

**POPULATION STATUS AND DISTRIBUTION OF ASSAMESE  
MACAQUE (*Macaca assamensis* McClelland 1839) IN  
WESTERN NEPAL**



Entry 14  
M.Sc. Zoo Dept Ecology and Environment  
Signature *Anand*  
Date: 2078-11-15  
27- Feb- 2022

**Laxmi Prasad Upadhyaya**

T.U. Registration No: 5-3-28-297-2017

T.U. Examination Roll No: 623

Batch: 2074/2075

A thesis submitted in partial fulfilment of the requirements for the award of the degree of  
Master of Science in Zoology with special paper Ecology and Environment.

**Submitted to**  
Central Department of Zoology  
Kathmandu Nepal  
February, 2022

## Declaration

I hereby declare that the work presented in this thesis entitled “**Population status and distribution of the Assamese macaque (*Macaca assamensis* McClelland 1839) in western Nepal**” has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

Date: 27- Feb - 2022



Laxmi Prasad Upadhyaya



त्रिभुवन विश्वविद्यालय  
TRIBHUVAN UNIVERSITY

01-4331896  
01-4331896

Email: info@cdztu.edu.np  
URL: www.cdztu.edu.np

प्राणी शास्त्र केन्द्रीय विभाग

**CENTRAL DEPARTMENT OF ZOOLOGY**

कीर्तिपुर, काठमाडौं, नेपाल।  
Kirtipur, Kathmandu, Nepal.

पत्र संख्या :-

च.नं. Ref.No.:-

**Recommendation**

This is to recommend that the thesis entitled “**Population status and distribution of the Assamese macaque (*Macaca assamensis* McClelland 1839) in western Nepal**” has been carried out by Mr. Laxmi Prasad Upadhyaya for the partial fulfillment Master’s Degree of Science in Zoology with special paper Ecology and Environment. This is him original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institutions.

Laxman Khanal, Ph.D.

Associate Professor

Central Department of Zoology

Tribhuvan, University

Kirtipur, Kathmandu, Nepal

Date 27- Feb- 2022



त्रिभुवन विश्वविद्यालय  
TRIBHUVAN UNIVERSITY

01-4331896  
01-4331896

Email: info@cdztu.edu.np  
URL: www.cdztu.edu.np

प्राणी शास्त्र केन्द्रीय विभाग  
CENTRAL DEPARTMENT OF ZOOLOGY

कीर्तिपुर, काठमाडौं, नेपाल।  
Kirtipur, Kathmandu, Nepal.

पत्र संख्या :-

च.नं. Ref.No.:-



Letter of approval

On the recommendation of supervisor Dr. Laxman Khanal, Associate Professor, Central Department of Zoology, Tribhuvan University, this thesis submitted by Mr. Laxmi Prasad Upadhyaya entitled "**Population status and distribution of the Assamese macaque (*Macaca assamensis* McClelland 1839) in western Nepal**" is approved for the examination and submitted to the Tribhuvan University in partial fulfillment of the requirements for Master's Degree of Science in Zoology with special paper Ecology and Environment.

Prof. Dr. Tej Bahadur Thapa

Head of Department

Central Department of Zoology,

Tribhuvan University

Kirtipur, Kathmandu, Nepal

Date: 27-Feb-2022



त्रिभुवन विश्वविद्यालय  
TRIBHUVAN UNIVERSITY



०१-४३३१८९६

01-4331896

Email: info@cdztu.edu.np

URL: www.cdztu.edu.np

प्राणी शास्त्र केन्द्रीय विभाग

**CENTRAL DEPARTMENT OF ZOOLOGY**

कीर्तिपुर, काठमाडौं, नेपाल ।  
Kirtipur, Kathmandu, Nepal.



पत्र संख्या :-

च.नं. Ref.No.:-

### CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Mr. Laxmi Prasad Upadhyaya entitled “**Population status and distribution of the Assamese macaque (*Macaca assamensis* McClelland 1839) in western Nepal**” has been accepted as a partial fulfillment for the requirement of Master’s Degree of Science in Zoology with special paper Ecology and Environment.

#### Evaluation committee

**Dr. Laxman Khanal**

Supervisor, Associate Professor

Central Department of Zoology

Tribhuvan University

Kirtipur, Kathmandu, Nepal

**Prof. Dr. Tej Bahadur Thapa**

Head of Department

Central Department of Zoology

Tribhuvan University

Kirtipur, Kathmandu, Nepal

**Dr. Narayan Pd. Koju**

External Examiner

**Dr. Bishnu Pd. Bhattarai**

Internal Examiner

**Date of Examination: March 21, 2022**

## **Acknowledgements**

I am grateful to my supervisor Dr. Laxman Khanal, Associate Professor, Central Department of Zoology for his continuous supervision and advice to complete this work.

I am thankful to Prof. Dr. Tej Bahadur Thapa, Head of Central Department of Zoology for providing such an opportunity to carry out this dissertation work.

I would like to express my gratitude to all my teachers and all staffs of Central Department of Zoology for their continuous aspiration and motivation. My special thanks go to Mr. Naresh Pandey and Mr. Chandan Sunar for his support in data analysis.

I also express my gratitude to RUFFORD foundation, UK for the research fund. I am very thankful to my senior Mr. Dharendra Chand, and friend Ms. Melina Karki, for their help and motivational support throughout my work.

I am grateful to family for the encouragement, all helping hands for support and love which finally lead to the successful completion of the research work.

**Laxmi Prasad Upadhyaya**

Examination Roll No.: 623/074

Batch No: 074/075

[laxmanupadhyaya016@gmail.com](mailto:laxmanupadhyaya016@gmail.com)

## Abstract

Climate change is one of the major global issues of the present time that causes the alteration in the distribution of species. Non-human primates are a sensitive group of animals to environmental changes. Range restricted species such as Assamese macaque (*Macaca assamensis* McClelland 1839) might be under the severe pressure of anthropogenic climate change. Nepal population of the Assamese macaque is distributed along the mid-hills across a narrow elevational range and recently, few troops have been reported from far-western Nepal. The population of the species in far-western Nepal is understudied. Using the modified transect method, this study surveyed the population of the species from western region (Mid-western and Far-Western provinces) along Bheri, Karnali, Seti and Chamelia rivers. A total of 10 troops, three from Surkhet District of Karnali Province and eight from Achham, Bajura, Baitadi and Darchula districts of Sudur Paschim Province were recorded. A total of 159 individuals counted from the 10 troops accounted for an average troop size of 15.9 individuals. Among the total, 45 were adult males, 73 were adult females and 41 were juveniles. The adult male to female sex ratio was calculated as 1:1.6223 and the infant to mother sex ratio was calculated as 0.56:1. The species distribution model by MaxEnt estimated 25,114 km<sup>2</sup> area of the western Nepal as suitable habitat for Assamese macaques. Annual mean temperature, isothermality and annual precipitation were the major contributing variables to the model. Current suitable habitat of the species ranged between 158 m asl to 3899 m asl. The current niche of the Assamese macaque was projected for 2050 and 2070 AD under three representative concentration pathways of greenhouse gases (RCP2.6, RCP4.5 and RCP6.0). The projected models revealed that a majority of current suitable habitat will be lost in the future under all the studied RCPs. The suitable habitat will be shifted towards higher elevations with respect to an increase in the concentration of greenhouse gases.

## Table of contents

<b>Declaration.....</b>	<b>I</b>
<b>Recommendation.....</b>	<b>II</b>
<b>Letterofapproval .....</b>	<b>III</b>
<b>Certificate of acceptance .....</b>	<b>IV</b>
<b>Acknowledgements .....</b>	<b>V</b>
<b>Abstract.....</b>	<b>VI</b>
<b>Table of contents .....</b>	<b>VII</b>
<b>List of tables.....</b>	<b>IX</b>
<b>List of figures.....</b>	<b>IX</b>
<b>List of abbreviations/acronyms .....</b>	<b>X</b>
<b>List of annexes .....</b>	<b>X</b>
<b>1. Introduction.....</b>	<b>1</b>
1.1 Background .....	1
1.3 Rationale of the study.....	3
1.4 Objectives.....	3
<b>2. Literature review .....</b>	<b>5</b>
2.1 Distribution of Assamese macaques .....	5
2.2 Ecological niche modeling for prediction of suitable habitats.....	7
2.3 MaxEnt as a promising tool for ecological niche modelling .....	9
2.4 Impact of climate change in distribution of species.....	9
<b>3. Materials and methods .....</b>	<b>11</b>
3.1 Study area.....	11
3.2 Methods.....	13
3.2.1 Field surveys.....	13
3.2.2 Species occurrence data.....	14
3.2.3 Environmental / bioclimaticvariables .....	14
3.2.4 Ecological niche modelling in MaxEnt .....	15
3.2.5. Data analysis.....	16

Population size.....	16
Species distribution modeling in MaxEnt .....	17
Projection of current niche for future distribution.....	17
Future projection of the nichefor2050 and 2070 AD .....	18
Elevation wise distribution of Assamese macaques .....	19
<b>4. Results .....</b>	<b>20</b>
4.1 Population status of Assamese macaques in western Nepal .....	20
4.2 Current potential distribution of Assamese macaques .....	21
4.2.1 Model evaluation and importance of bioclimatic variables.....	21
4.2.2 Current suitable habitat of Assamese macaques.....	22
4.3 Future potential distribution of Assamese macaques.....	24
4.4 Elevational range shift of Assamese macaques.....	26
<b>5. Discussion.....</b>	<b>28</b>
5.1 Population status of Assamese macaques in western Nepal .....	28
5.2 Current potential distribution of Assamese macaques .....	29
5.3 Future predicted distribution of Assamese macaques .....	30
<b>6. Conclusion and recommendations.....</b>	<b>32</b>
<b>Annexes .....</b>	<b>33</b>
Annex 1. Correlation matrix of bioclimatic variables.....	33
Annex 2. Percentage contribution and permutation importance of all bioclimatic variables in the model .....	34
Annex 3. Response curve of three most important variables (Bio01, Bio12 and Bio17) of the ecological niche modeling in MaxEnt .....	35
<b>References.....</b>	<b>36</b>

## List of tables

<b>Table 1.</b> Occurrence data of Assamese macaque ( <i>M. assamensis</i> ) from western region of Nepal .....	15
<b>Table 2.</b> List of 19 bioclimatic variable and their description.....	16
<b>Table 3.</b> Occurrence point and troop size of Assamese macaques in western Nepal .....	21
<b>Table 4.</b> Average group size of Assamese macaque at different elevational range...22	
<b>Table 5.</b> Spatial analyses of the current and future potential geographical distribution in 2050 and 2070 of Assamese macaque.....	25

## List of figures

<b>Figure 1.</b> Map of Nepal showing the study area in Karnali and Sudur Paschim provinces .....	11
<b>Figure 2.</b> Average area under curve (AUC) for 25 replicates of MaxEnt runs (red line is average value and blue bars represent $\pm 1$ standard deviation for Assamese macaque .....	21
<b>Figure 3.</b> Percentage contribution of bioclimatic variables to the model .....	22
<b>Figure 4.</b> Variable importance by Jackknife test for ENM of Assamese macaque. The blue, aqua and red bars represent the results with each variable, remaining all variables and all the variables, respectively.....	22
<b>Figure 5.</b> Map showing current potential distribution area of Assamese macaques in western Nepal.....	23
<b>Figure 6.</b> Current potential distribution areas for Assamese macaques at different elevational range .....	24
<b>Figure 7.</b> Bar diagram of different percentage of area at different suitability level of Assamese macaque in year 2050 and 2070.....	25
<b>Figure 8.</b> Future potential geographical distribution of <i>M. assamensis</i> by 2050 and 2070 at different greenhouse emission scenarios RCP 2.6, RCP 4.5 and RCP 6.0.....	26
<b>Figure 9.</b> Suitable areas (Km <sup>2</sup> ) in different RCPs of future year 2050 and 2070 .....	27

## List of abbreviations/acronyms

ASL: Above Sea Level

AUC: Area Under the Curve

CART: Classification and Regression Tree

DD: Data Deficient

GAM: Generalized Additive Model

GLM: Generalized Linear Model

GPS: Global Positioning System

IUCN: International Union for Conservation of Nature

Km<sup>2</sup>: Square Kilometers

LC: Least Concern

MaxEnt: Maximum Entropy

NT: Near Threatened

RCP: Representative Concentration Pathways

ROC: Receiver Operating Characteristic

VU: Vulnerable

## List of annexes

**Annex 1.** Correlation matrix of bioclimatic variables .....34

**Annex 2.** Percentage contribution and permutation importance of all bioclimatic variables in the model .....35

**Annex 3.** Response curve of three most important variables (Bio01, Bio12 and Bio17) of the ecological niche modeling in MaxEnt .....36

# 1. Introduction

## 1.1 Background

In an ecosystem, a primate plays a vital role as an ecosystem engineer by altering the structure of plant communities (Chapman et al. 2013). Out of 119 species of primates (Roos et al. 2014), Asian primates are grouped into three families i.e. Hylobatidae (one species), Loridae (7 spp.), and Cercopithecidae (35 spp.). Assamese macaque (*Macaca assamensis*) belongs to the *sinica*-group of macaques under the family Cercopithecidae (Khanal et al. 2021). The species has been divided into two subspecies- eastern Assamese macaque (*M. assamensis assamensis* McClelland 1839) and western Assamese macaque (*M. assamensis pelops* Hodgson, 1840) according to color variation. The two sub-species are geographically demarcated by the Brahmaputra River (Roos et al. 2014). The eastern Assamese macaque is known to occur in Bhutan, China, India, Bangladesh, Myanmar, Vietnam, and Lao PDR. Its range stretches from 200 to 2750 meters above sea level however Western Assamese macaques have been recorded from the mid-mountains of Nepal, Bhutan, north-eastern India, and Bangladesh (Molur et al. 2003, Chalise 2013, Khanal et al. 2021). The westernmost subpopulation of the species is also called ‘*M. assamensis* Nepal Population’ due to its distinct morphology and distribution range (Molur et al. 2003) and phylogenetically, it may be a distinct species (Khanal et al. 2021). Assamese macaque has multimale – multifemale group, linear hierarchy system among group members, female philopatry and male dispersal as noted by Bernstein and Cooper (1999). They are highly social, less aggressive, more sluggish and very shy primate than other (Chalise 2003, Zhou et al. 2014).

