CHAPTER-IV

ECOLOGICAL NICHE MODELLING AND POPULATION STATUS OF THE ENDANGERED *Macaca Munzala* IN ARUNACHAL PRADESH, INDIA

4.1 Introduction

Among the new species discovered in the Eastern Himalayas over the last decade, the Arunachal macaque (*Macaca munzala*) has received much attention due to its IUCN endangered status and confusion over its taxonomy [1]. In 2003, *M. munzala*, a member of the *sinica* macaque taxonomic group, was first discovered in the high altitude area of Tawang and West Kameng districts of Arunachal Pradesh, India and was reported to be restricted to these two districts only [2,3]. The species is characterized by its distinct facial marks on the temple and forehead, prominent dark crown patch, pale collar of hair around the neck, and its distinctive tail length [3]. Preliminary studies on *M. munzala* have reported its distribution, population status, and ecology [4–8]. Kumar et al. [6] described their habitat as being tropical wet evergreen, semi-evergreen forest in low altitudes, and temperate broad leaf forests and coniferous forests in higher altitudes ranging from 2,000 to 3,000 m asl. A phylogenetic study of *M. munzala* was carried out later by Chakraborty, [9] in the Upper Subansiri and West Siang districts revealing their presence in these areas as well. Kumar et. al. [6] reported a total of 35 troops from Tawang and West Kameng districts. Subsequently, a total of 20 troops (422 individual) of *M. munzala* in Tawang and West Kameng districts were recorded by Biswas et al. [1]. Our current knowledge of this species is based on limited population and distribution data. Furthermore, owing to the inaccessibility of the species' habitat, comprehensive population and distribution data remain scarce. To overcome these limitations, ecological niche modeling can be a useful tool to identify the species' potential distribution range based on preliminary occurrence data [10], which essentially provides baseline information for which habitats should be surveyed. As most of the statistical tools determine species niche based on bioclimatic data and ground verification, these statistical modelling tools can be an effective means for identifying potential habitat. Maximum entropy modeling using the MaxEnt model is the most popularly used statistical tool for predicting the potential habitat of a species [11,12].

The present study aimed to model the potential habitat of *M. munzala* in Arunachal Pradesh using a maximum entropy algorithm based on bioclimatic factors. Maximum entropy modeling was found to be very useful in various other primate species' distribution modeling (e.g., Mexican primates: Vidal-Garcıa and Serio-Silva [12]; Buffy tufted ear ́ Marmosets: Norris, Rocha-Mendes, Marques, NobreRde, and Galetti [13]; Nycticebus spp. Thorn, [14]; Slender Loris: Kumara, [15], and *Hoolock* *leuconedys*: Sarma et al. [11]. The major significance of this model is to recognize areas of higher probability of species distribution range based on environmental variables, and thus, outcomes might be helpful in understanding the selection of habitat by the species and prove to be useful for further population surveys. Thus, the study attempt to report data on the population status of *M. munzala* collected during extensive field surveys across Arunachal Pradesh following its predictive distribution range, and the current population status in Tawang and West Kameng districts.

4.2 Methods

4.2.1 Study area

A preliminary survey was carried out in Tawang and West Kameng districts of Arunachal Pradesh (91°36′–93°13′E, 26°52′–27°58′N), India to collect the occurrence data of *M. munzala* followed by an extensive population survey during the year 2013–2014 (Fig. 4.1). The Tawang and West Kameng districts cover an area of 2,172 and 7,422 km2, respectively. The two districts are divided into nine valleys along the river banks, namely, Nymjang Chu, Tawang Chu, and Mago Chu in Tawang district, and Bichom Chu, Tenga Chu, Dirrang Chu, Shergaon Chu, Domkho Chu, and Kameng Chu in West Kameng district and survey was conducted. The forest type of the study area has been classified into Broadleaf forest (up to 3,000 m), Conifer broadleaf forests (3,000–4,200 m), Rhododendron scrubland (4,000–4,300 m), Dwarf Rhododendron meadows (4,200–4,600 m), and High altitude grassy meadows (4,350–5,250 m) [16].

