Mya (Delson 1992). The colobines have been described to have experienced recent and rapid adaptive divergence, in addition, they are more diverse and widespread for different climate environments (Wang *et al.* 2013).

Hanuman langurs are unique among the Asian colobines in terms of their wide distribution in a range of habitats (Roonwal & Mohnot 1977). They are distributed throughout most parts of India and Sri Lanka, and are also found in some parts of Pakistan, most of the areas of Nepal, and some areas in Bangladesh (Karanth *et al.* 2010). The species and subspecies status of various populations of the Himalayan langurs (*Semnopithecus entellus*) have been disputed in many literatures (Karanth *et al.* 2010). Earlier, most authors considered the single species, *S. entellus*, of Hanuman langurs dividing the species up to 16 subspecies (Roonwal & Mohnot 1977). More recently, the genus *Semnopithecus* has been divided into two (Brandon-Jones 2004), three (Karanth 2010), and even seven (Groves 2001) distinct species. Ashalakshmi *et al.* (2014) studied the phylogenetic relationship among the South-Indian populations of *Semnopithecus* and validated the species status of *S. priam* and *S. hypoleucus* described based on morphology. However, the taxonomic positions of the Himalayan langurs (*S. entellus*) are yet to be tested by molecular analyses.

Before delineating the taxonomic boundaries, it is important to identify the potential distribution areas of the species, so that, the taxonomic study could use the samples from its all the extant populations. Determining the spatial distribution of a species is a multifaceted task (Boubli & de Lima 2009). At present, availability of several mathematical techniques that are based on the concept of a species' fundamental ecological niche facilitates prediction of geographical distribution of a species (Mazel *et al.* 2017). The fundamental niche of a species comprises of a set of all necessary conditions that allow potential distribution and long-term survival, whereas its realized niche is a subset of the fundamental niche that is currently occupied as the realized distribution (Hutchinson 1957, Phillips *et al.* 2006). The species' realized niche is often smaller than its fundamental niche as it is under the influence of human activities; biotic interactions such as inter-specific competition and predation; or geophysical barriers that hinder their dispersal and colonization. Prevalence of such factors often prevent the species from inhabiting conditions encompassing its full ecological potential (Pulliam 2000).

If the realized niche and fundamental niche of a species fully coincide with each other, the modeling algorithm can characterize the species' full fundamental niche (Warren *et al.* 2008). A niche-based model predicts the suitability in an ecological space, that in turn is projected into geographic space, yielding a geographic area of potential presence for the species (Phillips *et al.* 2006). Ecological niche models identify consistent differentiation patterns in characters related to the ecological niche and might provide alternative means of recognizing putatively independent lineages and thus act as an effective tool in delimiting species boundaries (Ortiz-Martinez *et al.* 2008).

Ecological niche modeling (ENM) can be coupled with the systematic survey of species presence to identify the species' potential distribution range (Ortega-Huerta & Peterson 2008) relating the field observations to environmental layers of predictor variables (Guisan & Thuiller 2005). ENMs are useful in one of four ways- i) to estimate the species niche, ii) to estimate the relative suitability of currently distributed areas of the species, iii) to estimate the relative suitability of potential habitat in geographic areas yet to be discovered for occurrence of the species, and iv) to estimate changes in the suitability of habitat over time under a specific scenario for environmental change (Warren & Seifert 2011). The popularity of ENM tools have been increased for predicting the geographic ranges of species and have made important contribution for conservation (Kremen *et al.* 2008), for predicting changes in distribution from past or future climatic events (Hijmans & Graham 2006), and for investigating patterns of speciation and niche divergence (Warren et al. 2008).

The ENM offers multiple benefits over the traditional mapping techniques by producing a more accurate and robust map even with an incomplete and noisy dataset (Acharya *et al.* 2018). ENMs establish relationships of known species occurrences with potential environmental covariates, then predict spatial and temporal distribution of the species. MaxEnt, Boosted Regression Tree (BRT), Tree Net and Random Forest are some of the widely used machine learning ENM algorithms (Acharya *et al.* 2018, Merow *et al.* 2013). Among the ENM techniques available at present, maximum entropy method or MaxEnt (Phillips *et al.* 2004) is designed to depict the distribution of individual species using presence-only data (Phillips *et al.* 2006). It outperforms other existing predictive methods (Elith *et al.* 2006) and has exponential growth in its application since introduction in 2004 (Morales *et al.* 2017).

