ABSTRACT

The thesis has been written in 8 (Eight) chapters and outline of each chapter are briefly described here. References are given at the end of each chapter for better understanding of citations include in the chapter. The structure and format of the thesis is as per the Ph. D. thesis guidelines of the Tezpur University, Assam, India.

Chapter 1: Introduction

Arunachal Pradesh, North-eastern region of India, is a part of eastern Himalaya biodiversity hotspot but biodiversity of the state is poorly assessed scientifically. Subsequently, many new species has been described from the state in recent years. Arunachal macaque (*Macaca munzala*) is new to science that described from the high altitude region of Arunachal Pradesh. *M. munzala* is a non-human primate belongs to the sinica group from genus Macaca. However, the knowledge on distribution, population status and behaviour ecology of the species are very limited. The research gap is discussed thoroughly in the introduction chapter and accordingly, objectives have been put forwarded for investigation.

Chapter 2. Literature review

An emphasised has been given in this chapter to review on studies of primate's distribution and niche adaptation, morphometry and colour variation, habitat structure and conservation, and behaviour ecology. Almost all relevant studies on *Macaca munzala* has been thoroughly reviewed in this chapter. Based on review of available literature, it has been noticed that only a few studies on population distribution, habitat ecology and behavioural pattern (time activity pattern, feeding pattern and ranging behaviour) of *M. munzala* has been undertaken on a very short duration. Moreover, no study has been undertaken on colour variation, nutritional ecology and vocalization of *M. munzala*.

Chapter 3. Study area, materials and methods

The geopolitical feature followed by socio-economic demography, geo-morphology, climate, forest type, and biodiversity component of the study area has been described in this chapter. The study was carried out in western part of Arunachal Pradesh bordering to

Bhutan and Tibet of China. The western Part of Arunachal Pradesh comprise of 2 (two) districts viz., Tawang and West Kameng district.

The overview of method has been written in methodology section but details method has been explained in each respective chapter. The present study conducted ecological niche modelling using environmental variable and occurrence data of *M. munzala* followed by population survey; habitat survey using quadrat method; behavioural study using scan sampling method; home range and habitat use pattern using grid method; nutritional ecology study by quantifying "nutritive value" of major food plant material; vocalization study using acoustic analysis; and morphometry and colour variation study using photogrammetry method.

Chapter 4. Ecological niche modelling and population status of the endangered *Macaca munzala* in Arunachal Pradesh, India

The chapter reports the population of *Macaca munzala* in Tawang and West Kameng districts and its predictive distribution range in entire Arunachal Pradesh, estimated using ecological niche modelling. The study revealed the potential distribution of *M. munzala* based on environmental variables and the present population status in Tawang and West Kameng districts of Arunachal Pradesh, India. Environmental variables and occurrence data obtained from a preliminary survey were used in the MaxEnt modeling, a statistical model to know the potential distribution area of the *M. munzala*. Later, a population survey was carried out in Tawang and West Kameng districts of the state following existing trails and paths. The distribution model revealed that only 2.4% of the total landmass of the state is potential distribution habitat range for *M. munzala*, whereas 10.19% of the total area of the two districts were shown to be potential habitat of the species. A total number of 971 individuals (including two solitary males) comprising 41 troops of *M. munzala* were recorded during the population survey. The mean troop size was 23.63 ± 1.21(SE) individuals per troop ranging from 12 to 44 individuals. On average, *M. munzala* troops were comprised of juveniles (30.37%), adult females (23.83%), infants (18.22%), adult males (11.53%), sub-adult females (9.81%), and sub-adult males (6.23%). The recorded population size of *M. munzala* of the present study area (Tawang and West Kameng districts) is higher when compared with the earlier available records.

Chapter 5: Habitat structure, status and conservation of *Macaca munzala* in protected and   non-protected habitat, western Arunachal Pradesh, India

The chapter deals with quantification of plant community structure of *M. munzala*'s habitat. The study recorded 149 plant species belonging to126 genera and 66 families. Of of the total species, 58 species were tree from 52 genera under 34 families; 41 were shrub species from 38 genera under 24 families and 52 species were herb from 42 genera under 24 families. *M. munzala* habitat was dominated by tree species contributing up to 38.39% followed by herb species (33.56%) and shrub species (27.52%). The Simpson diversity index was found within the range of 0.10 to 1.67; Shanon diversity index (H) was between the range of 1.93 to 3.22, whereas, Evenness index (J´) varied from 0.49 to 0.95. Based on vegetation characteristics and altitudinal gradient, habitats are classified into four categories namely, Eastern Himalayan subtropical wet hill forest (EHSWHF), Eastern Himalaya broadleaf forest (EHBLF), Mixed coniferous forest (MCF) and Degraded scrub forest (DSF). Overall, the highest similarity index was found between the habitat of EHBLF and DSF (31.90%) and EHSWHF had very less percentage of similarity with other habitat. The highest similarity index of tree, shrub and herb species were recorded between the habitat of EHBLF and DSF. Among the studied habitat, the highest individual of cut stumps were recorded in EHBLF habitat (17 individual) but highest basal area of cut stump was found in EHSWHF (97.23 m^2ha^{-1}). The encounters rate of hunting activity and firewood collection were found highest in EHSWHF habitat (encounter rate: 0.87 per day), whereas, hunting was found absent in EHBLF and MCF habitat during study period. The timber extraction was found frequent in EHSWHF compare to other studied habitats. The present study revealed that species composition of *M. munzala* habitats were varied according to altitudinal gradient and various anthropogenic activities are posing threats to the habitats thereby affecting heterogeneous structure and function of vegetation.