Assamese macaques show similarities with Rhesus macaques by their different ecological, behavioral, adaptive nature and the existence of several morphological criteria (Hill and Bernstein 1999). They raid crops like maize, rice, millet, wheat, potato and cultivated fruits (Koirala and Chalise 2014, Zhou et al. 2014, Adhikari et al. 2018). Assamese macaques prefer the tropical mid-hill area having broadleaf, riverine forest, subtropical broadleaf evergreen forest, mixed deciduous with utilized or utilizing forest (Brockelman 1981, Aggimarangsee 1992, Ahsan 1994, Wada 2005). Among the two different group of Assamese macaques they were diversified by different causes such

as surrounding environment, isolation either by river or mountain and geographic condition. The Nepalese population of the species also diversified with adjacent population of India, Bhutan and Bangladesh based on color, body shape and size or by DNA sequencing (Wada 2005, Kawamoto et al. 2006, Khanal et al. 2021). Kaligandaki River of Nepal was considered as the westernmost limit of the distribution of the Assamese macaques (Chalise 2003, Wada 2005, Regmi et al. 2018) but later three troops were recorded from Achham, Baitadi and Darchula districts of far-western Nepal (Khanal et al. 2019).

The prediction of the geographical distribution of the species, factors limiting their distribution, occurrence of the species to landscape features, characterization of the species, also for rare, cryptic and nocturnal species, ecological niche modelling is very important tool (Thorn et al. 2009). Species are distributed in different niches and face the different type of climatic condition. Most important factors for distribution of species are precipitation, temperature; their interaction shapes the species distribution (Bell et al. 2014). The application of the ecological niche modelling is to discover the unknown distributional areas and undiscovered species (Raxworthy et al. 2003, Bourg et al. 2005), prediction of the impact of the climate change (Iverson and Prasad 1998, Brooker et al. 2007), testing the evolutionary hypothesis (Peterson et al. 1999, Graham et al. 2004), predicting the species invasions (Peterson 2003) and supporting the protection planning (Ferrier et al. 2002).

Climate change led to the habitat shifting of organisms through either shrinking or expanding of habitats at different elevation gradients (Lamsal et al. 2018). Rapid climate change, habitat fragmentation, invasion by foreign species, water, soil, and air pollution, exploitation of nature, and human population growth are the most significant factors that destroy the structural and functional integrity of ecosystems (Barnosky et al. 2011). Changes in temperature, precipitation, and humidity can cause extreme environmental conditions causing the extinction of some species or changing their habitats or niches (Worth et al. 2015). By using the species distribution modeling tools such as the MaxEnt (Phillips and Dudik 2008), we can predict the present distribution and future distribution of organisms by using different concentration of greenhouse emission.

The Nepalese population of Assamese macaque is one of the poorly documented species of primates having patchy distribution in a small number. Most of the troops of Assamese macaques were observed from small fragmented forests of the mid-hill of country and majority were recorded from outside the protected areas. They are highly threatened due to small population size and human intervention (Ghimire et al. 2021). Climate change, habitat fragmentation, hunting, low forest productivity and biological invasion are the threats to primates (Alley et al. 2003, Pyritz et al. 2010, Adhikari et al. 2012, Oates 2013). This study intended knowing present population status of Assamese macaque, present habitats and map the future distribution in the western Nepal on the basis of different greenhouse gases emission scenarios by combined with environmental, bioclimatic, and topographic features and occurrence information in bio-climatic models under future climate conditions to 2050 and 2070.

### **1.3 Rationale of the study**

In Nepal, highest number of Assamese macaque individuals were counted by Chalise (2013) with 1099 individuals under 51 troops but the latest study described only 43 troops and 829 individuals (Khanal et al. 2019). However, the findings of the former were not from a systematic survey, rather was an accumulation from the opportunistic observations made over a decade of field work. Based on the IUCN Red List (Boonratana et al. 2020), the Assamese macaque (*M. a. assamensis*) is considered Near Threatened, and the Nepal population (*M. a. pelops*) is considered endangered based on the small population size and distribution area. Assamese macaques from the western Nepal are unexplored. First time three troops of Assamese macaques were documented in Achham, Baitadi and Darchula by Khanal et al. (2019) but there is no further work done. In the context of Assamese macaques, they have morphological similarities with crop raiding Rhesus monkeys. So, killing by farmers is a threat for the species protection. In order to understand the population and distribution of Assamese macaques in western Nepal, a scientific study is required.

### **1.4 Objectives**

The general objective of this study was to document the population status and potential distribution of Assamese macaque in the western Nepal.

#### **Specific objectives:**

- To explore population status of Assamese macaque in western Nepal
- To understand current potential distribution of Assamese macaque at present time in western Nepal
- To predict future potential distribution in future at different climate change scenarios.

## 2. Literature review

### 2.1 Distribution of Assamese macaques

Plant community structure, disease, interspecific competition and parasites also play a vital role in the population structure of primates (Isbell et al. 2009, Holzmann et al. 2010). Temperature, precipitation, humidity, etc. are major bioclimatic factors influencing organisms' growth, reproductive success, population densities, and distributions (Majolo et al. 2013, Lamsal et al. 2018, Khanal et al. 2019). Assamese macaque *Macaca assamensis* (McClelland 1839) is a primate and its holotype location is Assam, India. It has two subspecies according to color variants: Eastern Assamese macaque *Macaca assamensis assamensis* (McClelland, 1839) and western Assamese macaque *M. assamensis pelops* (Hodgson, 1840). The distribution of the subspecies *M. a. assamensis* is South East Asia and distribution ranges from 200–2750 m, east of the great bend of the Brahmaputra River, in Southwest China, North East India, South and East through North and East Myanmar, North and West Thailand, Laos and North Vietnam (Hill and Bernstein 1969). Distribution of the subspecies *M. a. pelops* is in Himalayan area up to 3100 m, from China to Nepal (West limit Tippling, E83°36') East through North East India (North West Bengal, Sikkim and West Assam states), and Bhutan (East limit Manas River, E90°58') with a widely disjunction record of what may be a geographic relict, in coastal South West Bangladesh (Sundarbans) (Hill and Bernstein 1969).

Out of the 43 species of Asian primates, 4 are CR, 25 are EN, 2 are VU, 6 are NT, 4 are LC, and 2 are DD (Molur et al. 2003). Asian Primates are grouped into three orders, such as Hylobatidae (1 spp.), Loridae (7 spp.), and Cercopithecidae (35 spp.). Among them, *M. assamensis* belongs to the largest order, Cercopithecidae (Molur et al. 2003). The adult of *M. assamensis* shows similarities with *M. mulatta* by their different ecological, behavioral, adaptive nature and the existence of several morphological criteria (Hill and Bernstein 1969). Globally, Assamese macaques have been distributed in Bangladesh, India, Myanmar, Laos, Thailand, Vietnam, China and Nepal.

In Nepal, three species of monkey were recorded: Rhesus macaques *M. mulatta* (Zimmermann 1780), Hanuman Langur *Semnopithecus entellus* (Dufresne 1797), and the Assamese macaque *M. assamensis* (McClelland 1839). The distribution of *M.*

*assamensis assamensis* (McClelland, 1839) is Tropical evergreen forest, subtropical evergreen forest, semi-evergreen broad-leaved forest, Broad-leaved evergreen forest, semi-evergreen forest, moist deciduous forest ranges from 50-1300m elevation (Molur et al. 2003), but Nepalese population distribution range is 600m to 3500m and sometimes above then this elevation (Chalise 2003). In Nepal, Kaligandaki was regarded as the westernmost limit of the distribution of the *M. assamensis* (Chalise 2003, Wada 2005, Regmi et al. 2018) but three troops were recently recorded from Achham, Baitadi and Darchula districts (Khanal et al. 2019). The highest number of individuals and troops are also recorded from the Kaligandaki River system (21 groups and 377 individuals), Koshi River system (13 troops and 377 individuals), Shivapuri- Nagarjun National Park (6 groups and 104 individuals) and Karnali-Mahakali river system (3 groups and 61 individuals) were recorded and the elevation range of distribution of Macaque is 130 m eastern Nepal to 2650 m in Langtang National park of central Nepal (Khanal et al. 2019). From different riverine systems of Nepal, 43 troops of Assamese macaques were observed having 829 individuals with an average group size is  $18.5 \pm 10.24$  and  $20.1 \pm 10.77$  individuals (Khanal et al. 2019).

The Assamese macaque is an arboreal, terrestrial, diurnal, omnivorous, multi-male and multi-female group. Its habitat is Himalayan foothills with Sal forest, mixed deciduous forest, temperate broadleaved forest, rocky outcrops along rivers (Chalise 2003, Matawa et al. 2012). The macaques inhabiting forests were markedly disturbed by the over-utilization of forests by humans who cultivate crops in fields, cut tree branches as food for domestic animals and collect firewood (Regmi and Kandel 2008). Assamese macaques spend most of their time on feeding activities (Chalise 2003, Schülke et al. 2011, Sarkar et al. 2012). Some studies showed that the diet of Assamese macaque is highly folivorous, in which leaves accounted for 77.4%, whereas fruit only constituted 17.4% of total feeding records (Zhou et al. 2011). The Nepalese population of the Macaque is highly frugivorous and raid the crops like maize, rice, millet, wheat, potato and cultivated fruits (Chalise 2003, Koirala and Chalise 2014). They have different vocalization such as "Thruuu", seeing people, "Pio" for see deer, "Quinch" for harassed sub-adult by adult or male, "Chrkyak" and "Khio" for see observer.

"Chianck" is thrown by people or alarm for raptors and this species is less quarrelsome, more sluggish and very shy (Chalise 2003). Females spend more time on grooming, but males and females for approximately the same time for grooming juveniles and counter

the aggression of male is more in troops (Bernstein and Cooper 1999, Cooper and Bernstein 2000;2002). Assamese macaques have different vocalization systems during threats, such as "Thruuu" for seeing people, "Pio" for seeing deer, "Quinch" for harassing sub-adults by adults or males,"Chrkyak" and "Khio" for seeing observer. "Chianck" for stone throw by peoples or alarm for raptors (Chalise 2003). Assamese macaques spend most of their time searching for food like other primates (Chalise 2003, Adhikari et al. 2018) and they like canopy rather than open ground (Nisbett and Ciochon 1993). The habitat of *M. a. assamensis* is tropical evergreen forest, subtropical evergreen forest, semi-evergreen broad-leaved forest, broad-leaved evergreen forest, semi-evergreen forest, and moist deciduous forest. Another sub species, *M. a. pelops*, is distributed in the same type of habitat but most of them are recorded from riverine broadleaf forest (Molur et al. 2003, Khanal et al. 2019).

## **2.2 Ecological niche modeling for prediction of suitable habitats**

Knowledge about the species distribution not for only individuals is one of the crucial part of species conservation strategy (Corsi et al. 2000). In the past, the species distribution modelling technique is very poor in which the data were collected by making the polygons and grid and collect the presence absence data from all polygons then predict the distribution (Scott et al. 1993, Stoms and Estes 1993, Elith 2000). The prediction of the geographical distribution of the species, factors limiting their distribution, occurrence of the species to landscape features, characterization of the species, also for rare, cryptic and nocturnal species, Ecological niche modelling is very important tool (Thorn et al. 2009). In modelling, those species which are rare and restricted environmentally and geographically appeared greater accuracy in modelling than common and general species and also only presence data is used for modelling (Graham et al. 2004). With the development of the different tools such as GIS, different types of predictive models were also developed in ecological field which are very useful to identify the potential distribution of the species in environment (Guisan and Zimmermann 2000). The species and environment relationship can be hypothesized by the help of the different climatic variables in the ecology and that variables are very important for the distribution of the species in spatial area, changing consequences of the environment on species distribution (Woodward and Cramer, 1996), diversity of aquatic plants (Lehmann et al.1997; Lehmann, 1998), and animals (Owen, 1989; Fraser,

1998). For the modelling we need to develop some formats such as conceptual model, statistical formulation, calibration, prediction and evaluation respectively (Guisan and Zimmermann 2000). Different types of modelling methods in ecology are used to predict the species distribution such as Ordinary multiple regression and its generalized form (GLM) and other methods include neural networks, ordination and classification methods, Bayesian models, locally weighted approaches (e.g. GAM), environmental envelopes or even combinations of these models (Guisan and Zimmermann 2000). Prediction Modelling tools are very important for biogeography, evolution, conservation, ecology and invasive species management (BUSBY 1986, Wilson et al. 1992)

For presence only modelling, different tools were used to predict the species distribution such as GIS based modelling having both occurrence points and bioclimatic data were noted and used (Corsi et al. 2000). Some tools such as Bioclimatic envelopes which predict the suitable condition in rectilinear region (Nix 1986), DOMAIN method is apply by using the suitability index in environmental space (Carpenter et al. 1993) Canonical correspondence analysis (Ter Braak and Verdonschot 1995), Multivariate distance methods (Elith 2000), Generalized linear method and Generalized additive method, both can be apply in presence/absence datasets (Hastie and Tibshirani 1990, Agresti 1999) but nowadays they are used in presence only modelling by taking the random pixels 'pseudo absence'(Ferrier et al. 2002), Habitat suitability indices (Elith 2000), Machine learning method (Breiman et al. 1984), Neural network and Genetic algorithms which is used as sets of negative and positive rules by using the background pixels and presence pixels (Mitchell 1998).