Because of the limited studies on non-human primates in South Asia, the spatial extent of the Himalayan langur distribution is poorly known. Therefore, we aimed to unleash the ecological niche of the species and project that to the potential distribution in the southern flank of the Himalaya. By extensive surveys along the tributaries of major three river systems of Nepal, we assessed the population status of Himalayan langurs and collected geographical points of the species occurrence. We used species occurrence data and bioclimatic variables to model the ecological niche of the species employing maximum entropy (MaxEnt) algorithm.

## MATERIALS AND METHODS

### Study area and research animal

Nepal stands on latitude between 26˚ 21′ to 30˚ 27′ North and longitude between 80˚ 4′ to 88˚ 12′ East (Sharma 1999). It is roughly rectangular and slightly slanted towards the lower latitudes in the east. It extends about 800 kilometers along its east-west Himalayan axis and the width varies between 150 and 250 kilometers covering the total area of 147,181 square kilometers. The Nepal Himalaya forms the central one-third of the entire Himalayan range and includes multiple bioclimatic zones. It has geographic diversity ranging from 60 metres elevation in the tropical Tarai, beyond the perpetual snow line to over 7,000 metres including Earth's highest 8,848 meters (Mount Everest).

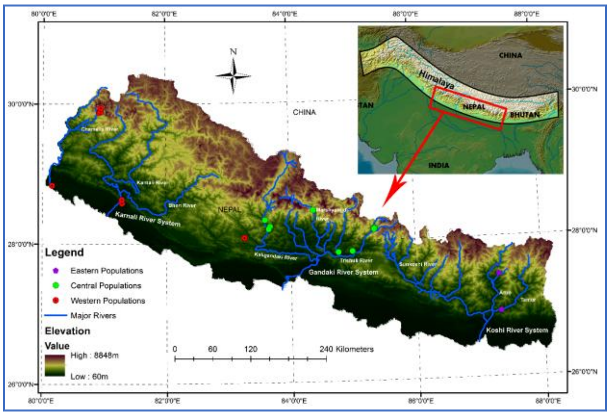


**Fig. 1. Map of Nepal showing the elevational gradient and some occurrence points of Himalayan langur** (Khanal *et al.* 2018b)

Surveys were conducted in three physiographic zones (Tarai, mid hills and lower Himalaya) across the three major River systems of Nepal- Koshi River System (KRS) on the eastern Nepal, Gandaki River System (GRS) on the central Nepal and Karnali- Mahakali River System (KMRS) on the western Nepal. Surveys were conducted in Tarai, Siwalik zone, mid hill zones and lesser Himalaya of the catchment areas of the three river systems (Fig. 1). It included some parts of eight protected areas of Nepal and non-protected Himalayan langur habitats in the mid hills.

Himalayan langurs are widely distributed from low-land Tarai to lower Himalayas. Chalise *et al.* (2005) suspected three subspecies of Himalayan langur in Nepal, with different IUCN red list status- *Semnopithecus entellus hector* (lesser hill langur) as critically endangered, *Semnopithecus entellus ajax* (western Himalayan grey langur) as endangered and *Semnopithecus entellus schistaceus* (central Himalayan langur or Nepal grey langur) as near threatened. *S. entellus ajax* is reported from East Langtang and Melamchi area of central Nepal. *S. entellus hector* is described from Central to West Nepal in outer Tarai and *S. entellus schistaceus* is reported from south to north in Central Nepal (Chitwan, Kathmandu & Langtang) and the *S. entellus hector* is the smallest in size among the three, with yellowish fur on their chest and abdomen. The medium sized among these three is *S. entellus ajax* with mixed yellowish gray chest and abdomen. *S. entellus schistaceus* is the largest among the three with whitish chest and abdomen (Chalise *et al.* 2005).