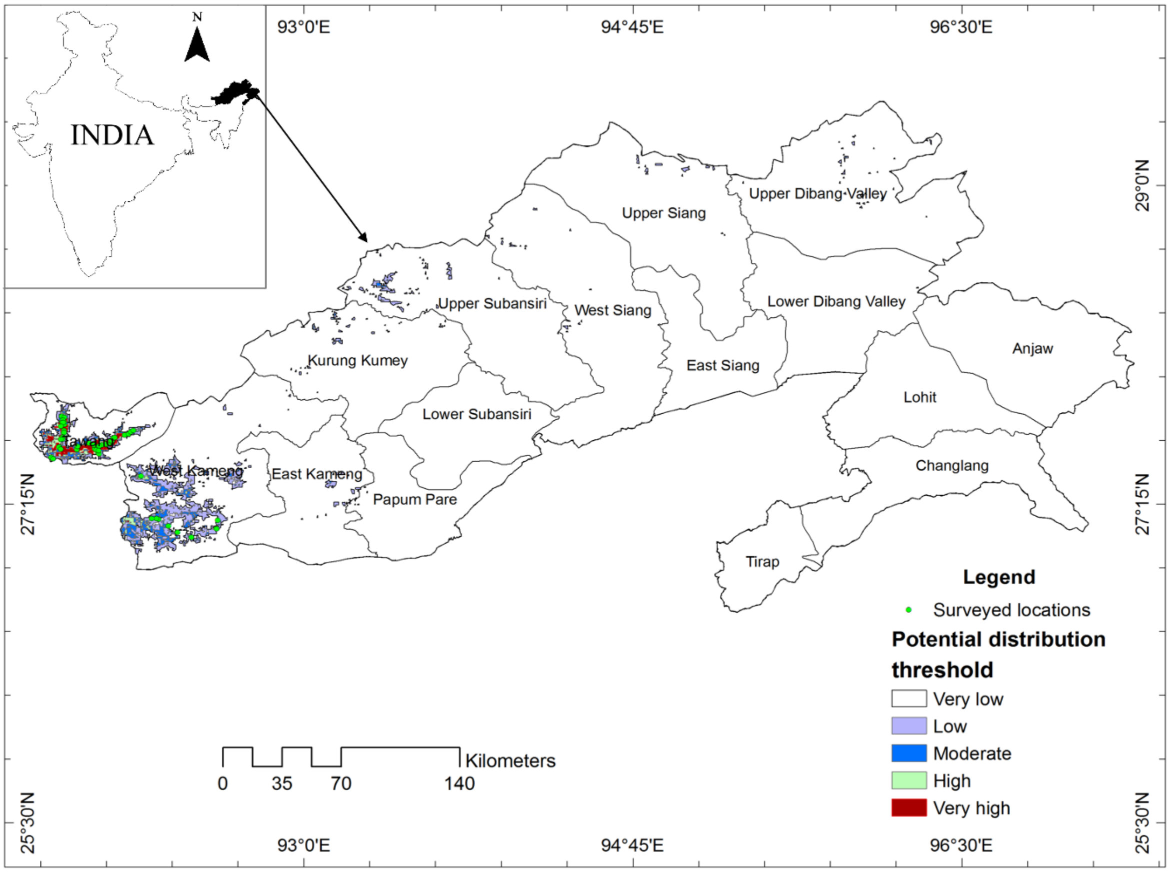

Figure 4.1. Map of Arunachal Pradesh and Maxent modeling output map of distribution threshold of *M. munzala* in Arunachal Pradesh, India

4.2.2 Initial occupancy survey

A simple random sampling method was carried out for the initial occupancy survey in Tawang and West Kameng districts. These two districts have been preselected as they are already known as the distribution range of *M. munzala* [4,16]. Presence of the species was confirmed through informal interviews with the local people, followed by tracking of the troops in forested and non-forested areas. GPS location points were recorded wherever a troop was sighted. The species is identified by its morphological features described by Sinha et al. [3]. The collected location samples (Geo-cordinates) were used as occurrence data in the modelling exercise (Table 4.1).

Table 4.1. List of geo-coordinates point of *Macaca munzala* troops recorded during the preliminary survey and population survey (study area)

Overlap location of preliminary and population survey					
Sl. No.	Locality	Latitude (N)	Longitude (E)	Valley	District
1	Jang	27°35'5.93"N	91°58'30.17"E	Tawang Chu	Tawang
2	Lhau	27°34'51.80"N	91°56'35.13"E	Tawang Chu	Tawang
3	Bomdir	27°34'15.94"N	91°54'36.89"E	Tawang Chu	Tawang
4	Mukto	27°31'53.55"N	91°54'21.62"E	Tawang Chu	Tawang
5	Mukto	27°32'40.54"N	91°54'30.39"E	Tawang Chu	Tawang
6	Lamberdung	27°34'36.73"N	91°52'55.94"E	Tawang Chu	Tawang
7	Tawang Monastery	27°35'11.50"N	91°51'26.70"E	Tawang Chu	Tawang
8	Gispu	27°33'48.67"N	91°41'46.32"E	NymjangChu	Tawang
9	Shakti	27°36'22.54"N	91°42'53.43"E	Nymjang Chu	Tawang
10	BTK	27°39'19.51"N	91°43'22.47"E	Nymjang Chu	Tawang
11	Gorsam	27°41'55.25"N	91°43'6.10"E	Nymjang Chu	Tawang
12	Lumpo	27°43'7.18"N	91°42'54.41"E	Nymjang Chu	Tawang
13	Upper Dung	27°41'22.66"N	91°43'32.89"E	Nymjang Chu	Tawang
14	Khelengteng	27°42'5.14"N	91°43'24.61"E	Nymjang Chu	Tawang
15	Socktsen	27°43'37.10"N	91°43'33.70"E	Nymjang Chu	Tawang
16	Bletting	27°30'3.06"N	91°39'53.10"E	Nymjang Chu	Tawang
17	Thongleng	27°34'6.32"N	91°47'44.11"E	Nymjang Chu	Tawang
18	Sherbang	27°33'8.96"N	91°42'25.07"E	Nymjang Chu	Tawang
19	New Melling	27°37'46.40"N	92° 2'45.30"E	Mago Chu	Tawang
20	Thingbu	27°39'21.01"N	92° 5'35.57"E	Mago Chu	Tawang
21	Tawang Monastery	27°35'11.50"N	91°51'26.70"E	Tawang Chu	Tawang
22	Sessa	27° 6'53.68"N	92°32'11.30"E	Kameng Chu	West Kameng
23	Padma	27°24'20.70"N	92° 8'2.70"E	Dirrang Chu	West Kameng
24	Morshing	27°10'18.18"N	92°11'25.10"E	Domkho Chu	West Kameng
25	Nichipu Pass	27° 9'46.07"N	92°33'26.98"E	Kameng Chu	West Kameng
26	Eaglenest	27° 4'10.13"N	92°24'4.37"E	Kameng Chu	West Kameng
New location recorded in population survey					
1	Nuranang Fall	27°35'22.30"N	91°58'56.30"E	Tawang Chu	Tawang
2	Fourth Bridge	27°35'1.96"N	91°58'17.40"E	Tawang Chu	Tawang

3	Lhau	27°34'36.13"N	91°55'24.32"E	Tawang Chu	Tawang
4	Mukto	27°31'50.66"N	91°54'31.87"E	Tawang Chu	Tawang
5	Bletting	27°30'31.63"N	91°39'24.12"E	Nymjang Chu	Tawang
6	Shakti	27°36'26.90"N	91°42'24.73"E	Nymjang Chu	Tawang
7	Shakti	27°37'10.82"N	91°42'59.10"E	Nymjang Chu	Tawang
8	Lower Gorsam	27°40'41.82"N	91°42'23.90"E	Nymjang Chu	Tawang
9	Lumpo	27°42'42.71"N	91°43'5.52"E	Nymjang Chu	Tawang
10	Brocklynthang	27°43'59.19"N	91°42'44.46"E	Nymjang Chu	Tawang
11	Jangda	27°35'59.61"N	91°58'20.27"E	Mago Chu	Tawang
12	Rho	27°37'3.13"N	91°59'40.28"E	Mago Chu	Tawang
13	New Melling	27°38'8.20"N	92° 4'4.10"E	Mago Chu	Tawang
14	New Melling	27°38'56.00"N	92° 4'45.00"E	Mago Chu	Tawang
15	Domkho	27°10'20.37"N	92°12'53.74"E	Domkho Chu	West Kameng