ENM is one of the best techniques that help to identify the best potential distribution area by using the observed occurrence data (Pearson et al. 2007, Elith et al. 2011). Realized niche with source habitat data are mostly useful in niche-based modelling having only presence data (Pulliam 2000). The application of the ecological niche modelling is to discovered the unknown distributional areas and undiscovered species (Raxworthy et al. 2003, Bourg et al. 2005), prediction of the impact of the climate change(Iverson and Prasad 1998, Brooker et al. 2007), testing the evolutionary hypothesis (Peterson et al. 1999, Graham et al. 2004), predicting the species invasions (Peterson 2003) and supporting the protection planning (Ferrier et al. 2002).

### **2.3 MaxEnt as a promising tool for ecological niche modelling**

MaxEnt is one of the simple and more adventitious tools in prediction of the geographical distribution of the species and has more advantages than other tools in prediction due to only occurrence data with environmental variables are needed, it can read both categorical and continuous data, it predict the maximum distribution area, MaxEnt could apply in presence/absence data by using the conditional model and it provides the all process in the mathematical form but it has some drawbacks in processing because it has no special statistical guideline for run and result interpretation like GLM and GAM, machine learning is rare in unconditional methods, might be more extrapolation in study area (Phillips et al. 2006). Maximum entropy (MaxEnt) was used for modelling of the habitat use of the different ecologically important species and limited sample size (Thorn et al. 2009, Voskamp et al. 2014, Nekaris et al. 2015). Habitat measurement such as tree density, tree light, connectivity, visibility, and anthropogenic disturbance was also measured by different methods. For the modelling, Forest was categorized into 4 levels such as late stage secondary forest, secondary forest, forest plantation and agricultural areas (Thorn et al. 2009). MaxEnt v.3.4.1 was used to model and map the potential distribution of *M. assamensis* in whole Nepal (Khanal et al. 2018). There are several methods to estimate the distribution pattern of the species. Classical regression methods (RSF), Generalized Linear Models (GLM), algorithmic modeling based on machine learning, Classification And Regression Trees (CART) also popular methods in resent year and Maximum Entropy (MaxEnt) are some distribution modeling methods which are generally used in modeling of species but most efficient method to correction of the sampling error is the MaxEnt (Fourcade et al. 2014). Classification and Regression Tree (CART), TreeNet (boosting), Random Forest (bagging), and MaxEnt machine learning algorithms with elevation as well as 19 biometric variables for prediction of distribution.

### **2.4 Impact of climate change in distribution of species**

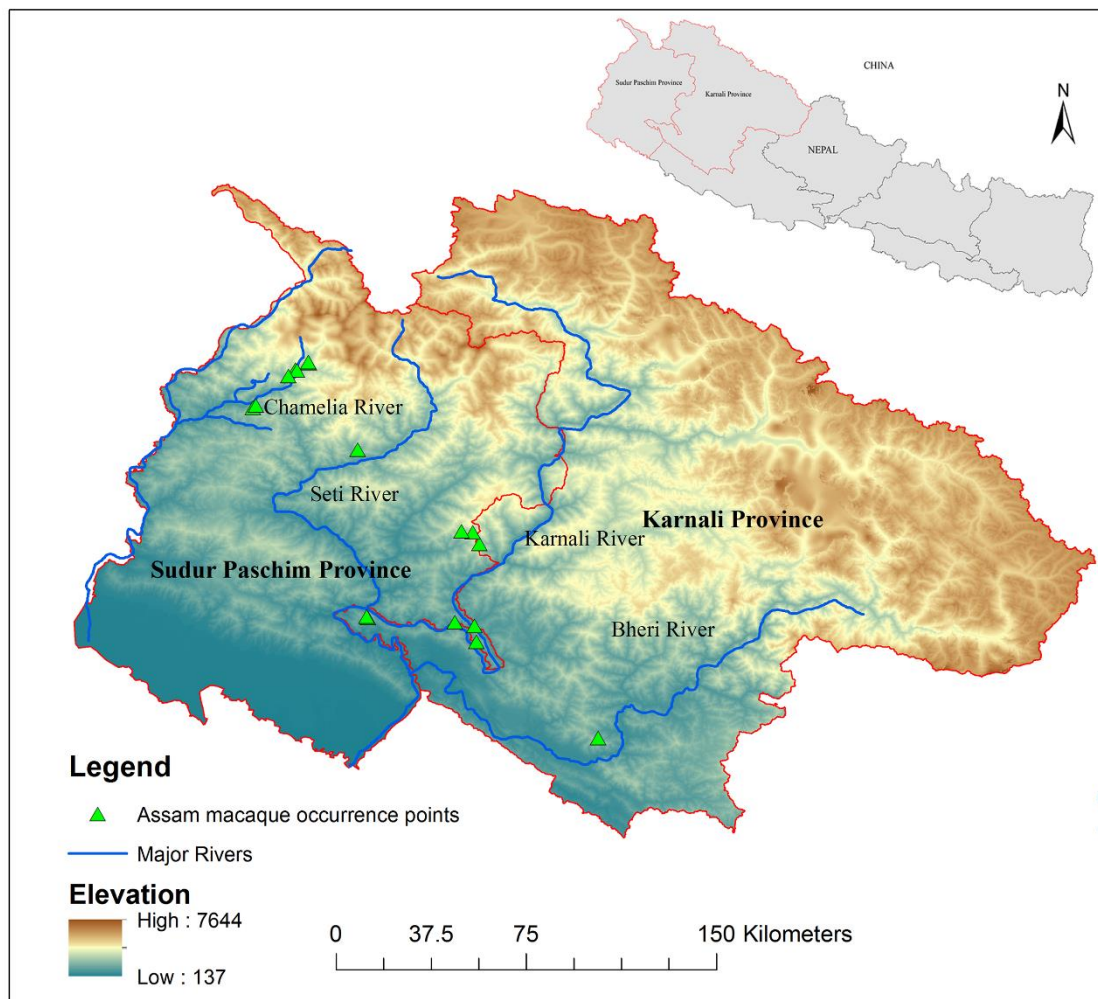
Over production and utilization of resources are the causes of deforestation, urbanization and industrialization resulting variations in solar energy, temperature and precipitation variation threat to the lives in the world that majorly effects on water resources, agriculture, coastal regions, freshwater habitats, vegetation and forests, snow cover and melting and geological processes such as landslide, desertification and

floods, and has long-term effects on food security as well as in human health (Upreti 1999, Alley et al. 2003, Dahal 2012, Weiskopf et al. 2020). Climate change is likely to negatively affect the habitats of non-human primate species. Exponential growth of CO<sub>2</sub> and other greenhouse gases in the atmosphere is causing climate change cause shrunken of habitat of non-human primates (Stewart et al. 2020). Many species were shift their habitat from tropical to temperate region from different altitudinal gradients due to the abrupt climate change due to the global warming (Walther et al. 2002, Schloss et al. 2012). The distribution of species with different level of greenhouse gases emission causes either expand or contract the habitat of species. The current and future prediction of the Himalayan Musk Deer were modelled by using the different RCP value such as RCP4.5 and RCP8.5 for 2050 and 2070 and they were resulted that climate change is the major problem to Himalayan species either by contraction or by expansion of species habitat and about 29.47% area were decreased by 2070 under RCP4.5 mostly from western Nepal (Lamsal et al. 2018). Khanal et al. (2019) were resulted that the mid-hills of eastern and central Nepal outside the protected areas as the major habitats of Assamese macaque.

### 3. Materials and methods

#### 3.1 Study area

This study was conducted in western Nepal along the river axes of Bheri, Karnali, West Seti, Chamelia and Mahakali rivers and their major tributaries. Nepal lies on the southern flank of the central Himalaya between China and India, ranging at latitudes of 26°22' and 30°27' N and longitudes of 80°40' and 88°12' E (Sharma 1999).



**Figure 1.** Map of Nepal showing the study area in Karnali and Sudur Paschim provinces

Karnali Province is one of the mountainous provinces covering nearly 19% (30,211 km<sup>2</sup>) of Nepal's area but least Population size 1570418 (Male: 767923, Female: 802495) i.e. 6%. Acharya and Paudel (2020). It has the elevational range from 180 m to 7348 masl.

Due to the diverse climatic, geographic situation, diverse assemblage of flora and fauna and strong beautiful landscapes of Karnali province it makes garden of diverse ecosystem. With the many threatened and endemic flora and fauna Province contain large proportion of Nepal's birds (46%) including some globally threatened birds such as Black-necked crane (*Grus nigricollis*), red-headed vulture (*Sarcogyps calvus*) and woolly-necked stork (*Ciconia episcopus*), mammals (42%) including some flagship species such as snow leopard (*Panthera uncia*), wild yak (*Bos mutus*), red panda (*Ailurus fulgens*) and musk deer (*Moschus chrysogaster*), Butterflies (22%), fishes (32%) (Acharya and Paudel 2020). Three endemic fish species have been recorded from top cold area of the province (Khatri et al. 2020), reptiles (11%), amphibians (43%) and flowering plants (42%). Flora of Karnali Province consists of five Eco regions and 21 forest types, some of them are well-developed and specific to the province. More than half the province's land surface (51%) is covered by vegetation, which includes forest (30%), shrubland (3%) and grassland (18%).

Karnali province is home to the Bon religion. Four lingual groups, namely, Raji, Khamchi (Raute), Kaike and Dolpali are only spoken in the province. The Chhetri is the most dominant ethnic group among at least 56 caste/ethnic groups present in the province. Forests play an important role in sustaining the livelihoods of the majority of the population in Karnali province. The province is rich in aromatic and medicinal plants, in which Dolpa alone shares 57% (n=400) of Nepal's medicinal and aromatic plants. People living on the northern frontiers along the Nepal-Tibet border rely on Tibetan medicine called Amchi for curing various diseases.

The Sudur Paschim Province is the smallest province among the other provinces. The country lies between 80° 03' & 81° 25' East longitude and 28° 22' & 30° 09' North latitude, having 2,552,517 population, which is 9.63% of the total population of Nepal. The area of Sudur Paschim is 13.27% of the total area of the country.

Many languages are spoken in provinces on the basis of ethnic group. The majority of the population is Hindu, about 97%, and Buddhist, Christian and others. Approximately 60% of the people of the province reside in urban areas. Most of the people of the province are engaged in agriculture.

The far-western Nepal is rich in biodiversity with 71 species of non-timber forest products (NTFP) and hundreds of species of medicinal herbs (jadibuti), with more than 1.6 million kg annual production. The Yarshagumba of Darchula district is considered among the best in quality. Three protected areas, such as one National park, one conservation area and one wildlife reserve have diverse types of floral and faunal diversity present inside or outside. Khaptad National Park, which occupies about 225 sq. km<sup>2</sup> area within Bajhang, Bajura, Doti and Achham districts. Suklaphanta National Park lies in Kanchanpur district and covers 305 sq. km. Api Nampa Conservation Area lies in Darchula and covers a total of 1,903 sq. km. Wildlife like the snow leopard, clouded leopard, musk deer and Himalayan black bear are found there, along with birds like the crimson pheasant, blood pheasant, red billed chough and yellow billed chough. Many endangered plants and animals are also present.

## **3.2 Methods**

### **3.2.1 Field surveys**

Field surveys were conducted in between December 2019 and December 2021. Field was surveyed by using the modified line transect method for counting the Assamese macaques (Buckland et al. 2010). It was started from an elevation of about 100m asl and continued along river axis to about 3000m asl. The line transect was placed roughly parallel to the axis of river on the both sides. Different river system of western region such as Bheri River (Surkhet district), Karnali River (Dailekh, Surkhet and Achham), Seti River (Achham western, Doti and Bajhang), Chamelia River and Kailashkhola area of Achham were surveyed. In the Karnali Province, the Karnali and Bheri river systems were surveyed. Species was identified by expert, their habitat, colour, feeding habit and ecological niche followed by Chalise (2003) to distinguish the age and sex of Assamese macaques.

From the survey, occurrence group, distance from the human settlement, distance from cultivated area, distance from water source, population size and population composition were also noted. For the demographic analysis, individuals were categorized into adults (males and females), sub-adults, juveniles and infants as (Chalise 2003). The geographic locations were noted by GPS and monkeys were observed by using the binocular. Counting was repeated three times to minimize the bias in distinguishing age

and sex of the groups. The survey was mostly focused in riverside of far and mid-western region of Nepal.