**Field survey and population census**

Field surveys were conducted along both the sides of river tributaries by modified line transect methods starting from less than 100 m above sea level (asl) continued up to 4000 m asl. Three tributaries from each river system- Tamor, Arun and Sunkoshi from KRS, Trishuli, Marshyangdi and Kaligandaki from GRS and Bheri, Karnali and Chamelia from KMRS were surveyed. A total of 48 line-transects of each roughly 2 km length were surveyed on each river system. Wherever the Himalayan langur troops were observed, the detail population censuses were conducted for the troops. The geographical location of the troop was noted using Garmin 64s GPS. The troop size and population composition were observed in detail from the observation distance varying from about 10 to 100 m aided with the binocular whenever necessary. The individuals were divided into four age groups, namely- adults (male and female), sub-adults, juveniles and infants following the method of Chalise (2003). The counting was repeated until the concurrent readings were obtained for total count and age groups.

**Population distribution analysis**

The male to female sex ratios were calculated among the adult and sub-adult age groups separately as the number of males out of 100 females. The infant to female ratio of the monkey was calculated by dividing total number of infants by total number of adult females in the troop. The average troop size was computed as the mean of number of individuals among the observed troops. The significant difference in troop size, sex ratio and infant to female ratio among the three river systems and four physiographic zones were tested statistically by $\chi^2$- test.

$$\text{Average troop size} = \frac{\text{Total no. of individual observed}}{\text{Total no. of troop observed}}$$

$$\text{Male : female ratio} = \frac{\text{No. of males of that age group}}{\text{No. of females of same age group}}$$

$$\text{Infant : female ratio} = \frac{\text{Total no. of infants}}{\text{Total no. of reproductive females age}}$$

**Ecological niche modeling**

*Model development*

We used the maximum entropy (MaxEnt) (Phillips *et al.* 2006) modeling approach for ecological niche modeling of Himalayan langur using the MaxEnt v.3.4.1(Phillips *et al.* 2017). MaxEnt is a machine learning program that uses presence- only data to predict distributions based on the principle of maximum entropy (Acharya *et al.* 2018). The basic principle of the MaxEnt model is to estimate the potential distribution of a species by determining the distribution of the maximum entropy(i.e., closest to uniform), with constraints imposed by the observed spatial distributions of the species and the environmental conditions (Phillips *et al.* 2006).

For the ENM of Himalayan langur, 33 occurrence points were recorded during the field survey. MaxEnt can have robust prediction with smaller number of occurrence points also (Phillips *et al.* 2006) and hence 33 occurrence points which covered almost entire Nepal are enough to represent the study area. The bioclimatic variables (Table 1) were clipped to a region from 78°E to 92°E and from 24°N to 31°N and exported to ASCII format. Seven bioclimatic variables (Bio: 1, 3, 5, 11, 12, 15, 18) were selected after removing highly correlated ($r \geq |0.8|$) variables based on Pearson correlation test ($P < 0.05$).

*Model validation and analyses*

Jackknife validation method was used for validation of the model (Pearson *et al.* 2006). The species presence data were randomly divided into 75 % as the training dataset and 25 % as the validation dataset. To account for uncertainty introduced by training and validation set splits, 25 replicated models based on the cross-validation method were generated (Otto-Bliesner *et al.* 2006). It was used the linear quadratic and hinge features and set the maximum number of background points to 1,000 in this study. The accuracy of the models was evaluated by using area under the curve (AUC) of the receiving operating curve (ROC).

The logistic outputs of habitat suitability were converted to the binary outputs of unsuitable and suitable habitats using the threshold of maximum training specificity and sensitivity (maxTSS= 0.3777) as explained for the model generated employing presence-only data by Liu *et al.* (2013). Then, the altitudinal range of the suitable habitat was evaluated by overlaying binary outputs to the SRTM DEM (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1). The elevations of the suitable habitat pixels were extracted and their mean, maximum and minimum were computed.