4.2.3 Distribution modelling

Environmental variables and occurrence data Bioclimatic variables include annual trend (e.g., mean annual temperature and annual precipitation), seasonality (e.g., annual range in temperature and precipitation), and extreme environmental factors (i.e., temperature of the coldest and warmest month, and precipitation of 3 months of the wet and dry period) derived from the monthly temperature and rainfall data (www.worldclim.org). Nineteen bioclimatic variables of temperature and precipitation with 30 s spatial resolution available in WorldClim database (www.worldclim.org; Table 4.2) were used in modelling as per Hijmans et. al. [17]. As *M. munzala* is mainly dependent on plant material for food [5], the effect on phenology and distribution of plant species by bioclimatic variables can influence its distribution [12].´Topography has an effect on vegetation characteristics, species abundance, and influences ecosystem composition [18,19]. The Digital Elevation Model (DEM) derived different topographic-geomorphometric parameters using the Geographical Information System (GIS) [18]. The DEM highly correlates with temperature, moisture, and geomorphological processes; hence, DEM is an important tool that can be used in vegetation analysis as an indication of habitat condition in a landscape [20,21]. Advanced Very High Resolution Radiometer (AVHRR), a sensor that measures four spectral bands, is used in the Normalized Difference Vegetation Index (NDVI) calculation to determine the density of plant growth and green leaves (www.earthobservatory.nasa.gov). All the environmental variable data and statistical analysis of those data can be obtained through the DIVA GIS [22]. The study used SRTM (Shuttle Radar Topographic Mission) 90 m resolution DEM data and a LULC (Land Use Land Cover) map of Arunachal Pradesh downloaded from Diva GIS (www.diva-gis.org). NDVI layers from January to December, derived from AVHRR, are used in the model. The occurrence data of *M. munzala* were collected through field surveys. A total of 26 occurrence data of *M. munzala* were collected, and all were used in the modelling process (Table 4.1).

Table 4.2. Environmental and its associated variables used in the study and their percentage contribution in the model.

Code	Environmental variables	Unit	Percentage contribution	Percentage permutation
Bio1	Annual mean temperature	◦C	0.1	0.9
Bio2	Mean diurnal range (mean of monthly max. and min. temp.)	◦C	-	-
Bio3	Isothermality ((Bio2/Bio7) × 100)	-	-	0.1
Bio4	Temperature seasonality (standard deviation ×100)	-	-	-
Bio5	Maximum temperature of warmest month	◦C	-	-
Bio6	Minimum temperature of coldest month	◦C	1	33.5
Bio7	Temperature annual range (Bio5–Bio6)	◦C	-	-
Bio8	Mean temperature of wettest quarter	◦C	-	-
Bio9	Mean temperature of driest quarter	◦C	-	-
Bio10	Mean temperature of warmest quarter	◦C	-	0.1
Bio11	Mean temperature of coldest quarter	◦C	-	-
Bio12	Annual precipitation	mm	-	-
Bio13	Precipitation of wettest period	mm	1.4	-
Bio14	Precipitation of driest period	mm	8.2	41.7
Bio15	Precipitation seasonality	mm	8.3	11.4
Bio16	Precipitation of wettest quarter	mm	-	-
Bio17	Precipitation of driest quarter	mm	6.3	-
Bio18	Precipitation of warmest quarter	mm	7	0
Bio19	Precipitation of coldest quarter	mm	11.9	2.1

enu1_1	January	-	9.4	0
enu2_1	February	-	8	1
enu3_1	March	-	5.7	-
enu4_1	April	-	9.6	2.1
enu5_1	May	-	6.5	0.4
enu6_1	Jun	-	0.1	-
enu7_1	July	-	-	-
enu8_1	August	-	0.1	0.5
enu9_1	September	-	-	-
enu10_1	October	-	-	-
enu11_1	November	-	6	5.9
enu12_1	December	-	10.1	0.3
DEM	Elevation	-	0.3	-

4.2.4 Ecological niche modelling (ENM)

We extensively followed the methodology of ENM given by Phillips et al. [23] for the prediction of potential habitat of the species. Environmental variables and species occurrence data were fitted into MaxEnt software version 3.1.0 (Computer Sciences Department—Princeton University, 2004) and a final output map of predicted potential habitat area was projected using ArcGIS 10.1.

4.2.5 Validation of model

Jackknife validation methodology was used explicitly for the validation of the model, which is shown to be effective for sample sizes of 25 or less [24]. We enabled 80% of the data for training and the rest 20% for testing, employing the 10 percentile threshold rule. Linear quadratic and hinge features were used and the maximum number of background points was 1,000. A total of 100 runs were set for model building [25]. To avoid over fitting of the model, goodness-of-fit test was performed by AUC (Area Under the receiving operator Curve); the highest AUC was considered as the best performer. The contributions of the variables were weighed through Jackknife procedure. The final output was divided into five potential distribution areas that were regrouped with the range of 0–1, namely, Very Low potential (<0.18); Low potential (0.18–0.35); Moderate potential (0.35–0.53); High potential (0.53–0.71), and Very High potential (>0.71). Very low potential distribution threshold (<0.18) covered the maximum area under the predicted output map. MaxEnt modelling does not consider historical or physical barriers of the species distribution [26,27] that might affect the very low distribution threshold. Thus, the very low potential threshold (<0.18) category has been excluded from the analysis. A similar analysis has been done by Sarma et al. [11] for prediction of suitable habitat of gibbons *Hoolock leuconedys* in northeast India.

4.2.6 Population survey

A population survey was carried out in nine valleys of Tawang and West Kameng districts of Arunachal Pradesh, India following existing trails and paths. Three valleys, namely, Mago Chu, Tawang Chu, and Nymjang Chu were from Tawang district and six valleys (Bichom Chu, Tenga Chu, Kameng Chu, Shergaon Chu, Domkho Chu, and Dirrang Chu) were from West Kameng district. Troops encountered directly were counted to note age and sex of each individual, and their locations were recorded through handheld GPS. The survey was performed by walking on existing forest trails of the valleys and covering a distance of 10.56 km on an average per day. Surveys were carried out from morning (06.00) and terminated in the evening (16.00). Whenever a glimpse of species was sighted, scan was done using binoculars (Nikon 56 × 50) and record number of individuals (troop size), troop structure (age–sex) etc. Age–sex identification was done as per Sinha et al. [3] and Dittus and Thorington [28]. However, unidentified individuals were excluded from the age–sex analysis. Also, habitat type of the sighting area was noted. Only the broad habitat parameter of forest type and dominate tree species were recorded.

4.3 Result

4.3.1 Predicative distribution range

The output map of MaxEnt modelling shows the minimum area of Arunachal Pradesh potentially included in the distribution range of *M. munzala* at varying thresholds. (Fig. 4.1) Only 2.4% of the total landmass of the state is the potential distribution range of the species (Fig. 4.2).