### 3.2.2 Species occurrence data

Sample points were identified for the presence data according to the observed data from where species distributed naturally (Khanal et al. 2019). The occurrence points were collected by using the Garmin GPS Etrex 10. The descriptive data of sample points are listed below in the Table 1.

**Table 1.** Occurrence data of Assamese macaque (*M. assamensis*) from western region of Nepal

S.N.	Area, District	Latitude	Longitude	Elevation
1	Balde, Achham	81.41071389	28.91569167	684m
2	Kotpera, Baitadi	80.69386667	29.67496389	1207m
3	Ghusa, Darchula	80.845425	29.81096944	2260m
4	Dungeshor, Darchula	81.47976	28.90285	800m
5	Chaubiso, Darchula	80.89251	29.83461	2229m
6	Pokhare, Surkhet	81.10261	28.9305	1123m
7	Chabis, Bajhang	81.06545	29.5276	1153m
8	Bhairabsthan, Accham	81.48714	28.84595	678m
9	Ramarosan, Achham	80.70492	29.68349	1815m
10	Ramarosan, Achham	81.49735	29.19327	2550m
11	Ramaroshan, Achham	81.4737	29.2343	2447m
12	Chuabiso, Surkhet	80.85022	29.80889	1570m
13	Chaubiso, Surkhet	80.81986	29.78869	1380m
14	Chaubiso, Surkhet	80.8904	29.83795	1865m
15	Lagam, Surkhet	81.09753	28.93589	1480m
16	Dasrathpur, Surkhet	81.91825	28.50458333	1655m
17	Saina, Achham	81.4344	29.23813	1739m

### 3.2.3 Environmental / bioclimatic variables

For the ecological niche modeling, data of 19 bioclimatic variables were downloaded from the WorldClim database (<https://www.worldclim.org>) as a form of raster file and this file was converted into Nepal projection system WGS 1984. MaxEnt was run after

prepared the MaxEnt layer and select the suitable variables by Jackknife analysis. Multicollinearity test among 19 variables (Annex 1) was done and only one variable was taken among two highly correlated variables and threshold criteria was  $r < |0.80|$ . WorldClim version 1.4 has minimum, maximum, and mean temperatures information of year. The spatial resolution of 30 arc second ( $\sim 1 \text{ km}^2$ ) were derived from the observational data in WorldClim for current distribution.

### 3.2.4 Ecological niche modelling in MaxEnt

Species distribution model (SDM) was used to predict the potential distribution of Assamese macaques in western region. Having limited data, MaxEnt is best tool to predict the potential distribution (Phillips et al. 2006, Elith et al. 2011). With the presence of occurrence points to previous points using a machine learning algorithm MaxEnt can run. MaxEnt can use non-systematically collected occurrence records from a variety of sources (Elith et al. 2006). Total 17 different occurrence coordinates were collected from different geographic area by using the GPS.

All bioclimatic variables were clipped to the boundary of Nepal using ArcGIS 10.5 and exported in ASCII format. Eight bioclimatic variables (Bio: 1, 3, 5, 11, 12, 15, 16, 18) were selected for the ENM after removing highly correlated ( $r \geq |0.8|$ ) variables based on the Pearson correlation test ( $p < 0.05$ ) (Supplementary Table 2).

**Table 2.** List of 19 bioclimatic variables and their description

S.N.	Abbreviation	Description
1	Bio1	Annual mean temperature
2	Bio2	Mean diurnal range [mean of monthly (max temp–min temp)]
3	Bio3	Isothermality (P2/P7) ( $\times 100$ )
4	Bio4	Temperature seasonality (standard deviation $\times 100$ )
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

<b>13</b>	Bio13	Precipitation of wettest month
<b>14</b>	Bio14	Precipitation of driest month
<b>15</b>	<b>Bio15</b>	<b>Precipitation seasonality (coefficient of variation)</b>
<b>16</b>	<b>Bio16</b>	<b>Precipitation of wettest quarter</b>
<b>17</b>	Bio17	Precipitation of driest quarter
<b>18</b>	<b>Bio18</b>	<b>Precipitation of warmest quarter</b>
<b>19</b>	Bio19	Precipitation of coldest quarter

### 3.2.5. Data analysis

Data of the occurrence point of Assamese macaques from six different districts of western Nepal were inserted in Arc GIS map 10.5 for preparation of the distribution map.

#### Population size

A group was defined following Hanya et al. (2003). The ratio of the average group size, male: female (Sex ratio) ratio, infant ratio was calculated for the collected data. Average troop size was calculated by division of total number of individuals out of total number of troops observed.

Male female sex ratio was calculated by division of the number of same age group of males to same age group female. Infant female ratio was calculated by division of total number of infants to total number of adult females.

Young to adult ratio =  $\frac{\text{Number of juveniles and infants}}{\text{Number of adults}}$   
 Infant to mother ratio =  $\frac{\text{Total number of infants observed}}{\text{Total number of adult females}}$

$$\text{Sex ratio} = \frac{\text{Number of adult male}}{\text{Number of adult female}}$$

$$\text{Young to adult ratio} = \frac{\text{Number of juvenile and infant}}{\text{Number of adult}}$$

$$\text{Infant to mother ratio} = \frac{\text{Total number of infants observed}}{\text{Total number of adult females}}$$

$$\text{Average troop size} = \frac{\text{Total number of individual record}}{\text{Total number of troop observed}}$$

## **Species distribution modeling in MaxEnt**

Current distribution of Assamese macaque was modelled by using the MaxEnt v.3.4.1 (Phillips et al. 2006) applied with auto features. Seven bioclimatic variables were selected from 19 variables for the study in the Arc GIS 10.5 were uploaded to MaxEnt software and the current geographical distribution of Assamese macaque. The presence data were divided into 75% random training dataset and validation data set is 25%. Twenty-five replication models based on cross-validation method was generated and accuracy was evaluated by area under the curve (AUC) of the receiving operating curve (ROC). AUC help in modelled the success of model with all possible thresholds. If AUC is greater than 0.5 (Phillips and Elith 2010). AUC values were evaluated as if  $AUC \geq 0.9$  = very good,  $0.9 > AUC \geq 0.8$  = good, and  $AUC < 0.8$  = poor (Gassó et al. 2012). The Jackknife test were done to evaluate the contribution of environmental variable (Pearson et al. 2007). The logistic output data were further categorized in least suitable, suitable, moderately suitable and highly suitable by using the maximum training sensitivity and specificity clog log (maxTSSCloglug= 0.33) in Arc GIS 10.5. In the Arc GIS, reclassify tool of the spatial analyst tool was used to reclassify the four different classes and pixel were counted in attribute table of reclassified map (Jarvis et al. 2008).

## **Projection of current niche for future distribution**

Using logistic threshold value (equal training sensitivity and specificity), an inbuilt functionality of MaxEnt, current and projected habitat suitability maps for 2050 and 2070 were prepared using ArcGIS 10.5. Different RCPs value were used to identification of the present and future (2050 and 2070) greenhouse emission rate. For the future greenhouse emission rate identification, the RCP2.6, RCP4.5 and RCP6.0 for both year (2050 and 2070 AD). To test the habitat suitability ranges in the 2050s (2041–2060) and 2070s (2061–2080), RCP2.6 (the minimum scenario for GHG emissions), RCP4.5 (the intermediate scenario for GHG emissions) and RCP6.0 (the high scenario for GHG emission) were used.

MaxEnt v.3.4.1 (Phillips et al., 2006) was used to model and map the current potential distribution of Assamese macaque. For model evaluation purposes, 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, 53 replicated models were generated based on the cross-validation method (Otto-Bliesner et al., 2006). The area under the curve (AUC) of the receiving operating curve (ROC) was used to evaluate the accuracy of the model. AUC values range from 0 to one where the AUC values  $>0.5$  show the model to be better. For the processing of the Maximum Entropy environmental layers need to convert into ASCII format having same pixel size, bond and coordinates and output coordinates are set in WGS\_1984\_UTM. For the running of the MaxEnt, require environmental layers and occurrence sample, all phylogenetic or environmental data and presence data were converted into the ASCII file format. The CSV file of presence data of Assamese macaque and environmental data insert into the menu of MaxEnt tool. For the measure of variable, Jackknife option select after each variables of ASCII data changed either categorical or continuous to determine the contribution of environmental variables in the MaxEnt software (Shcheglovitova and Anderson 2013).

To determine the performance of the model, values in the area under the curve (AUC) from the receiver operating characteristics (ROC) were analyzed (Phillips 2005, Wang et al. 2007). The success of of the model with all possible threshold can be define by the AUC value where  $AUC > 0.5$ , it shows the better model performance (Phillips and Elith 2010). If value of AUC is closer with  $\geq 0.9$  it shows very good,  $0.9 > AUC \geq 0.8$  = good, and  $AUC < 0.8$  is poor (Hosmer Jr et al. 2013). This test enables us to determine the significance of each independent variable in the creation of the model. Four thresholds were used for the distribution area to create potential distribution maps ranging from 0 to 1. These values are grouped into four different groups such as  $<0.2$  unsuitable,  $0.2-0.40$  moderately suitable  $0.41-0.60$  means suitable,  $> 0.6$  means highly suitable (Yang et al. 2013, Çoban et al. 2020).

### **Future projection of the nichefor2050 and 2070 AD**

By using logistic threshold value, current and projected habitat suitability maps for 2050 and 2070 were prepared using ArcGIS 10.5 along with the calculation of habitat loss and gain. Equal training sensitivity and specificity threshold refers to a model that has an equal probability of being sensitive. The performance of model was analyzed by the AUC. The contribution of the different bioclimatic variables was analyzed such as

per-cent variable contribution and jackknife procedures through MaxEnt (Elith et al. 2011).

The future prediction map for 2050 and 2070 was prepared according to two different climate change scenarios which was compared with the current potential distribution map. In future scenarios, the bioclimatic data for 2050 represent the mean values from 2041 to 2060, while the data for 2070 represent the mean values from 2061 to 2080 (Çoban et al. 2020). The data from three different time points were converted to polygon data with the raster/vector conversion function using GIS for determination of changes in future.

Three different model were used to study about the present and future climatic condition. Three different model of Representative concentration pathway (RCP 2.6, RCP 4.5 and RCP 6.0) were used to test the future possible distribution of Assamese macaque in different greenhouse gases emission scenarios. RCP 2.6 represent least emission of Greenhouse gas; RCP 4.5 represent emission of greenhouse gases as present time and RCP 6.0 represent increase emission of concentration of greenhouse gases. The all future climate scenarios (2.6, 4.5 and 6.0) for two periods (2050 and 2070 AD) were downloaded from the Worldclim database ([www.worldclim.org](http://www.worldclim.org)). Species response curves were created to investigate the relationship between target species habitat suitability and environmental factors.

### **Elevation wise distribution of Assamese macaques**

The DEM map of study area was uploaded in the Arcmap 10.5 with MaxEnt result and elevation data for the calculation of the Elevation distribution of the Assamese macaque in different elevational gradient. The uploaded Map of study area reclassify again into different ranking of habitat suitability. The four different ranking were given such as Unsuitable, Moderately suitable, suitable and highly suitable with the different value such as less than 0.20, 0.21–0.40, 0.41–0.60 and >0.61 manually in Arcmap 10.5, respectively. By using the Attribute table, the number of pixels for current time and for future (2050 and 2070) were counted on the basis of different RCPs (2.6, 4.5 and 6.0). The elevation of study area was categorized with the difference 1000m.

## 4. Results

### 4.1 Population status of Assamese macaques in western Nepal

A total of 10 troops of Assamese macaques were observed from western Nepal. In addition, nine occurrence points were identified using the fecal materials. The maximum number of individuals (n=39) was recorded from Balde, Achham and minimum troop size (n=7) was recorded from Pokhare, Surkhet (Table 3). The total observed individuals were 159 and among them, the total number of adult females was 73, the total number of males was 45 and the total number of infants was 41. Eight troops (139 individuals) of Assamese macaques were recorded from Sudur Paschim Province and only two troops (20 individuals) were recorded from Karnali Province. The average troop size of the Assamese macaque was calculated to be 15.9 individuals. The adult male and female sex ratio was calculated as 1:1.6223. The infant to mother sex ratio was calculated as 0.56:1. The infant to adult ratio was found to be 0.35:1.

**Table 3.** Occurrence point and troop size of Assamese macaques in western Nepal

S.N.	Area	Latitude (X)	Longitude (Y)	Elevation (m)	Troop size
1	Balde, Achham	81.4107	28.9157	684	39
2	Kotpera, Baitadi	80.6939	29.675	1207	8
3	Ghusa, Darchula	80.8454	29.811	2260	14
4	Dungeshor, Darchula	81.4798	28.9029	800	12
5	Pokhare, Surkhet	81.1026	28.9305	1123	7
6	Chabis, Bajhang	81.0655	29.5276	1153	9
7	Ramarosan, Achham	80.7049	29.6835	1815	15
8	Ramarosan, Achham	81.49735	29.19327	2550	26
9	Dasrathpur, Surkhet	81.9183	28.5046	1655	13
10	Saina, Achham	81.4344	29.2381	1739	16
<b>Total</b>					159

The elevation range of the Assamese macaque was recorded from 684m to 2550m. On the basis of different elevation gradients, the maximum number of troops was recorded from 1000m to 2000m and the high troop size was calculated to be 25.5 from 0 to 1000m elevation (Table 4). The occurrence points and troops were mostly recorded

from non-protected areas, especially from semi-cultivated areas or disturbed fragmented patches of forest and riverside.