**Table 1. Bioclimatic variables used in the construction of ENM for Himalayan langur**

| S. No. | Variables | Description |
|---|---|---|
| 1* | Bio1 | Annual mean temperature |
| 2 | Bio2 | Mean diurnal range [mean of monthly (max temp–min temp)] |
| 3* | Bio3 | Isothermally (P2/P7) (×100) |
| 4 | Bio4 | Temperature seasonality (standard deviation × 100) |
| 5* | Bio5 | Max temperature of warmest month |
| 6 | Bio6 | Min temperature of coldest month |
| 7 | Bio7 | Temperature annual range (P5–P6) |
| 8 | Bio8 | Mean temperature of wettest quarter |
| 9 | Bio9 | Mean temperature of driest quarter |
| 10 | Bio10 | Mean temperature of warmest quarter |
| 11* | Bio11 | Mean temperature of coldest quarter |
| 12* | Bio12 | Annual precipitation |
| 13 | Bio13 | Precipitation of wettest month |
| 14 | Bio14 | Precipitation of driest month |
| 15* | Bio15 | Precipitation seasonality (coefficient of variation) |
| 16 | Bio16 | Precipitation of wettest quarter |
| 17 | Bio17 | Precipitation of driest quarter |
| 18* | Bio18 | Precipitation of warmest quarter |
| 19 | Bio19 | Precipitation of coldest quarter |

***** *Variables in the bold letters were used for the ENM after multicollinearity test*

## RESULTS

A total of 559 individuals of Himalayan langur were counted from 33 troops during the field survey (Table 2). The troop size ranged between 3-39 individuals per troop. The overall average troop size was calculated to be 16.94 (±8.39).

### Age-sex composition

The Himalayan langur population had 278 adults and 281 young individuals that accounted the adult to young ratio of 1: 1.01. The adult male to female sex ratio was computed to be 1:1.99. The adult to young ratio and adult male to female sex ratio varied among the river systems but there was no significant statistical difference in the variation (Adult sex ratio, $\chi^2 = 0.136$, df = 2, $P = 0.934$; Adult to young ratio, $\chi^2 = 0.002$, df = 2, P = 0.99).

### River system and elevation wise distribution of Himalayan langur

Highest number of troops and individuals were observed from GRS (12 troops and 233 individuals) in central Nepal followed by the KMRS (13 troops and 214 individuals), and KRS (8 troops and 112 individuals) (Table 3). The highest average troop size was computed from GRS (19.41 individuals per troop) and the least was recorded from KRS (14 individuals per troop), however, there was no significant difference in average troop size among three river systems ($\chi^2 = 0.884$, df = 2, P = 0.64).

The populations were grouped into five groups (Table 4) based on the elevation of their observation. Highest percentage of population was recorded from the elevation range from 500 to 1500 m above sea level followed by < 500 m asl, whereas, least percentage of population were observed from the elevation range beyond 3500 m above sea level (Table 4). There was a significant difference in distribution of populations at various elevation ranges ($\chi^2 = 19.50$, df = 4, $P < 0.01$). The number of troops and the average troop size also varied with the elevation gradients, however there was no significant difference in average troop size among the elevation groups ($\chi^2 = 3.73$, df = 4, $P = 0.44$). A total of 334 individuals of 18 troops were recorded within protected areas and rest 225 individuals of 15 troops were from outside protected areas.

### Ecological niche model for Himalayan Langur

The MaxEnt produced similar results on both the sampling strategies. The mean AUC of 25 cross validation multiplication run was 0.892 (SD=0.088) (Fig. 2) suggesting the potential distribution of Himalayan langur fits well with our data. The annual precipitation (Bio12) had the highest contribution to the model (40.3 %), while, the contributions of precipitation seasonality (Bio15; 22.1 %) and mean temperature of the coldest quarter (Bio11; 16.9 %) were moderate. The response curves revealed that Bio12 in the range of 1600-2100 mm, Bio15 between 95-115 and Bio11 between 50-150 (5-15°C) were ideal to define suitable habitat of Himalayan langur. The results of Jackknife test (Fig. 3) also validated the importance of Bio12 (annual precipitation) in defining the suitable habitat of Himalayan langur.