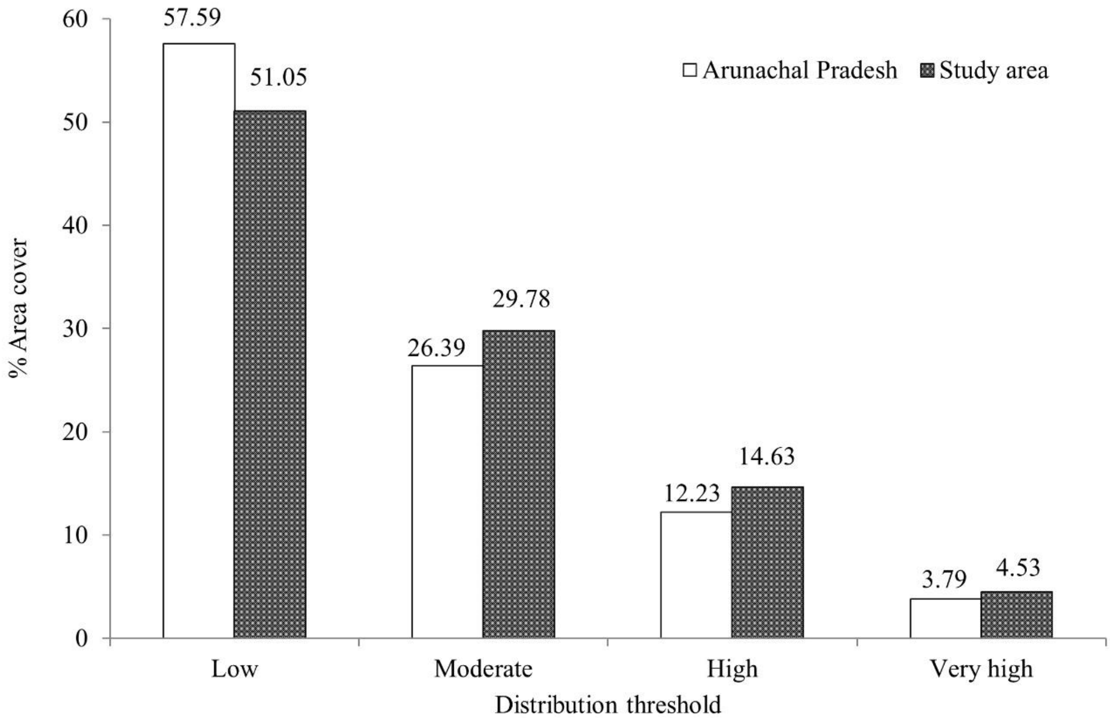

Figure 4.2. Percentage of total predicted distribution area of *M. munzala* in different threshold categories in study area (Tawang and West Kameng districts) and Arunachal Pradesh

However, comparatively higher concentrations of the species distribution range was exhibited in Tawang and West Kameng districts, comprising 10.19% of the total area of the two districts. The result of the model calibration test for *M. munzala* was found to be satisfactory (AUCtrain = 0.99 ± 0.001 and AUCtest = 0.99 ± 0.01) which was also confirmed with Jackknife validation (Fig. 4.3).

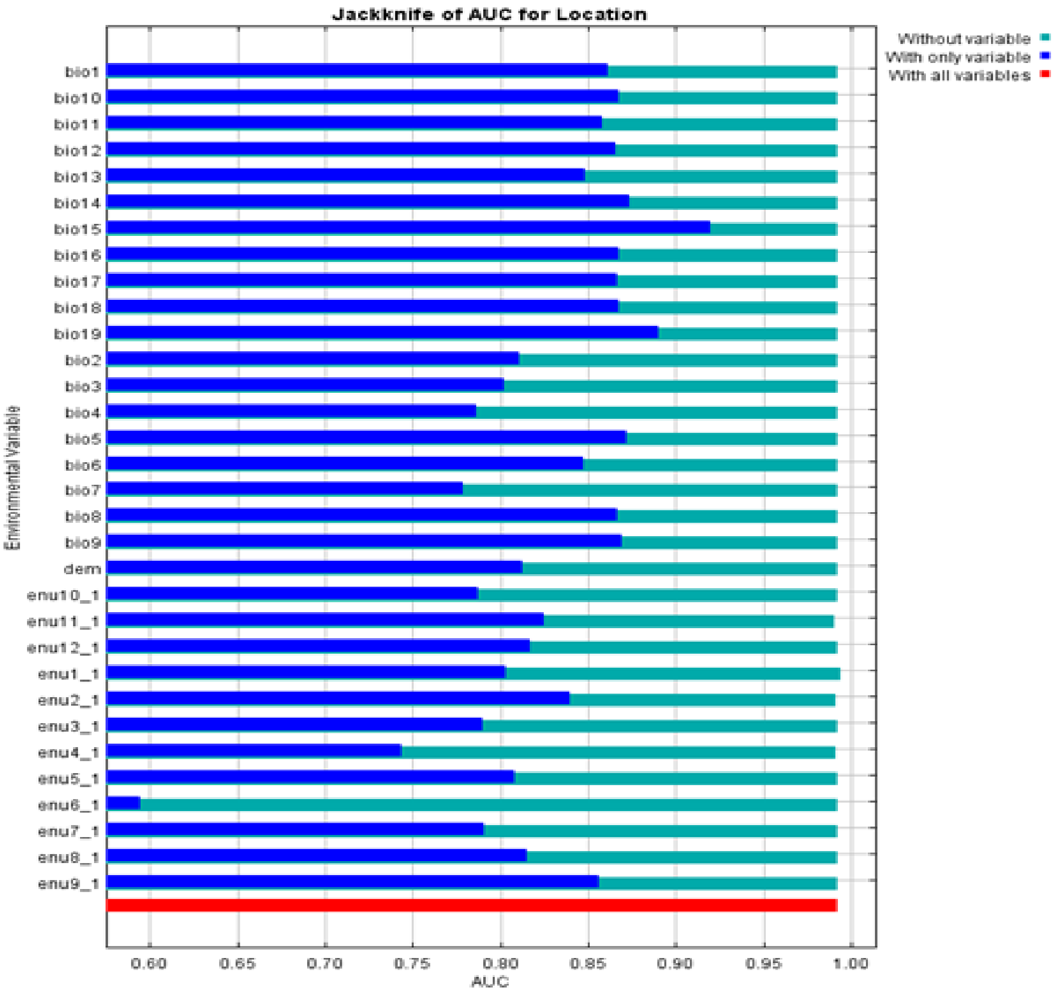

Figure 4.3. Result of Jackknife test for assessing relative contribution of input of environmental variables.