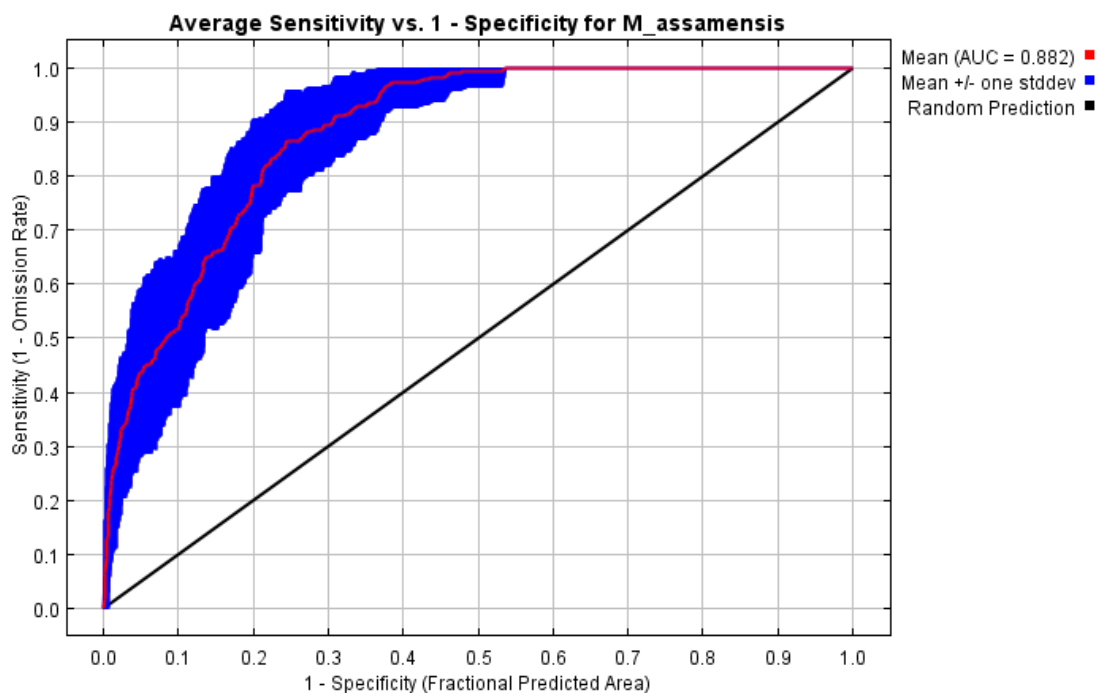
**Table 4.** Average group size of Assamese macaque at different elevational range.

Elevational range	No. of troops	Troop size	Average group size
0–1000m	2	51	25.5
1000–2000m	6	68	11.34
2000–3000m	2	40	20

## 4.2 Current potential distribution of Assamese macaques

### 4.2.1 Model evaluation and importance of bioclimatic variables

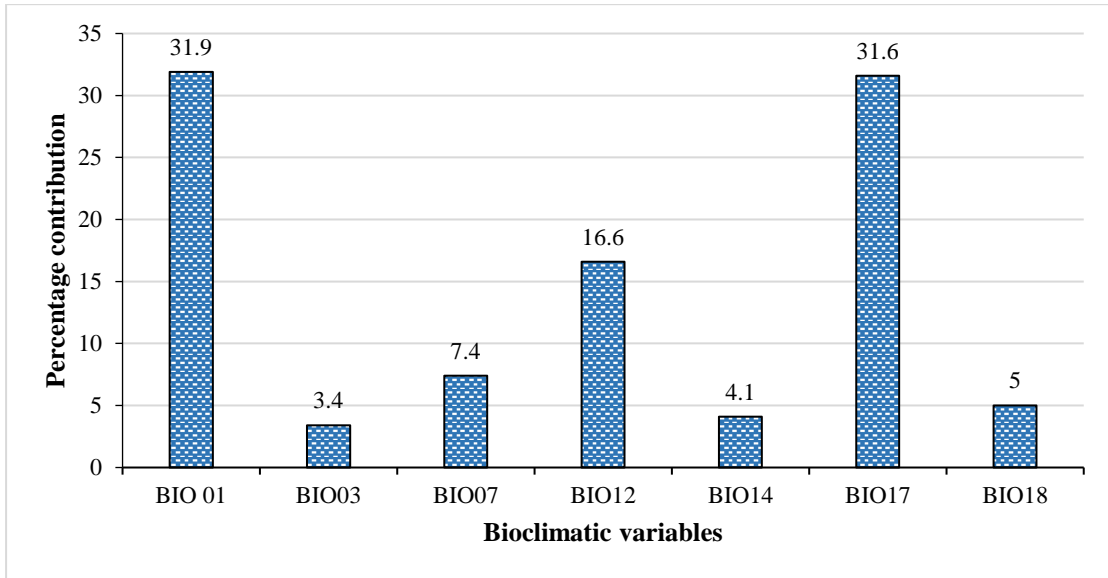
The MaxEnt produced similar results on both the sampling strategies. The mean AUC of 25 cross validation multiplication run was 0.882 (SD=0.078) (Fig. 2), suggesting the potential distribution of Assamese macaques fits well with observed distribution data.



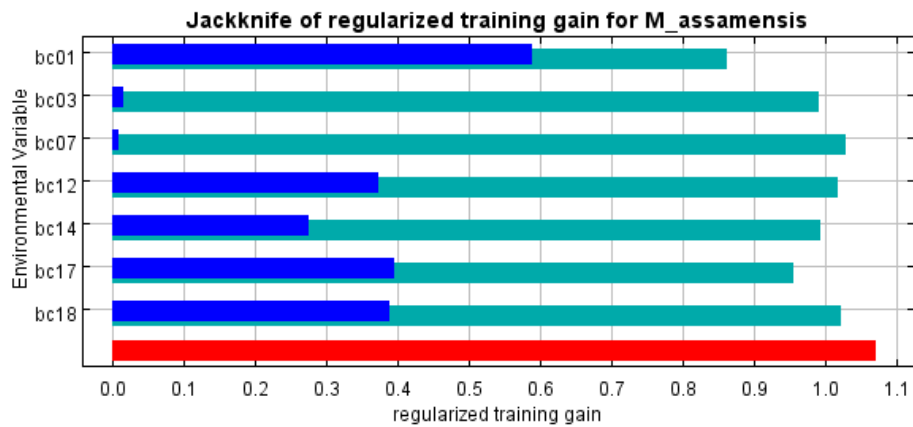
**Figure 2.** Average area under curve (AUC) for 25 replicates of MaxEnt runs (red line is average value and blue bars represent  $\pm 1$  standard deviation for Assamese macaque

To determine the contribution of the bioclimatic variables, the Jackknife test option in the MaxEnt modeling program was also used to determine the contribution of bioclimatic variables (Fig. 3). The Bio1, Bio17 and Bio18 had higher contributions to models. The percentage contribution of annual mean temperature (Bio01) was the

highest (31.9%), precipitation in the driest quarter (Bio17) contributed 31.6% and annual precipitation (Bio12) contributed 16.6%. These three variables contributed more than 80% to the model (Fig.3). The results of the Jackknife test (Fig. 4) also validated the importance of Bio01 (annual mean temperature) in defining the suitable habitat of Assamese macaques in western Nepal.



**Figure 3.** Percentage contribution of bioclimatic variables to the model

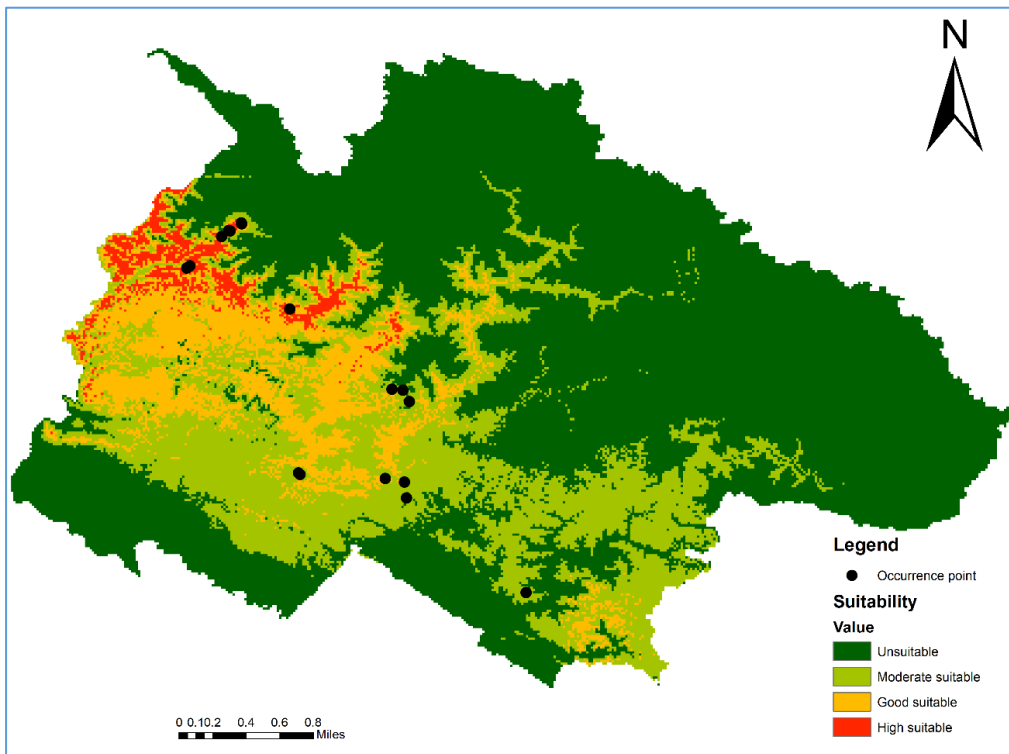


**Figure 4.** Variable importance by Jackknife test for ENM of Assamese macaque. The blue, aqua and red bars represent the results with each variable, remaining all variables and all the variables, respectively.

#### 4.2.2 Current suitable habitat of Assamese macaques

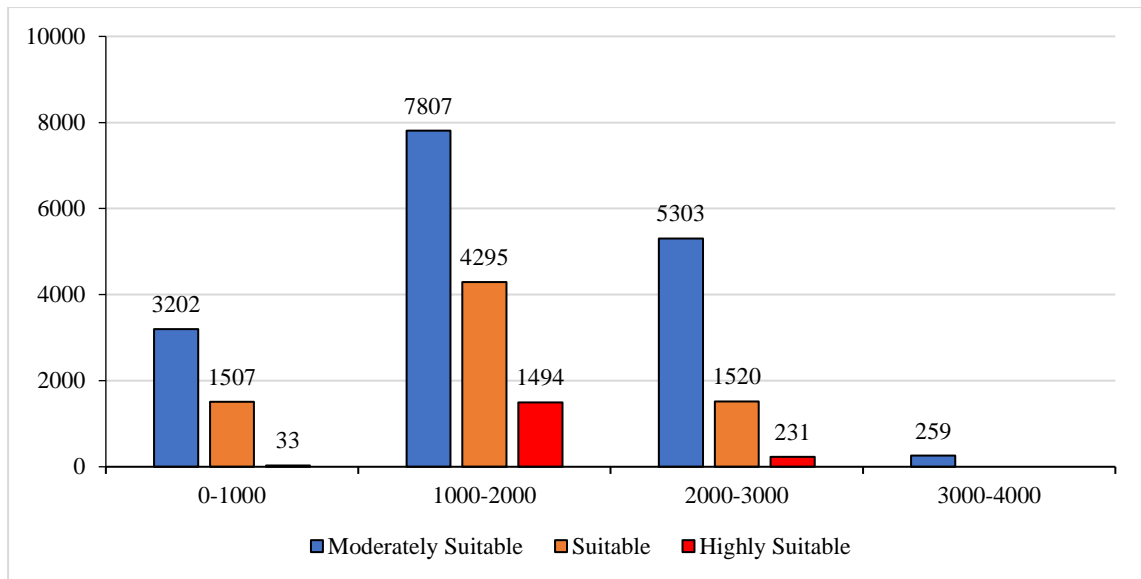
Out of 67813 km<sup>2</sup> area of western Nepal, 62.97% (42699 km<sup>2</sup>) area occupied by unsuitable area for Assamese macaque. There are three other different classes of suitability index; moderate suitable habitat is about 16697 km<sup>2</sup> (24.63%), suitable is

about 7024 km<sup>2</sup> (10.35%) and high suitable area is about 1393 km<sup>2</sup> (2.055%) (Table 5). The approximate suitable area for Assamese macaques according to presence occurrence point is about 37.03% (25114 km<sup>2</sup>) (Fig. 2, Table 5).



**Figure 5.** Map showing current potential distribution area of Assamese macaques in western Nepal

The moderate elevation for the species ranges from 186 m asl to 3370 m asl. Suitable elevation ranges from 158 m asl to 3899 m asl. The highly suitable elevation ranges from 140 m asl to 3568 m asl. The unsuitable habitat for the current distribution of the Assamese macaque is high but its elevation range is lower than suitable habitat. While highly suitable habitat, Assamese macaques can be distributed from 140 m asl to 3568 m asl, which is approximately double the range of unsuitable habitat. It revealed that an increase in habitat unsuitability is inversely related with the elevation habitat range of the Assamese macaque (Fig.6).