**Table 0. Geographic positions and population census of Himalayan langur in Nepal (2016/17)**

| S. No. | Place | Location | | | Population | | | | Rem. |
|---|---|---|---|---|---|---|---|---|---|
| | | Latitude | Longitude | ASL | AM* | AF* | Young | Total | |
| 1 | Mulghat west | 26º56'07.21" | 87º19'56.14" | 280 | 3 | 7 | 14 | 24 | KRS |
| 2 | Bishranti Temple | 26°55'50.99" | 87°19'28.78" | 270 | 3 | 0 | 0 | 3 | KRS |
| 3 | Bumlingtar | 27°27'26.31" | 87°07'32.84" | 460 | 5 | 9 | 11 | 25 | KRS |
| 4 | Dongma | 27°27'34.4" | 87°07'19.85" | 554 | 2 | 5 | 6 | 13 | KRS |
| 5 | Tamku | 27º27'34.64" | 87º18'58.79" | 556 | 3 | 6 | 14 | 23 | KRS |
| 6 | Chatara | 26°50'25.40" | 87°09'05.89" | 123 | 2 | 3 | 4 | 9 | KRS |
| 7 | GCA office | 27°44'19.60" | 86°10'00.52" | 964 | 2 | 3 | 7 | 12 | KRS |
| 8 | Bungy jump | 27º52'36.27" | 85º53'30.18" | 1227 | 1 | 2 | 0 | 3 | KRS |
| 9 | Riverside, LNP | 28º09'55.99" | 85º25'58.35" | 2594 | 3 | 5 | 9 | 17 | GRS |
| 10 | Rishing, LNP | 28º10'21.28" | 85º21'01.94" | 1950 | 5 | 11 | 23 | 39 | GRS |
| 11 | Khanjim | 28º10'05.63" | 85º21'40.75" | 2508 | 4 | 7 | 13 | 24 | GRS |
| 12 | Shyafrubesi | 28º09'35.82" | 85º20'53.77" | 1477 | 1 | 4 | 4 | 9 | GRS |
| 13 | Khalte | 27º51'03.80" | 84º59'29.30" | 689 | 4 | 6 | 14 | 24 | GRS |
| 14 | Baseri | 27º50'28.15" | 84º45'59.61" | 382 | 3 | 7 | 9 | 19 | GRS |
| 15 | Saattale | 28º27'05.73" | 84º22'33.25" | 1533 | 5 | 9 | 18 | 32 | GRS |
| 16 | Jagaat | 28º24'44.92" | 84º24'38.31" | 1400 | 4 | 9 | 11 | 24 | GRS |
| 17 | Kushma | 28º13'37.42" | 83º40'26.34" | 877 | 3 | 6 | 5 | 14 | GRS |
| 18 | Dhairing | 28º13'19.53" | 83º35'43.53" | 1080 | 1 | 3 | 3 | 7 | GRS |
| 19 | Balewa | 28º11'30.56" | 83º39'07.74" | 685 | 4 | 7 | 10 | 21 | GRS |
| 20 | Siddheswor Cave | 28º13'27.42" | 83º40'29.34" | 895 | 3 | 0 | 0 | 3 | GRS |
| 21 | Reshunga | 28º04'24.54" | 83º15'42.14" | 1748 | 2 | 4 | 7 | 13 | GRS |
| 22 | Banke | 28º35'09.47" | 81º17'06.51" | 225 | 2 | 5 | 5 | 12 | KMRS |
| 23 | Chisapani | 28º37'59.05" | 81º16'57.72" | 212 | 3 | 8 | 14 | 25 | KMRS |
| 24 | Babai bridge | 28º44′57.42" | 81º22′38.77" | 251 | 2 | 5 | 6 | 13 | KMRS |
| 25 | Dhab, Dailekh | 28º54′57.42" | 81º24′38.77" | 695 | 2 | 5 | 7 | 14 | KMRS |
| 26 | Suklaphanta NP | 28º50'09.90" | 80º09'02.28" | 180 | 1 | 4 | 6 | 11 | KMRS |
| 27 | Okhreni | 29º52'43.80" | 80º54'58.60" | 2513 | 3 | 8 | 13 | 24 | KMRS |
| 28 | Dhaumula | 29º53'48.90" | 80º56'11.12" | 3328 | 3 | 5 | 4 | 12 | KMRS |
| 29 | DhauloOdhar | 29º56'41.06" | 80º56'27.78" | 3798 | 3 | 7 | 11 | 21 | KMRS |
| 30 | Simar falls | 29º53'87.00" | 80º56'25.40" | 2871 | 4 | 9 | 13 | 26 | KMRS |
| 31 | Chamelia | 29º56'25.50" | 80º56'49.10" | 3466 | 3 | 7 | 6 | 16 | KMRS |
| 32 | Khayokot | 29º51'38.60" | 80º53'89.20" | 2139 | 2 | 5 | 5 | 12 | KMRS |
| 33 | Dharmghar | 29º48'39.20" | 80º51'11.60" | 1769 | 2 | 4 | 9 | 15 | KMRS |
| **Total** | | | | | **93** | **185** | **281** | **559** | |