Among the input environmental variables, precipitation in the coldest quarter of the year (BIO 19) made the highest contribution to the model (11.9%) and the 12 layers of NDVI collectively contributed 55.5%, with the layer for December being the highest contributor (10.1%) among them all (Table 4.3). Among the four threshold categories of potential distribution in Arunachal Pradesh, the highest percentage of area is under Low threshold (57.59%) and the lowest was recorded for the Very High category (3.79%) (Fig. 4.2). A similar trend was found in the study area as well; when the potential area of distribution was found highest for the Low (51.05%) category and lowest for the Very High (4.53%) category (Fig. 4.2).

4.3.2 Population status and troop composition

Out of the nine valleys surveyed, *M. munzala* were recorded in six, namely, Nymjang Chu, Tawang Chu, and Mago Chu of Tawang district, and Dirrang Chu, Domkho Chu, and Kameng Chu of West Kameng district. A total of 971 individuals (including 2 solitary males) comprising of 41 troops in the study area (Table 4.3). The highest population was recorded in Nymjang Chu valley (17 troops, 493 individuals) and the smallest population was recorded in the Dirrang Chu valley (1 troop, 19 individuals) (Table 4.3). *M. munzala* was not sighted in Bichom Chu, Tenga Chu, and Shergaon Chu valleys of West Kameng district.

A population study was carried out on 41 troops (969 individuals excluding the solitary individuals). The age–sex analysis is based on 442 identified individuals. In Tawang district, 35 troops comprised of 865 individuals were recorded. In the West Kameng district, 6 troops comprised of 104 individuals were recorded. The age–sex class breakdown of the entire population of *M. munzala* in order of decreasing representation included 30.37% juvenile, 23.83% adult females, 18.22% infants, 11.53% adult males, 9.81% sub-adult females, and 6.23% sub-adult males (Fig. 4. 4). The age–sex ratio was 0.48:1 for adult males to adult females, 1.05:1 for adult to immature, and 1.30:1 for adult females to infants. Mean troop size was 23.63 ± 1.21 individuals, ranging from 12 to 44. Most of the *M. munzala* troops (17) ranged in size between 21 to 25 individuals, followed by 15 to 20 individuals (12 troops) and only two troops were having >35 individuals (Fig. 4. 5). *M. munzala* was encountered between 1,400 and 3,000 m asl. Altitude influenced the distribution pattern of the species. *M. munzala* were mostly found at altitudes of 2,000–2,200 m asl (12 troops, 290 individuals), 1,800–2,000 m asl (7 troops, 190 individual), and 2,200–2,400 m asl (6 troops, 146 individuals), as shown in Fig. 4.6.

Table 4.3. Details of survey efforts, population status and encounter rate of *M. munzala* in western Arunachal Pradesh, India

Name of district	Valleys	No. of survey efforts (in days)	Total trail distance covered (km)	Altitudinal Range (m msl)	No. of troops	Total No. of individuals	Mean troop size (±SE)	Encounter rate (±SE) (Per Km)
Tawang	Nymjang Chu	60	122	1588-2761	17	493	29.00 (±2.05)	0.16 (±0.03)
	Tawang Chu	23	180	1923-2981	12	253	21.08 (±1.27)	0.08 (±0.01)
	Mago Chu	30	96	2613-2843	06	119	19.83 (±1.16)	0.06 (±0.01)
West Kameng	Dirrang Chu	09	151	2023	01	19	19	0.01 (±0.01)
	Domkho Chu	10	104	2110-2137	02	45	22.50 (±1.50)	0.02 (±0.01)
	Kameng Chu	16	121	1464-2456	03	40	13.66 (±0.88)	0.04 (±0.01)
	Bichom Chu	8	65	0	0	0	0	0
	Tenga Chu	5	75	0	0	0	0	0
	Shergaon Chu	7	123	0	0	0	0	0
	Total	**168**	**1037**	**1464-2981**	**41**	**969**	**23.65 (±1.20)**	**0.07 (±0.01)**

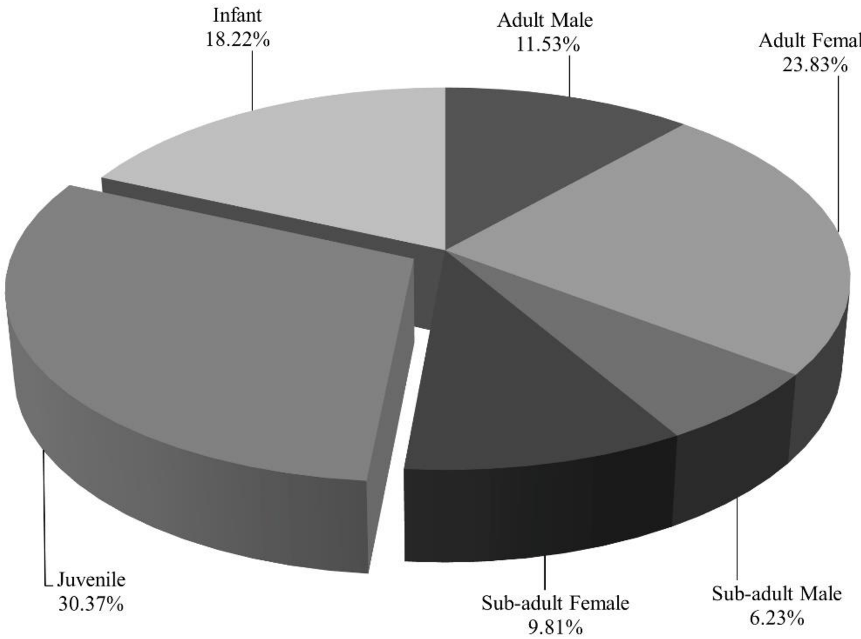

Figure 4. 4. Percentage age–sex composition of population of *M. munzala* in the study area