**Figure 6.** Current potential distribution areas for Assamese macaques at different elevational range

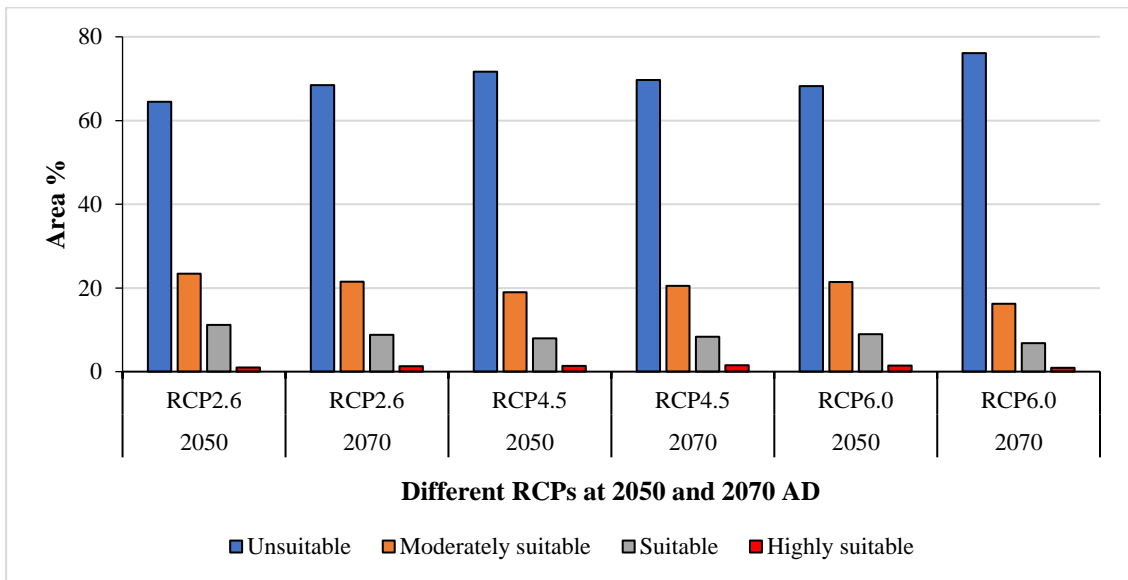
### 4.3 Future potential distribution of Assamese macaques

Out of the 67813 km<sup>2</sup> area of western Nepal (Far-western and Karnali Province), the suitable habitat of the Assamese macaque is about 25114 km<sup>2</sup> in the current distribution model, which represents 37.03% of the total country area and the remaining 42699 km<sup>2</sup> is unsuitable and it occupies about 62.97% area (Table 1). Similarly, the unsuitable area is continuously expanding in different RCP by the year 2050. The unsuitable area of RCP 2.6 in year 2050 is 64.44%, in RCP4.5 is 71.67% and in RCP 6.0 is 68.23%. In 2070, the unsuitable area is about 68.48%, 69.69% and 76.1% in RCP 2.6, 4.5 and 6.0 respectively. The total suitable area in 2050 was 35.56%, 28.33% and 31.77% with RCP 2.6, 4.5 and 6.0 respectively. The total suitable habitat in 2070 is about 31.52%, 30.31% and 23.9% with RCP 2.6, 4.5 and 6.0 respectively. This result shows that habitat suitability has decreased with respect to the increase in greenhouse gas emissions.

**Table 5.** Spatial analyses of the current and future potential geographical distribution in 2050 and 2070 of Assamese macaque

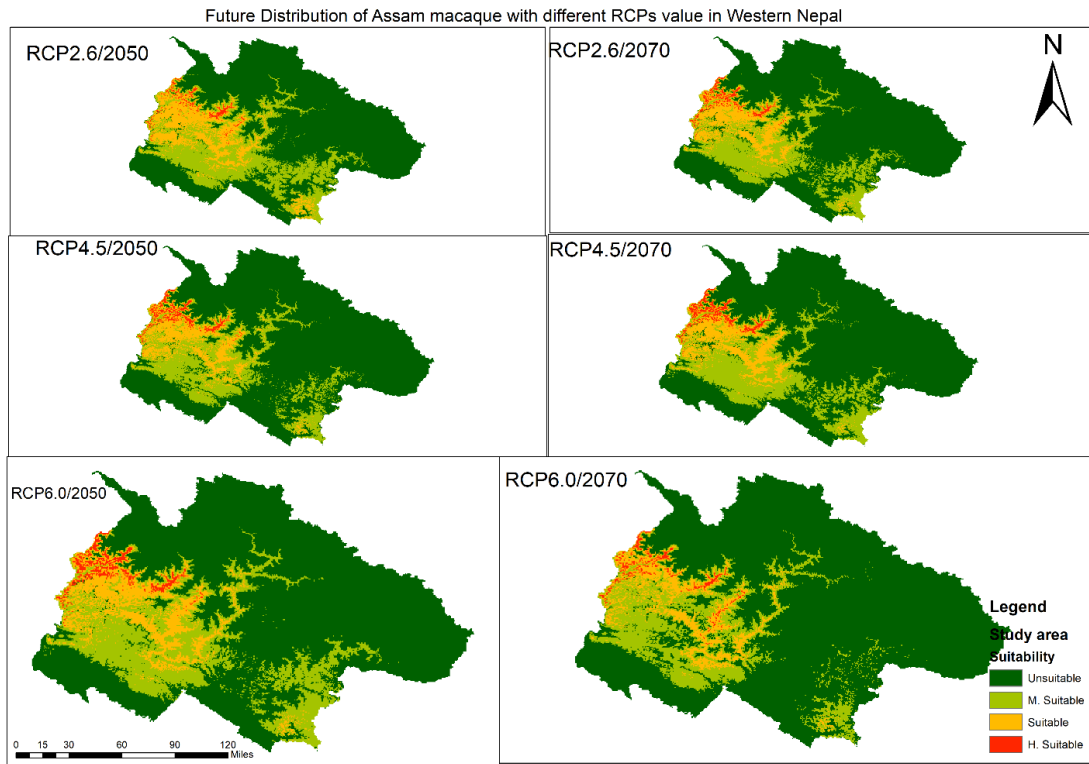
Year	Period	Coverage	Unsuitable	Moderately suitable	Suitable	Highly suitable
2022	Current	Area	42699	16697	7024	1393
		Cover (%)	62.97	24.63	10.35	2.055
2050	RCP2.6	Area	43698	15874	7587	654
		Cover (%)	64.44	23.4	11.19	0.97

<b>2050</b>	RCP4.5	Area	48597	12875	5402	939
		Cover (%)	71.67	18.986	7.97	1.39
<b>2050</b>	RCP6.0	Area	46268	14502	6086	957
		Cover (%)	68.23	21.39	8.98	1.42
<b>2070</b>	RCP2.6	Area	46437	14552	5957	867
		Cover (%)	68.48	21.46	8.79	1.28
<b>2070</b>	RCP4.5	Area	47257	13885	5631	1040
		Cover (%)	69.69	20.48	8.31	1.54
<b>2070</b>	RCP6.0	Area	51612	10979	4618	604
		Cover (%)	76.1	16.19	6.8	0.89



**Figure 7.** Bar diagram of different percentage of area at different suitability level of Assamese macaque in year 2050 and 2070.

The above figure (Fig. 7) shows that in RCP2.6 from 2050 to 2070 the unsuitable area increased by approximately 4%, in RCP4.5 the unsuitable area decreased by 1.98% from 2050 to 2070 and in RCP6.0 the unsuitable area increased by 7.87%. So, we can conclude that if the rate of greenhouse gas emission increases, the habitat unsuitability also increases with respect to different time periods.



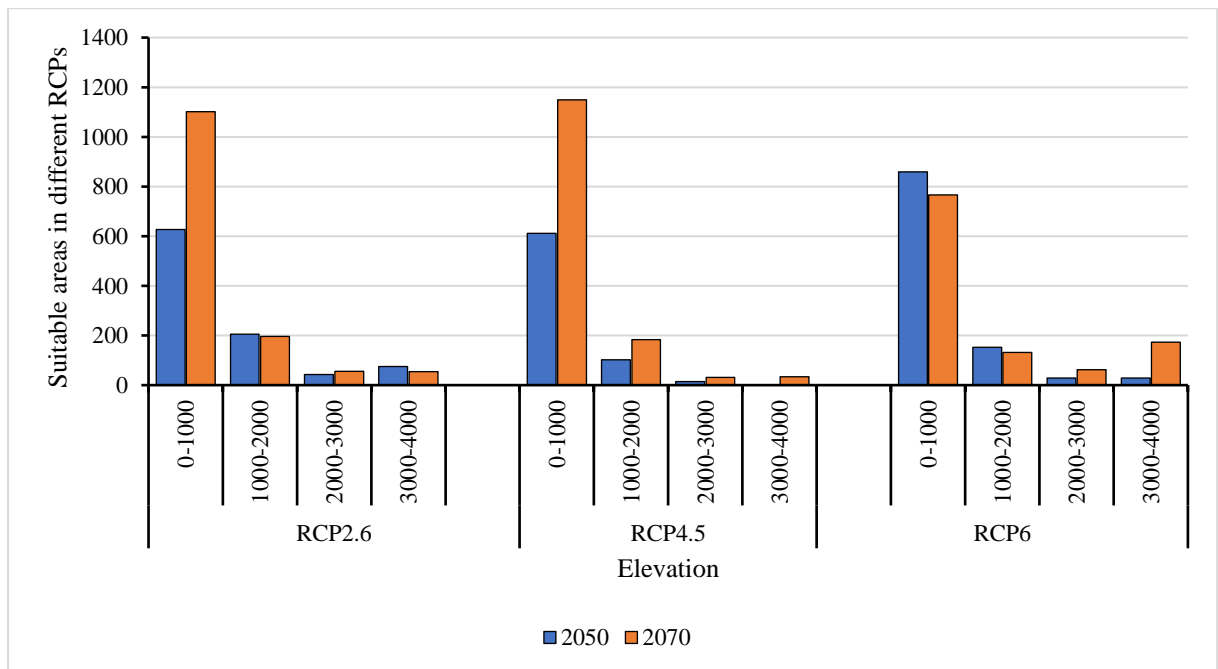
**Figure 8.** Future potential geographical distribution of *M. assamensis* by 2050 and 2070 at different greenhouse emission scenarios RCP 2.6, RCP 4.5 and RCP 6.0.

The changes in habitat suitability and prediction of distribution were identified by comparing them with present and future distribution model maps (Fig. 8). In different scenarios of greenhouse gas emission rates with respect to different RCP, the distribution of Assamese macaques will shrink when RCP increases from 2.5 to 6.0 in 2050 as well as in 2070. This prediction suggests that the potential distribution area of the Assamese macaque will be decreased with the increase in the concentration of greenhouse gases.

#### 4.4 Elevational range shift of Assamese macaques

The MaxEnt model predicted the potential habitat of the Assamese macaque within the elevation range for current occurrence point between 140m and 3568 m asl. The maximum area of highly suitable habitat (1494 km<sup>2</sup>) was in an elevation range between 1000m to 2000m. This model also predicted that the currently available habitat for the Assamese macaque from the western region is about 37.82%. The model also predicts the elevational range shift of the Assamese macaque with respect to different RCP but more areas were recorded from the lower range than the current high suitable elevation. On all three RCP values, most of the suitable areas were predicted to be below 1000m

elevation. The highly suitable habitats were found at less than 1000m elevation in RCP2.6 of the year 2070 (1101km<sup>2</sup>). The same result was also found in RCP 4.5 of year 2070 (1149km<sup>2</sup>). In RCP6.0, the higher suitable areas were predicted at less than the 1000m elevation range, but areas decreased from 2050 to 2070. In RCP2.6, RCP4.5 and RCP6.0, the 0 to 1000m elevational range occupies about 66%, 84% and 80% of the areas, respectively. For the year 2070, in RCP2.6, RCP4.5 and RCP6.0, the suitable areas were calculated at approximately about 78%, 82.19% and 67.60%, respectively. This data shows that the potential distribution of Assamese macaques in western Nepal will be increased from 2050 to 2070 in RCP2.6 and RCP4.5. But in the case of RCP6.0, the suitable habitat will be decreased by approximately 13%.



**Figure 9.** Suitable areas (Km<sup>2</sup>) in different RCPs of future year 2050 and 2070

## 5. Discussion

### 5.1 Population status of Assamese macaques in western Nepal

This study documented a total of 159 individuals of Assamese macaques belonging to 10 troops from western Nepal. Geographical dynamics, human intervention, abundance, distribution and quality of food affect the group size of the macaques (Ménard and Vallet 1997, Chalise 2003, Machairas et al. 2003). One of the least researched species of Nepal is the Assamese of Nepal Himalaya, most recorded from the Riverine side of the Mid-hill broadleaf forest (Chalise 2003, Zhou et al. 2011, Chalise 2013, Khanal et al. 2019), especially areas distributed in subtropical and temperate area (Chalise 2013). Due to the inter-specific competition between the Rhesus and the Assamese macaque, the habitat of the Assamese macaque is more discontinuous than other species of primate (Wada 2005). Assamese macaques were mostly recorded from different fragmented forest patches of Nepal and there is no sufficient data about them being recorded from whole areas of the country. The maximum troop sizes were recorded from the 0–1000m elevation range and maximum troops were recorded from 1000m to 2000m elevation. However, Wada (2005) recorded only 10 troops of Assamese macaques from different river-axis of Nepal and the presence of the troops were recorded from the 200-1800m elevation range and later Chalise et al. (2013) were also studied in the distribution and status of Assamese macaque accumulated by different years data and resulted that 1099 total individuals from 51 troops.