**AM- adult male, AF- adult female, ASL- above sea level*

**Table 3. The river system wise distribution of Himalayan langur population in Nepal**

| S.No. | River System | No. of Troops | Population | | | | Average Troop Size | Population Percentage |
|---|---|---|---|---|---|---|---|---|
| | | | AM* | AF* | Young | Total | | |
| **1** | KRS | 8 | 21 | 35 | 56 | 112 | 14 | 20.04 |
| **2** | GRS | 12 | 40 | 74 | 119 | 233 | 19.41 | 41.68 |
| **3** | KMRS | 13 | 32 | 76 | 106 | 214 | 16.46 | 38.28 |

**AM- adult male, AF- adult female*

**Table 4. The elevation wise distribution of Himalayan langur in Nepal**

| S. No. | Elevation (m above sea level) | No. of Troops | Population | | | | Average Troop Size | Population Percentage |
|---|---|---|---|---|---|---|---|---|
| | | | AM* | AF* | Young | Total | | |
| **1** | <500 | 9 | 24 | 48 | 69 | 141 | 15.67 | 25.22 |
| **2** | 500-1500 | 12 | 30 | 56 | 81 | 167 | 13.91 | 29.87 |
| **3** | 1501-2500 | 5 | 16 | 33 | 62 | 111 | 22.2 | 19.86 |
| **4** | 2501-3500 | 6 | 20 | 41 | 58 | 119 | 19.83 | 21.29 |
| **5** | > 3500 | 1 | 3 | 7 | 11 | 21 | 21 | 3.76 |

**AM- adult male, AF- adult female*

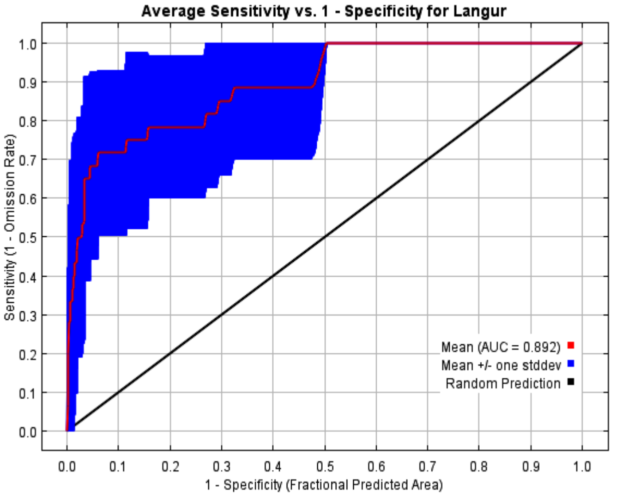


**Fig. 2. Average area under curve (AUC) for 25 replicates of MaxEnt runs (red line is average value and blue bars represent ± 1 standard deviation.**

The potential habitat for Himalayan langur is widely distributed along the southern flank of the Himalaya from Bhutan in the east to Kashmir in the west (Fig. 4). Within Nepal, it is mainly distributed at tropical lowland Tarai, subtropical mid-hills and temperate lower Himalaya of eastern and central region, and lowland Terai and mid-hills of western parts of the country. The elevation range of the current suitable habitat was found to be between 49 m to 4190 m above sea level with the mean value of 1823 m above sea level.