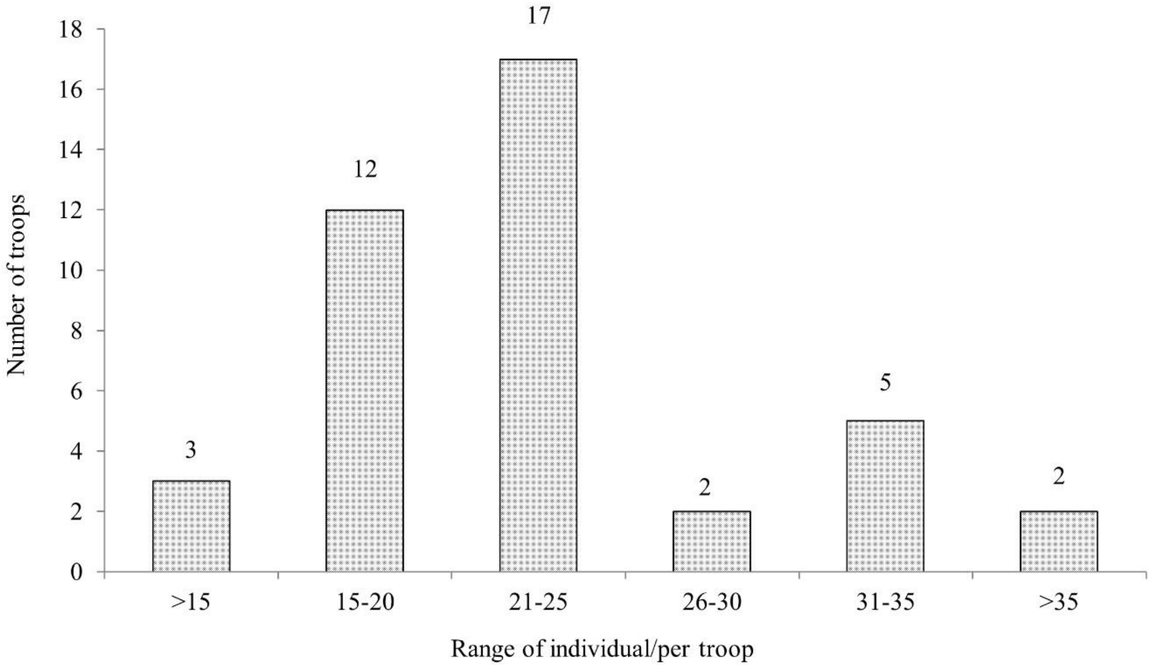

Figure 4.5. Total no. of troops and troops range recorded in the study area

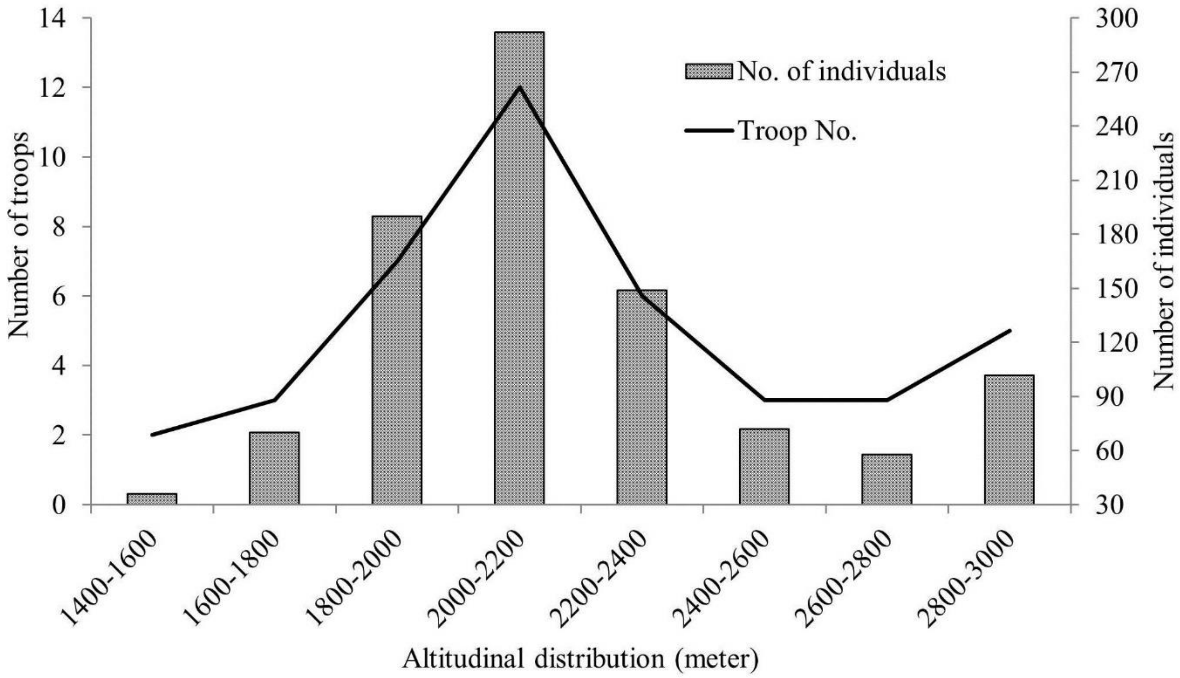

Figure 4.6. Altitudinal distributional pattern of *M. munzala* in the study area

Among the 41troops recorded, 62.12% (28troops) were observed in human-modified landscape (HMLC, e.g., crop fields, apple orchards, home gardens, road side areas, and human settlements) and the remaining 37.87% of the troops were sighted in different types of forested area. Among the troops sighted in forested areas, the highest number of troops (7 troops), were recorded in East Himalayan mixed coniferous forest (EHMCF) followed by the East Himalayan broad leaved forest (EHBLF) with 3 troops, East Himalayan sub-tropical wet hill forest (EHSTWHF) with 2 troops, and 1 troop in the East Himalayan sub-tropical pine forest (EHSTPF) (Table 4.4). In the Nymjang Chu valley, 13 troops were recorded in human-modified landscapes followed by 2 troops in EHBLF and 1 troop each in in EHSTPF, and 1 troop in EHMCF. Eleven troops were recorded in HMLC in the Tawang Chu valley followed by 1 troop in EHMCF (Fig. 4.7).

Table 4.4.Number of troop sighted in various forest types of the study area, classified according to Champion and Seth et al, [29].