He recorded macaques from the 380m to 2350m elevation range. This study was only limited to the east of the Kaligandaki River basin. So, both of these studies were unable to cover the spatial and temporal data of Assamese macaques from the whole country. The recent study was done by Khanal et al. (2019) and this study was able to collect three groups of 61 individuals of Assamese macaques from the Karnali and Mahakali river-axis of western Nepal by the line the transect method. 829 individuals were recorded from 43 troops the Elevational range 130m of Chatara of Eastern Nepal and highest elevation is 2650m were recorded from Langtang National park. In my study, the average troop size was calculated to be 15.5 and it is approximately near the average group size of Khanal et al. (2019), which was 19.29 ( $\pm 10.40$ ).

In my study, most of the troop sizes were recorded from 0 to 1000m elevation and most of the troops were recorded from 1000m-2000m elevation; this result is also similar to Khanal et al. (2019), 1001m to 1500m elevation and most of the sizes were recorded from less than 500m elevation while the troop size of Assamese macaque recorded by Wada (2005) were 19.1 and Chalise et al. (2013) were recorded 20.57 troop size. The disturbed and un-disturbed areas also determine the density of primates (Hanya et al. 2003). This study resulted that the troop size of Japanese macaque estimated that 1.43 and 0.737 groups/km<sup>2</sup> in disturbed and undisturbed area respectively whereas same results were concluded having groups size in disturbed and undisturbed area were 22.9 and 11.8 groups/km<sup>2</sup> respectively. In my study, all occurrence data were collected from disturbed and non-protected areas of the Western region. Regmi and Kandel (2008) recorded 213 individuals of Assamese macaques (*M. assamensis*) having 9 groups, group density of 0.0790 groups / km<sup>2</sup>, population density of 1.8691 individuals/ km<sup>2</sup> and a mean group size of 23.66 (Range 13-35) individuals.

## **5.2 Current potential distribution of Assamese macaques**

This study specially focused on the distribution of the Assamese macaque in the western part of Nepal. Many studies were done on status and potential habitat suitability in Nepal but there is no study done in a particular region of the country. The Assamese macaque is a threatened primate species and its population has been continually decreasing due to habitat fragmentation, deforestation and hunting (Chalise 2003, Wada 2005, Khanal et al. 2019). Many studies were done in Nepal to account of the distribution of the Assamese macaque (Chalise 2003, Wada 2005, Regmi and Kandel 2008, Chalise et al. 2013, Khanal et al. 2019) but they were unable to give the full status of Assamese macaque. In my study, 17 different troops of Assamese macaque were recorded from Western Nepal only. Most of the area was recorded from the Far-western region but Khanal et al. (2019) recorded 3 troops only from the western region. The Assamese macaque prefer Mid-hill area has broad leaf forest around the river basin at an elevation range between 140m to 2650m (Chalise 2003, Chalise et al. 2013, Khanal et al. 2019)

The MaxEnt model obtained AUC value of 0.87, a good level of accuracy, and the current habitat of Assamese macaque is totally matched with existing occurrence data (Fig 2). The annual mean temperature (BIO 1) is the most influential contributor and

contributes about 31.9% for the Assamese macaque contributors, precipitation (BIO 17) contributes 31.6% and the precipitation in the driest quarter (BIO 12) contributes 16.6%. Khanal et al. (2019) also did MaxEnt algorithms for prediction of suitable habitat for the Assamese macaque in Nepal and found out that BIO 12 has an important contribution to the distribution of the Assamese macaque. The most bioclimatic contributor for Assamese macaque in my study is different to Khanal et al. (2019). It might be due to the different study areas. That study researched the whole of Nepal and most of the occurrence points were collected from Eastern Nepal rather than Western Nepal.

Eastern Nepal is more humid than Western Nepal, but this study was done only in western Nepal, and western Nepal is drier than eastern Nepal. It might have caused annual mean temperature is major bioclimatic variables for distribution of Assamese macaque. The same results resulted for Himalayan Musk deer in which the annual mean temperature was the major contributor to the distribution of Himalayan musk Deer (Lamsal et al. 2018). Our model also estimated the suitable altitude for the Assamese macaque from 684m to 2550m and this result is also similar to the result of Khanal et al. (2019) and he concluded that the elevational range of the Assamese macaque is about 85m to 2,987m. The lower distribution range of my study and Khanal et al. (2019) is different. It might be due to the elevation of sea level being higher in my study area than in their study sites. Currently, about 35.02% of the area of the Western region is the potential for Assamese macaques (Table 5). By using the elevation range between 140m to 7568m. The maximum suitable habitat was predicted at about 1494 square kilometers, an elevational range between 1000m to 2000m elevation on the current map. Our studies show that most of the suitable areas were modelled by MaxEnt in the Temperate and tropical mid-hill broad leaf forest of western Nepal. Similar results were also reported by other studies (Chalise 2003, Wada 2005, Chalise 2013, Khanal et al. 2019).

### **5.3 Future predicted distribution of Assamese macaques**

Nepal's geography extends from 80m to 8848m elevation, having different climatic scenarios, such as tropical to tundra. Due to the high geographic heterogeneity of Nepal's landscape, it is easy to adopt with adverse climatic conditions. The connecting heterogeneous landscape can enhance the adaptability capability in climate change

were also reported by (Ackerly et al. 2010). Our occurrence points were mostly recorded from non-protected areas of the western region and were mid hill. Our result shows that the future habitat of the Assamese macaque will be extended towards a higher elevation than the presence occurrence point at a high value of RCP. In low RCP the distribution range moves towards a lower range of elevation than presence occurrence area. So, this result shows that for the conservation of the Assamese macaque population we need to build a protected area. In the RCP 2.6 scenario, the estimated range of Assamese macaques will decrease from 2050 to 2070 at elevation 0-1000m and the same result has resulted in RCP4.5. But in the case of RCP6.0, the suitable area will decrease in 2070 rather than 2050, which might be due to the over production of greenhouse gases.

## 6. Conclusion and recommendations

This study provides the current and future status of the Assamese macaque with a prediction of a possible future distribution in western Nepal. The present study observed 159 individuals belonging to 10 different troops of Assamese macaques from Western Nepal, including Sudur Paschim and Karnali provinces. Using the Maximum entropy algorithm in MaxEnt, this study identified the potential distribution area of the species in western Nepal. About 25,114 Km<sup>2</sup> of area in western Nepal ranging between 158 m to 3899 m in elevation is identified as habitat. Projections of the current niche of the species for 2050 and 2070 at different greenhouse emission scenarios revealed that the macaque will lose its current habitat in the future and its elevational range will be shifted northward towards a higher elevation. This study concludes that climate change plays a negative role in the distribution of Assamese macaques. As most of the troops were recorded from outside the protected area system of Nepal, the species needs special attention for conservation.

Due to the less aggressive habits of the Assamese macaque, most of the troops are threatened by dogs and humans. In many parts of western Nepal, retaliatory killings of macaques have been reported during this study. Therefore, future studies should focus on the level of human-macaque conflicts, their causes, consequences and potential remedies. The Assamese macaque population in western Nepal is small, sparsely distributed and understudied. Therefore, his study recommends an immediate conservation and management plan of Assamese macaques in western Nepal.

## Annexes

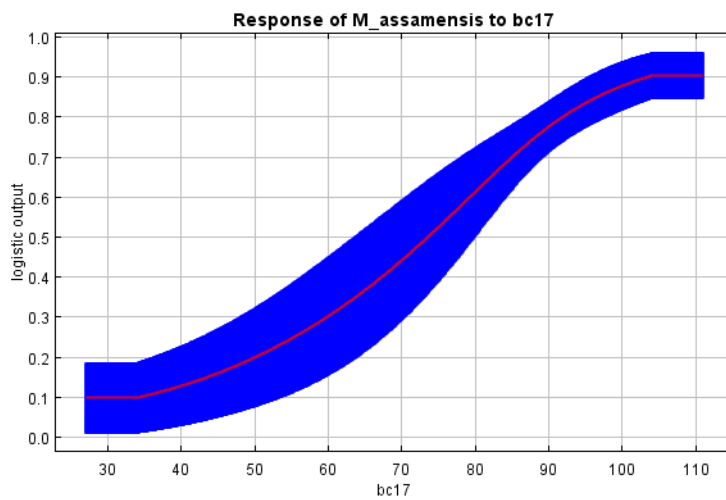
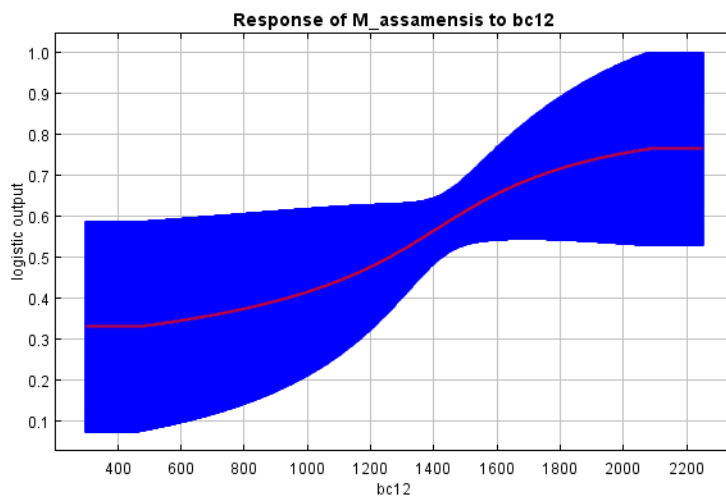
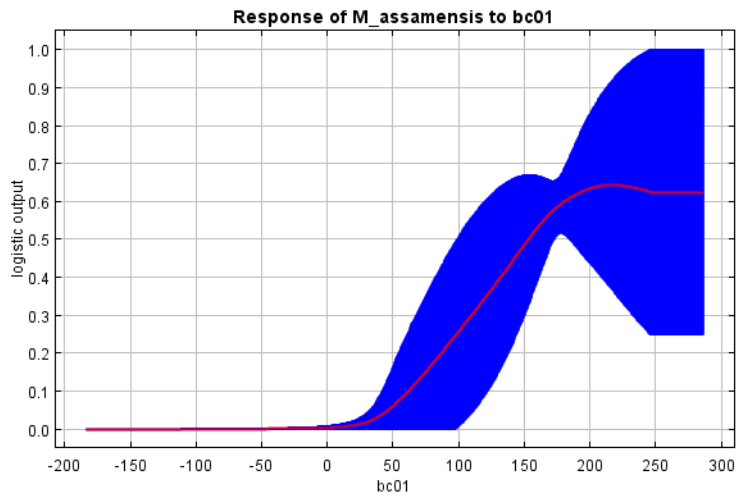
### Annex 1. Correlation matrix of bioclimatic variables

	BIO1	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO8	BIO9	BIO10	BIO11	BIO12	BIO13	BIO14	BIO15	BIO16	BIO17	BIO18	BIO19
BIO1	1																		
BIO2	0.354	1																	
BIO3	-0.316	0.111	1																
BIO4	0.038	0.618	-0.503	1															
BIO5	0.997	0.416	-0.324	1	1														
BIO6	0.994	0.271	-0.284	0.054	0.984	1													
BIO7	0.479	0.888	-0.346	0.919	0.54	0.386	1												
BIO8	0.998	0.386	-0.338	0.089	0.998	0.987	0.519	1											
BIO9	0.994	0.317	-0.311	-0.484	0.989	0.992	0.442	0.989	1										
BIO10	0.998	0.384	-0.342	0.091	0.999	0.988	0.519	0.999	0.991	1									
BIO11	0.999	0.327	-0.293	-0.516	0.993	0.997	0.443	0.994	0.994	0.995	1								
BIO12	0.69	0.348	-0.506	0.217	0.903	0.874	0.561	0.912	0.891	0.907	0.89	1							
BIO13	0.899	0.419	-0.513	0.281	0.907	0.864	0.633	0.913	0.887	0.91	0.887	0.985	1						
BIO14	0.117	-0.314	-0.241	-0.055	0.095	0.144	-0.193	0.119	0.121	0.114	0.12	0.246	0.141	1					
BIO15	0.869	0.467	-0.46	0.296	0.878	0.828	0.656	0.88	0.851	0.88	0.855	0.883	0.938	0.065	1				
BIO16	0.901	0.414	-0.505	0.268	0.908	0.867	0.624	0.914	0.889	0.911	0.889	0.989	0.997	0.138	0.935	1			
BIO17	-0.106	-0.509	-0.106	-0.31	-0.04	0.046	-0.439	-0.21	0.016	-0.024	0.004	0.108	-0.042	0.817	-0.303	-0.27	1		
BIO18	0.691	0.159	-0.321	0.024	0.678	0.683	0.292	0.701	0.687	0.688	0.689	0.799	0.758	0.249	0.677	0.775	0.193	1	
BIO19	-0.446	-0.601	0.033	-0.288	-0.465	-0.388	-0.587	-0.455	-0.408	-0.456	-0.431	-0.322	-0.455	0.54	-0.684	-0.441	0.839	-0.174	1