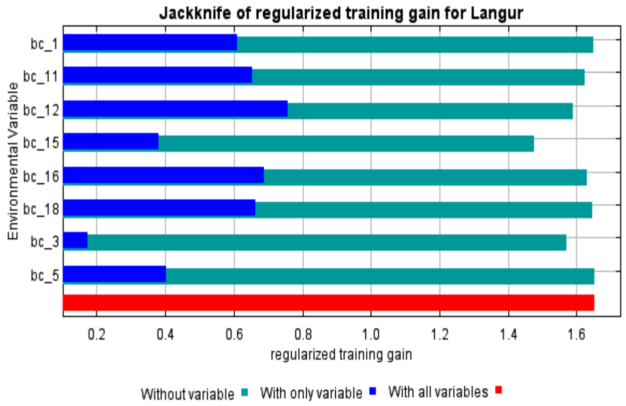


**Fig. 3. Variable importance by Jackknife test for ENM of Himalayan langur. The blue, aqua and red bars represent the results with each variable, remaining all variables and all the variables, respectively.**

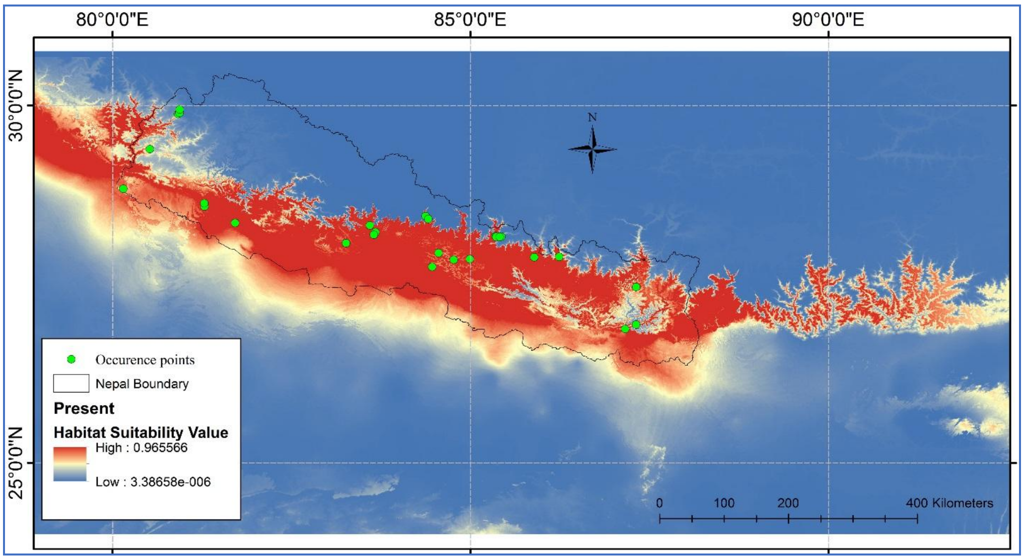


**Fig. 4. The map showing ecological niche model of potential distribution of Himalayan langur in southern flank of Himalaya**

## DISCUSSION

Amongst the most widely distributed non-human primates in South Asia, Himalayan langur is a common sight in diverse natural habitats and tourist areas (Groves 2001). The distribution range of Himalayan langur in Nepal Himalaya is wider than that of Assam macaque, another species of non-human primate having synoptic distribution at many places (Khanal *et al.* 2018a, 2018b). They have been observed from lowland Tarai to lower Himalaya up to the elevation of about 4000 m above sea level. They are distributed along entire east-west length of Nepal Himalaya and live everywhere in Nepal except in permanent snow (Chalise *et al.* 2005). The recent study on Himalayan langur counted 1,113 individuals from 67 troops in Nepal with average troop size of 16.61 individuals (Chalise 2013), but these observations were the accumulated results for the studies of last two decades.

The average troop size of the species (16.94) was found consistent with that of previous reports, 17 individuals per troop (Chalise 2008) in western Nepal and 16.61 individuals per troop in entire Nepal (Chalise 2013). During this study, the highest average troop size (22.2) was recorded for the elevation range of 1500-2500 m above sea level and the average troop size was higher for the populations within protected areas (PAs, 18.56) than those of outside the PAs (15.0). Highest number of Himalayan langur troops and individuals were recorded from GRS followed by KMRS in western Nepal, that differed with the distribution of Assam macaques which are more abundant in GRS and KRS in eastern Nepal (Khanal *et al.* 2018). Western Nepal is relatively drier than the eastern side receiving less precipitation from the summer monsoon. Dry tolerant nature of the Himalayan langur could acclimatize the species to the arid regions (Nag *et al.* 2014) of the western Nepal.