Sl. No.	Forest types/landscapes	No. of troops recorded	No. of individuals recorded
1.	Human modified landscape (HMLC)	28	602
2.	East Himalayan mixed coniferous forest (EHMCF)	7	244
3.	East Himalayan broad leaved forest (EHBLF)	3	74
4.	East Himalayan subtropical wet hill forest (EHSTWHF)	2	25
5.	Himalayan sub-tropical pine forest (HSTF)	1	24
	Total	41	969

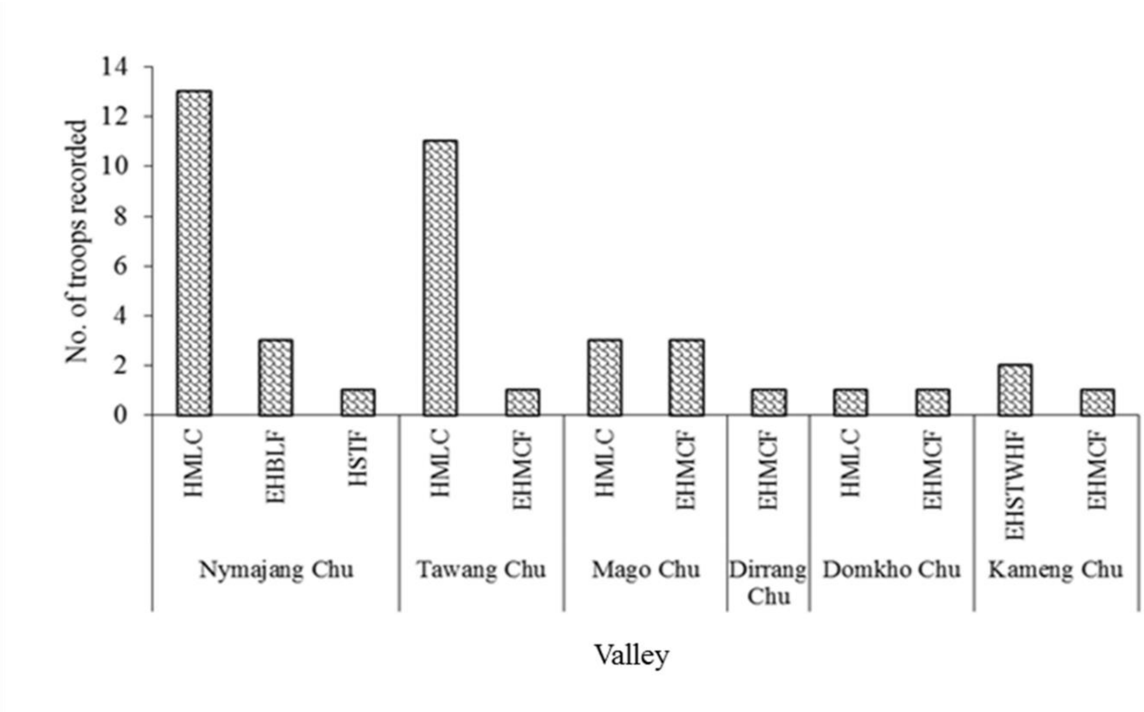

Figure 4.7. Number of troops of M. munzala recorded under various forest types in selected valley region

4.3.3 Encounter rate

The overall average encounter rate was 0.07 ± 0.01 in six valleys of the study area. The encounter rate was highest in Nymjang Chu valley (0.16 ± 0.3) followed by Tawang Chu valley (0.08 ± 0.01) and was the lowest (0.008 ± 0.008) in the Dirang Chu valley (Table 4.3).

4.4 Discussion

Determination of the geographical distribution of a species is a very complex and challenging task in hilly terrain due to difficulties associated with surveying [30,31]. In the present study, ecological niche modelling was applied to identify *M. munzala's* potential distribution range based on occurrence data of the species collected in the present study. It is noted that a very small area of Arunachal Pradesh is shown to be potential habitat for this species, strongly showing the importance of conserving the existing habitat. The study emphasis on population status review based on the known habitats of the species in Tawang and West Kameng [16]. However, Eastern Arunachal Pradesh are excluded from the known distribution range due to its disputed taxonomic status [1]. Bhutan [32] and other adjacent region of Arunachal Pradesh are also excluded from the modeling as well due to absence of occurrence data. The present model also calls attention to researcher to survey populations in other potential districts of the state. Predictive distribution of *M. munzala* depicted its distribution in nine districts, that is, Tawang, West Kameng, East Kameng, Papum Pare, Kurung Kumey, Upper Subansiri, West Siang, Upper Siang, and Upper Dibang Valley of Arunachal Pradesh. But, the challenging task is the identification of the species based on morphological features, as other morphological similar macaque species are also present in the state. A few surveys have revealed the presence of *M. munzala* in the Upper Subansiri and Upper Siang districts of the state [9]. Long-term extensive study of new potential habitats employing advanced molecular techniques is required to confirm these macaques to the species level. The prime objective of our study was to identify potential habitats. This exercise evokes important questions about the variables which are affecting the distribution of the species in Arunachal Pradesh. In the present model, precipitation of the coldest annual quarter (BIO 19) as well as the vegetation index (NDVI) was found to have profound effects on the distribution of *M. munzala* in this state. Vegetation growth is dependent on precipitation and it can even induce leaf growth earlier in a season than normal [33]. Precipitation in the winter months might influence the distribution of *M. munzala* since the species is known to be largely dependent on leaves [5,8]. Similarly, in other primates, this parameter is reported to have a major role in species distribution [11]. The species distribution pattern and speciation might have been influenced by a zoogeographic barrier as well. Unfortunately, MaxEnt does not take such barriers into account [26,27] and this might increase the probability of bias in determining potential habitat using this model. Biswas et al. [1] claimed that *M. munzala* and the macaques of Lohit and Changlang districts are the same population and a subspecies of *M. assamensis*. Lohit and Changlang districts were predicted to be very low potential habitat for *M. munzala* in the model's output and most of the potential habitat of the species depicted occurs at much higher altitudes. The model predicted distribution range overlaps with *M. thibetana* and *M. assamenesis* [34]. Moreover, predicted potential habitat in Upper Siang district is in proximity to the Medog (Tibet), where *M. leucogenys* was discovered [35]. Recently, *M. leucogenys* distribution was reported from the eastern region of the state [36]. Considering the morphological similarities and habitat type of these species, possible sympatric speciation cannot be denied, but a detailed study of their phylogeography is required. The altitudinal distribution of *M. munzala* in Tawang and West Kameng districts deviates from earlier reports by recording the lowest altitude of the species occurrence at 1464 m asl in the Sessa Orchid Sanctuary (West Kameng District) and the highest occurrence at 2,981 m asl in the Tawang district [16]. Altitude was found to be an influential factor in the distribution pattern of the species; the largest number of troops were occurred in the higher altitudes between 2,000 and 2,200 m asl. So far, the lowest altitudinal gradient (900 m msl) of *M. munzala* was recorded in Bhutan [32]. In this regard, the outcome of the study recommended that present adaptive niche of *M. munzala* in the study area might be due to consequence of shifting of habitat from lower to higher elevations in response to gradual climate warming [37].