Chapter 6: Behavioural and nutritive ecology of *Macaca munzala*

This chapter includes four sections presenting different behavioural activities of *Macaca munzala* like, activity and feeding pattern, home range use and habitat use pattern, acoustic characterization and nutritional ecology. Activity and feeding pattern*,* and their home range use and habitat use pattern were studied in three selected troops (KZ, KS and

LM troops) of *M. munzala* inhabited neighbouring to each other in Pangchen Valley (Zemithang circle) of Tawang district, Arunachal Pradesh. The KZ troop was inhabited in 'Eastern Himalaya broadleaf forest' (EHBLF), KS troop in 'Human dominated landscape and degraded scrub forest (DSF)' and LM in 'Mixed coniferous forest' (MCF).

6.1. Activity and feeding pattern of *Macaca munzala* in heterogeneous habitats of western Arunachal Pradesh, India

The study investigated time activity and feeding pattern of *Macaca munzala* inhabited in broadleaf forest, mixed coniferous forest and human modified landscape of Arunachal Pradesh. Behavioural data were collected using scan sampling method from three troops (KZ, KS and LM) of *M. munzala* inhabited neighbouring to each other. The study shown that maximum percentage of time spent of *Macaca munzala* of its daily active period was found in feeding activity (33.27 ±0.55) followed by resting (26.96 ±0.56), moving (23.30 ±0.64), grooming (10.12% ±0.20) and others (6.46 ±0.19). Seasonally, feeding (F=68.50, df=2, p<0.05), moving (F=71.71, df=2, p<0.05), resting (F=153.45, df=2, p<0.05) and grooming (F=5.64, df=2, p<0.05) activities were significantly different among the troops.

Diet of *M. munzala* comprised of plant material and animal matter where plant material contributed major portion (97.83%) of their diet and animal matter with 2.17%. Out of the total feeding time, *M. munzala* devoted 35.12±3.48% time on young leaf, 19.10± 2.93% on fruits and 17.64± 2.22% on stem and these three food items constituted a major part of their plant food diet. Seasonal variation in percentage time spent in behavioural activities and food plant contributions were significant in *M. munzala*. The availability of food plant material act as an influential factor in food plant selection of *M. munzala)* as exhibited in simple linear regression model analysis (Constant=0.64; B=2.49; R^2=0.40).

6.2. Home range use and habitat use pattern of Arunachal macaque *Macaca munzala* in western Arunachal Pradesh, India

The major goal of the study is to enumerate the ranging behaviour of the *Macaca munzala* that were inhabited in broadleaved forest, mixed coniferous forest, and human-dominated landscape and degraded scrub forest. The daily path length (DPL) of troops (KZ, KS and LM) was 1.23 ±0.10 km (mean ±SE) which varies from 0.24 to 5.14 km. *M. munzala* cover longest distance during the monsoon season (1.65 ±0.28 km) and shortest during the post-monsoon season (0.92 ±0.17 km). The home range of troops were found vary from 106 ha (LM troop) to 149 ha (KS troop), where KZ troop recorded 133 ha. The home range sizes of KZ and KS troops were maximum in monsoon season having 86 ha and 62 ha, respectively; whereas LM troop covered largest range during the winter season (62 ha). Out of the annual home range area, KZ troop covered 60.71% area in EHBLF but other two study troops were not using EHBLF at all. Similarly, DSF was mostly used by troop KS (77.85%) and MCF was mostly used by LM troop (83.18%). Home garden present in 'Human dominated landscape and degraded scrub forest' (DSF) was highly used by KS (18.79%) followed by LM (9.73%) and lowest by KZ (6.43%). The highest percentage of food plant was recorded in the core habitat of KS troop i.e., tree (75% and 83.33%), shrub (50% and 90%) and herb (64.70% and 54.54%). The result of the present study has shown that the distribution of preferred food plants is limiting the home range area and daily path length of *Maccaca munzala* in the study area.