Himalayan langurs are "generalist folivores" and as such take advantage of seasonal products when available and occupy a wide variety of habitat types from arid regions on the edge of deserts to the rain forests (Bishop 1979, Nag *et al.* 2014). They inhabit subtropical to temperate broadleaved forests, pine forests, montane forests, riverine forests, rocky outcrops, and scrub jungles (Molur *et al.* 2003). They are adapted to the encroaching heat of Tarai, the harsh winter of mid-hills and chilly atmosphere by occasional snow at the lap of Himalaya (Chalise *et al.* 2005). Nag *et al.* (2014), by species distribution modeling, predicted the highest area of suitable habitats for *S. entellus* within Indian Territory among different species of langurs. The MaxEnt model during this study revealed that the suitable habitat for Himalayan langur is mainly determined by higher annual precipitation and moderate temperature of the coldest quarter of the year. Higher annual precipitation totaled from the South Asian summer monsoon and winter westerlies may support broadleaved vegetations favored by the folivores like Hanuman langur. The suitable habitat for Himalayan langur is widely distributed along the southern flank of the Himalaya from Bhutan in the east to Kashmir in the west. The paleo-distribution reconstruction for Himalayan langur could not detect remarkable habitat loss and range shifts in LGM when compared to the present range (Khanal *et al.* 2018b). The projection of the current ecological niche of the species for future climate change scenario also didn't have statistically convincing model predictions (Khanal 2018).

Elevational range of Hanuman langur distribution is wide spanning from sea level to 4270 m above sea level in the Himalayas (Sayers & Norconk 2008). The molecular data analyses and paleo-distribution reconstruction did reveal that Himalayan langurs have long evolutionary history in the central Himalaya and experienced some degree of elevational range shift towards lower elevations during the dry and cold period of the last glacial maximum (Khanal *et al.* 2018b). This study predicted the current altitudinal distribution of the species ranging between 49 m to 4190 m above sea level with the mean value of 1823 m above sea level. The annual precipitation in the Hanuman langur habitats range between 10 cm and 740 cm (Nag *et al.* 2014). Though they have wide range of tolerance on available moisture, the ENM in this study revealed that 1600-2100 mm annual precipitation is ideal to define the optimum habitat of the species. In addition to the wide altitudinal range, Himalayan langurs have a wide latitudinal range inhabiting the moist riverine forests of north-eastern India and eastern Nepal influenced by the summer monsoon as well as relatively dry areas of western Nepal, north-western India and Kashmir which are much influenced by westerlies. Such a wide range of latitudinal and altitudinal distribution of the species since long has created morphological variations and the populations are doubted for separate taxonomic categories. Therefore, it is necessary to elucidate the taxonomic ambiguities among Himalayan langur populations by employing morphological, behavioral and molecular data recovered from all the extant populations.

Our study used only the bioclimatic variables in defining the ecological niche of Himalayan langur which alone may not define the complete niche, therefore it should be cautiously weighed in the light of limitations of ENM. Use of other variables, viz., vegetation indices, hydrological layers, canopy density, habitat preference, feeding pattern, troop dynamics, and niche occupancy could define more precise ecological niche of the Himalayan langur (Nag *et al.* 2014). Future research should focus on employing multiple variables and a greater number of occurrence data (Khanal *et al.* 2018c). Additionally, taxonomic subdivisions of the Himalayan langur (*S. entellus*) populations into subspecies level and predictions of ecological niches of individual subspecies separately would be of great importance.

## CONCLUSION

We conclude that Himalayan langur population in Nepal is distributed in a wide elevational and latitudinal range from tropical lowland Tarai to temperate lower Himalayas. The population is sporadically distributed at fragmented forest patches. The potential habitat of the species is widely distributed from Bhutan to Kashmir along the southern flank of the Himalaya. Further taxonomic subdivisions of the wide spread populations and respective ecological niche modeling would enlighten the detail distribution pattern of Himalayan langur.

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