Kumar et al. [16] reported a total of 35 troops and 569 individuals in the Tawang and West Kameng districts of Arunachal Pradesh and calculated a mean troop size of 16.3 individuals per troop. Subsequently, Biswas et al. [1] reported a total of 20 troops, 422 individuals with a mean troop size of 21.1 from Tawang and West Kameng districts. The present study estimated a population size (971 individuals with a mean troop size of 23.65 ± 1.20) was much higher than previouslky reported [1,16]. The Nymjang Chu valley had the largest number of troops (n = 17) in Tawang district, whereas the lowest was recorded in Dirang Chu in West Kameng district with only a single troop. Kumar et al. [16] also reported the largest number of populations in the Zemithang area within the Nymjang Chu valley. Moreover, the highest encounter rate was recorded was Nymjang Chu valley at the elevation between 2,000 and 2,500 m amsl might be the reason of favourable environment and accessibility to agricultural and forest food resources. It is noteworthy that the species is known to be very tolerant to human-modified landscapes [16]. Further, troop composition and mean troop size of *Macaca munzala* has shown similarity with Assamese macaque (*M. assamenesis*) (Table 4.5).

Table 4.5. Population distribution, age/sex composition (in percentage) and associated habitat characteristics of *M. munzala*'s and geographically closer sinica group of species in eastern Himalaya region

Species	Location	Sight. Alt. (m)	Habitat	Mean troop size (range)	AM	AF	SAM	SAF	JM	JF	IM	IF	INF	Ratio(AM:AF)	Reference
Macaca munzala	Western Arunachal Pradesh	1464-2981	EHSWHF, EHBLF, MCF, DSF	23.63	11.53	23.83	6.23	9.81	30.37		NA		18.22	0.48:1	Present study
		2000-2750	CF, DBL, OS, Abies forest, Oak, Riverine	16.3	NA		NA		NA		NA		NA	1:1.92	Kumar *et al.*, 2008
Macaca assamensis	Langtang NP, Nepal	1500-1700	Steep slope mountain	29. 6	18.24	31.08	15.54 (SNM)		14.19 (SNM)		NA		20.95	1:70	Chalise, 2008
	Nagarjun NP, Nepal	1000-2732	Sub-tropical to temperate	20.57	24.31	32.64	NA		2.78	22.22	NA		2.08 (M),1 5.97 (F)	1:1.34	Chalise *et al.*, 2013
	Darjeeling district, India	600-2120	NA	13.6	16.6	46.3	NA		20.7 (SNM)		NA		16.4	1:2.8	Murmu *et al.*, 2004
	Darjeeling district, India	231-1370	Himalayan subtropical wet hill forest	19.48	NA		NA		NA		NA		NA	NA	Mitra and Alfred, 2007
	Darjeeling district, India	>550	NA	13.6	19%	61.9%	NA		13.2 (SNM)		NA		5.9	1:3.3	Bhaitacharya *et al.*,

															2008
	Boromura Gandhari, Tripura, India	100-130	TMD	NA	12.5	25	50 (SNM)		NA				12.5	NA	Choudhury, 2018
	Namdapha NP, AP, India	NA	Evergreen forest	13.93	55.98 (SNM)		NA		28.23 (SNM)		NA		15.79	NA	Chetry *et al.*, 2002
	Tawang, AP, India	NA	NA	17-47	12.18	51.25	NA		17.81 (SNM)		NA		18.75	1:4.2	Alfred, 2004
M. a. pelops	Zhangmu, Tibet, China	2190	Evergreen broad-leaved forest	NA											Li *et al.*, 2015
	Tukeswari temple, Goalpara, India	110	Human Modified landscape	NA											Berstein and Cooper, 1999
	Tukeswari temple, Goalpara, India	110	Human Modified landscape	NA	14.94	28.74	NA		13.79	19.54	NA		9.20 (M); 11.49 (F)	1:1.92	Medhi et al., 2007
Macaca thibetana	Mt. Huangshan, China	1841	Mixed deciduous, evergreen forests	47.67	15.38	21.15	1.92	1.92	9.62	3.85	7.69	1.92	5.77	1.92	Berman *et al.*, 2004

	Huangshan, China	1841	Mixed deciduous, evergreen forests	40	15.38	20.51	NA	NA	Berman, 2013
					23.81	21.43			
					17.31	25.00			
					18.37	28.57			
					21.62	29.73			
					19.05	23.81			
	Mt. Emei, China	NA	NA	38.33	14.29	28.57	NA	1:3	Zhao and Deng, 1988
					14.71	29.41			
					7.14	28.57			
					12.31	27.69			
					17.14	25.71			
					5.00	32.50			

NP (National park), WLS (Wildlife sanctuary), AP (Arunachal Pradesh), AM (Adult male), AF (Adult female), SAM (Sub-adult male), SAF (Sub-adult female), JM (Juvenile male), JF (Juvenile female), IM (Immature male), IF (Immature female), INF (Infant) and SNM (Sex not mentioned), EHSWHF (Eastern Himalaya sub-tropical wet hill forest), EHBLF (Eastern Himalaya broadleaved forest), MCF (Mixed coniferous forest), DSF (Degraded scrub forest), CF (Crop field), DBL (Degraded broad-leaved), TMD (Tropical moist deciduous)

During the present study, it was observed that severe hill cutting for the expansion of roads, construction of new road networks, and forest clearance for the expansion of agricultural practices have posed a major factor for the degradation of the natural forest habitat of *M. munzala* and other wildlife. About 62.12% of the total population of *M. munzala* were found in human-modified landscapes (e.g., cultivation area, road side, degraded forest, etc.), where crop raiding activities were most pervasive [4,16]. Predation by domestic and feral dogs during crop raiding was also recorded in Zemithang and Nymjang Chu valleys and this has proved to be an alarming threat for the species. The population size of *M. munzala* is showing an increasing trend in the study area, but much of the population is concentrated in the Tawang district compared to West Kameng district. Hunting is not common among the Monpa tribe in Tawang district due to religious and cultural beliefs thereby preventing hunting of the primates [16,38]. On the other hand, in the West Kameng district, hunting is very prevalent and the species is in danger of being extirpated from this area.

In summary, the results of the present study enabled us to illustrate the potential habitats of *M. munzala* in Arunachal Pradesh, which in turn revealed species ecology in terms of habitat selectivity based on environmental and other associated parameters. The present study revealed a high population size for the species in the study area, that is, Tawang and West Kameng districts, compared with the earlier available records [1,16]. The predicted very less area of potential habitat (2.4% of the total landmass) of this endangered species in the state urgently required intervention in the formulation of a conservation action plan for its long-term survival.

4.5 References

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