6.3. Nutritional ecology of *Macaca munzala*: an approach to understand diet selection of non-human primates

The present study is an attempted to understand the major food plant selection of *Macaca munzala* through the interpretation of nutritive value (Calorific value), crude protein, crude fibre, total carbohydrates, secondary metabolites (Saponin) and minerals (Ca, Fe, Mg, Mn and Zn). A total of 17 major food plant material were selected for the assessment of nutritive quality out of which 15 food plant were from KZ troop and 14 food plant from LM troop. 13 food plant species were common among both the troops. The estimated mean nutritive value of food plant was 285.26 ±95.19 (mean ±SD), ranging from 116.35% to 454.03%. The study estimated highest protein content in the bark (20.50%) followed by young leaf (17.96% ±12.21), flower (17.79% ±9.56) and lowest in fruit (2.13 ±7.52%). The estimated total carbohydrate of food plants was 40.95

±18.61 (mean ±SD) ranging from 3.90% to 86.08% while estimated crude fat was 7.18% ±4.76 (mean ±SD) varying from 2.00% to 18.98%. The mean saponin content of food plants of troops was found to be 12.69 ±5.51 (range: 3.20% to 25.24%). The study established that *Macaca munzala* adopt a food plant as their staple food when the food plant is having higher nutritive value, protein content and available throughout the year to feed on.

6.4. Acoustic characterization of *Macaca munzala* alarm call

The chapter deals with investigation of different vocalization of the *M. munzala* and detail acoustic analysis of a distinct call of the species. The alarm call of *M. munzala* was found distinct among the other vocalization in terms of loudness and used for alert in presence of potential threat. The recorded mean time of calls was 0.25 ±0.03 which ranges from 0.21 sec to 0.30 sec. The mean pitch of calls was 346.22±66.15 Hz (range: 238.14 to 495.77 Hz) and mean intensity was 60.34 (dB) ±6.79 and range from 43.01 dB to71.32dB. The wave of call sequence follows periodic cycle but it has non-sinusoidal waveforms. The mean of spectral centre gravity (M1) was found from 1437.28 Hz to 1739.56 Hz and standard deviation (M2) ranges from 1067.12 Hz to 1239.42 Hz. The positive left skewed distribution has shown in the spectral (1.92-2.68) and kurtosis (M3) has shown positive value for spectrum that ranges from 4.90 to10.26.

Chapter 7. Morphometry and phenotypic characterization of *Macaca munzala* and *Macaca assamenesis pelops*

The chapter deals with comparative study of morphometric characteristics, colour variation and tail-body length variation of *Macaca munzala* that inhabit in high altitude cold climate (2000 m amsl) with sympatric *M. assamenesis pelops* that inhabit in warm and humid area of low altitude (100 m amsl). The presence of crown whorl in both the species was not found consistent in juvenile, sub-adult and adult individuals. Crown whorls were absent in infant but dark patch of hair at receding hairline was prominent in both the species. The dark hair at temporal side that extends to upper cheek to the ear side was a prominent characteristic in immature individuals of *M. munzala* and *M. a. pelops*.

The pattern of tail appearance was found similar between the *M. munzala* and *M. a. pelops*. The glans penis was found sagittate shape for both the species but in some

individual it appears as a round or ring shape. The mean tail length for *M. munzala* was 0.24 m ±0.005 and *M. a. pelops* tail length was 0.32 m ±0.01. The relative tail length of *M. a. pelops* was found to be higher (60.56% ±4.37) than the *M. munzala* (43.04% ±3.28). The coat colour of *M. munzala* gradually change from "Very dark grayish red (hcc #463a36) in sub-adult to "desaturated dark orange" (hcc hcc #977e61) in adult. Similarly, *M. a. pelops* had dark moderate orange colour (hcc #856849) and "slightly desaturated orange" colour in sub-adult (hcc #b7a37e) and adult (hcc #b89d75). *M. munzala* coat colour was found darker (RGB) than the *M. a. pelops* (RGB) based on RGB scale (0 to 255). The RGB value of adult male and female of *M. munzala* has shown lower value than *M. a. pelops* that depicted darker colour concentration in facial skin of *M. munzala*.

Chapter 8. Conclusion, recommendation and research scope

The chapter has summarised findings of the present study and put forward the future research scope and recommendations. The study concluded that *Macaca munzala* is a habitat generalist primate with greater ecological adaptation in terms of disturbance in habitat and feeding behaviour.

The findings of the present study recommend the need of further investigation in different research areas on *M. munzala*. Like, study on sympatric evolution of *Macaca munzala* based on molecular genetics and colour variation in response to altitudinal gradient and intensity of solar radiation. Study on population survey and behavioural ecology in sub-tropical habitat of other region of Arunachal Pradesh is required. Social and reproductive behaviour and self-medication behaviour of *M. munzala* need to be investigate. Moreover, present study also suggested community based conservation of *M. munzala* and its varied habitat in Arunachal Pradesh for long term existence and survivability of the species.

Finally, based on the overall finding of the study it is recommended that an urgent measures need to be taken up to check the existing various anthropogenic threats that disturbed the high potential habitat areas of *M. munzala* for conservation of the species in particular and wildlife in general.