**Annex 2. Percentage contribution and permutation importance of all bioclimatic variables in the model**

<b>Variable</b>	<b>Percent contribution</b>	<b>Permutation importance</b>
<b>BIO1</b>	31.9	37
<b>BIO17</b>	31.6	17.7
<b>Bio12</b>	16.6	11.3
<b>Bio7</b>	7.4	8.8
<b>BIO18</b>	5	8.7
<b>BIO14</b>	4.1	9.1
<b>BIO3</b>	3.4	7.4

**Annex 3. Response curve of three most important variables (Bio01, Bio12 and Bio17) of the ecological niche modeling in MaxEnt**



## References

- Acharya, K. P. and Paudel, P. K. 2020. Biodiversity in Karnali Province: Current status and conservation. Ministry of Industry, Tourism, Forest and Environment, Karnali Province Government, Surkhet, Nepal.
- Ackerly, D., Loarie, S., Cornwell, W., Weiss, S., Hamilton, H., Branciforte, R., et al. 2010. The geography of climate change: implications for conservation biogeography. *Diversity and Distributions* **16**:476–487.
- Adhikari, D., Barik, S. and Upadhaya, K. 2012. Habitat distribution modelling for reintroduction of *Ilex khasiana* Purk., a critically endangered tree species of northeastern India. *Ecological Engineering* **40**:37–43.
- Adhikari, K., Khanal, L. and Chalise, M. K. 2018. Status and effects of food provisioning on ecology of Assamese monkey (*Macaca assamensis*) in Ramdi area of Palpa, Nepal. *Journal of Institute of Science and Technology* **22**:183–190.
- Aggimarangsee, N. 1992. Survey for semi-tame colonies of macaques in Thailand. Mahidol University.
- Agresti, A. 1999. Modelling ordered categorical data: recent advances and future challenges. *Statistics in Medicine* **18**:2191–2207.
- Ahsan, M. 1994. Feeding ecology of the primates of Bangladesh. *Current Primatology* **1**:79–86.
- Alley, R. B., Marotzke, J., Nordhaus, W. D., Overpeck, J. T., Peteet, D. M., Pielke, R. A., Jr., et al. 2003. Abrupt Climate Change. *Science* **299**:2005–2010.
- Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O., Swartz, B., Quental, T. B., et al. 2011. Has the Earth's sixth mass extinction already arrived? *Nature* **471**:51–57.
- Bell, D. M., Bradford, J. B. and Lauenroth, W. K. 2014. Early indicators of change: divergent climate envelopes between tree life stages imply range shifts in the western United States. *Global Ecology and Biogeography* **23**:168–180.
- Bernstein, I. S. and Cooper, M. A. 1999. Dominance in assamese macaques (*Macaca assamensis*). *American Journal of Primatology: Official Journal of the American Society of Primatologists* **48**:283–289.
- Boonratana, R., Chalise, M., Das, J., Htun, S. and Timmins, R. 2008. *Macaca assamensis*. The IUCN Red List of Threatened Species. e.T12549A3354977

- Bourg, N. A., McShea, W. J. and Gill, D. E. 2005. Putting a CART before the search: successful habitat prediction for a rare forest herb. *Ecology* **86**:2793–2804.
- Breiman, L., Friedman, J., Olshen, R. and Stone, C. 1984. Classification and regression trees. Wadsworth International Group, Belmont, USA. Chapter 9. Bibliography
- Brockelman, W. Y. 1981. Field Research on Primates in Thailand. *Journal of Scientific Society of Thailand* **7**:9-17.
- Brooker, R. W., Travis, J. M., Clark, E. J. and Dytham, C. 2007. Modelling species' range shifts in a changing climate: the impacts of biotic interactions, dispersal distance and the rate of climate change. *Journal of Theoretical Biology* **245**:59–65.
- Buckland, S. T., Plumptre, A. J., Thomas, L. and Rexstad, E. A. 2010. Line transect sampling of Primates: Can animal-to-observer distance methods work? *International Journal of Primatology* **31**(3):485–499.
- Busby, J. R. 1986. A biogeoclimatic analysis of *Nothofagus cunninghamii* (Hook.) Oerst. in southeastern Australia. *Australian Journal of Ecology* **11**:1–7.
- Carpenter, G., Gillison, A. and Winter, J. 1993. DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity & Conservation* **2**:667–680.
- Chalise, M. K. 2003. Assamese macaques (*Macaca assamensis*) in Nepal. *Primate Conservation* **19**:99–107.
- Chalise, M. K. 2013. Fragmented primate population of Nepal. *Primates in Fragments*, Springer: 329–356.
- Chalise, M. K., Ogawa, H. and Pandey, B. 2013. Assamese monkeys in Nagarjun forest of Shivapuri Nagarjun National Park, Nepal. *Tribhuvan University Journal* **28**:181–190.
- Chapman, C. A., Bonnell, T. R., Gogarten, J. F., Lambert, J. E., Omeja, P. A., Twinomugisha, D., et al. 2013. Are primates ecosystem engineers? *International Journal of Primatology* **34**:1–14.
- Çoban, H. O., Örucü, Ö. K. and Arslan, E. S. 2020. MaxEnt modeling for predicting the current and future potential geographical distribution of *Quercus libani* Olivier. *Sustainability* **12**:2671.
- Cooper, M. A. and Bernstein, I. S. 2000. Social grooming in Assamese macaques (*Macaca assamensis*). *American Journal of Primatology* **50**:77–85.
- Cooper, M. A. and Bernstein, I. S. 2002. Counter aggression and reconciliation in Assamese macaques (*Macaca assamensis*). *American Journal of Primatology* **56**:215–230.

- Corsi, F., De Leeuw, J. and Skidmore, A. 2000. Modeling species distribution with GIS. In: Research Techniques in Animal Ecology. Columbia University Press. pp 389–434.
- Corsi, F., De Leeuw, J. and Skidmore, A. 2000. Modeling species distribution with GIS.
- Dahal, N. 2012. Implications of climate change on biodiversity in Nepal: Some observations and opportunities. 23<sup>rd</sup> Warden Seminar, Pokhara, November.
- Elith, J. 2000. Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. Quantitative methods for conservation biology, Springer: 39-58.
- Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **29**:129–151.
- Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E. and Yates, C. J. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* **17**:43–57.
- Ferrier, S., Watson, G., Pearce, J. and Drielsma, M. 2002. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. I. Species-level modelling. *Biodiversity & Conservation* **11**:2275–2307.
- Fourcade, Y., Engler, J. O., Rodder, D. and Secondi, J. 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. *PLoS ONE* **9**:e97122.
- Gassó, N., Thuiller, W., Pino, J. and Vilà, M. 2012. Potential distribution range of invasive plant species in Spain. *NeoBiota* **12**:25.
- Ghimire, S. C., Khanal, L. and Chalise, M. K. 2021. Feeding ecology of Assamese macaques (*Macaca assamensis*) troops in Kaligandaki and Budhigandaki River basins of central Nepal. *Biodiversitas Journal of Biological Diversity* **2**(7):2625–2634
- Graham, C. H., Ferrier, S., Huettman, F., Moritz, C. and Peterson, A. T. 2004. New developments in museum-based informatics and applications in biodiversity analysis. *Trends in Ecology and Evolution* **19**:497–503.
- Graham, C. H., Ron, S. R., Santos, J. C., Schneider, C. J. and Moritz, C. 2004. Integrating phylogenetics and environmental niche models to explore speciation mechanisms in dendrobatid frogs. *Evolution* **58**:1781–1793.
- Guisan, A. and Zimmermann, N. E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling* **135**:147–186.

- Hanya, G., Yoshihiro, S., Zamma, K., Kubo, R. and Takahata, Y. 2003. New method to census primate groups: estimating group density of Japanese macaques by point census. *American Journal of Primatology* **60**:43–56.
- Hastie, T. and Tibshirani, R. 1990. *Generalized additive models*. Chapman and Hall Inc., London.
- Hill, W. O. and Bernstein, I. S. 1969. On the morphology, behaviour and systematic status of the Assam macaque (*Macaca assamensis* McClelland, 1839). *Primates* **10**:1–17.
- Holzmann, I., Agostini, I., Areta, J. I., Ferreyra, H., Beldomenico, P. and Di Bitetti, M. S. 2010. Impact of yellow fever outbreaks on two howler monkey species (*Alouatta guariba clamitans* and *A. caraya*) in Misiones, Argentina. *American Journal of Primatology* **72**:475–480.
- Hosmer Jr, D. W., Lemeshow, S. and Sturdivant, R. X. 2013. *Applied logistic regression*. John Wiley & Sons.
- Isbell, L. A., Young, T. P., Jaffe, K. E., Carlson, A. A. and Chancellor, R. L. 2009. Demography and life histories of sympatric patas monkeys, *Erythrocebus patas*, and vervets, *Cercopithecus aethiops*, in Laikipia, Kenya. *International Journal of Primatology* **30**:103–124.
- Iverson, L. R. and Prasad, A. M. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. *Ecological Monographs* **68**:465–485.
- Jarvis, A., Reuter, H. I., Nelson, A. and Guevara, E. 2008. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database.
- Kawamoto, Y., Aimi, M., Wangchuk, T. and Sherub 2006. Distribution of Assamese macaques (*Macaca assamensis*) in the inner Himalayan region of Bhutan and their mtDNA diversity. *Primates* **47**:388–392.
- Khanal, L., Chalise, M. K., He, K., Acharya, B. K., Kawamoto, Y. and Jiang, X. 2018. Mitochondrial DNA analyses and ecological niche modeling reveal post-LGM expansion of the Assam macaque (*Macaca assamensis*) in the foothills of Nepal Himalaya. *American Journal of Primatology* **80**:e22748.
- Khanal, L., Chalise, M. K. and Jiang, X. 2019. Distribution of the threatened Assamese Macaque *Macaca assamensis* (Mammalia: Primates: Cercopithecidae) population in Nepal. *Journal of Threatened Taxa* **11**:13047–13057.

- Khanal, L., Chalise, M. K. and Jiang, X. L. 2019. Distribution of the threatened Assamese Macaque *Macaca assamensis* (Mammalia: Primates: Cercopithecidae) population in Nepal. *Journal of Threatened Taxa* **11**:13047–13057.
- Khanal, L., Chalise, M. K., Fan, P. F., Kyes, R. C. and Jiang, X. L. 2021. Multilocus phylogeny suggests a distinct species status for the Nepal population of Assam macaques (*Macaca assamensis*): implications for evolution and conservation. *Zoological Research* **42**(1):3–13.
- Khatri, K., Jha, B. R., Gurung, S. and Khadka, U. R. 2020. Freshwater fish diversity and its conservation status in different water bodies of Nepal. *Nepal Journal of Environmental Science* **8**:39–52.
- Koirala, S. and Chalise, M. 2014. Feeding ecology of Assamese macaque (*Macaca assamensis*) in the Nagarjun Forest of Shivapuri Nagarjun National Park, Nepal. *Nepalese Journal of Zoology* **2**:31–38.
- Lamsal, P., Kumar, L., Aryal, A. and Atreya, K. 2018. Future climate and habitat distribution of Himalayan Musk Deer (*Moschus chrysogaster*). *Ecological Informatics* **44**:101–108.
- Machairas, I., Camperio Ciani, A. and Gardelis, S. 2003. Interpopulation differences in activity patterns of *Macaca sylvanus* in the Moroccan Middle Atlas. *Human Evolution* **18**:185–202.
- Majolo, B., McFarland, R., Young, C. and Qarro, M. 2013. The Effect of Climatic Factors on the Activity Budgets of Barbary Macaques (*Macaca sylvanus*). *International Journal of Primatology* **34**:500–514.
- Matawa, F., Murwira, A. and Schmidt, K. S. 2012. Explaining elephant (*Loxodonta africana*) and buffalo (*Syncerus caffer*) spatial distribution in the Zambezi Valley using maximum entropy modelling. *Ecological Modelling* **242**:189–197.
- McClelland, J. 1839. List of mammalia and birds collected in Assam by John McClelland Esq. *Proceeding of Zoological Society of London, UK*.
- Ménard, N. and Vallet, D. 1997. Behavioral responses of Barbary macaques (*Macaca sylvanus*) to variations in environmental conditions in Algeria. *American Journal of Primatology* **43**:285–304.
- Mitchell, M. 1998. *An introduction to genetic algorithms*. MIT Press.
- Mittermeier, R. A., Wilson, D. E. and Rylands, A. B. 2013. *Handbook of the Mammals of the World: Primates*. Lynx Edicions.

- Molur, S., Brandon-Jones, D., Dittus, W., Eudey, A., Kumar, A., Singh, M., et al. 2003. Status of South Asian Primates: Conservation Assessment and Management Plan (C.A.M.P.)-2003. Workshop Report. Coimbatore, India, Zoo Outreach Organisation /CBSG-South Asia: viii+432.
- Nekaris, K. A., Arnell, A. P. and Svensson, M. S. 2015. Selecting a conservation surrogate species for small fragmented habitats using ecological niche modelling. *Animals (Basel)* **5**:27–40.
- Nisbett, R. A. and Ciochon, R. L. 1993. Primates in northern Vietnam: A review of the ecology and conservation status of extant species, with notes on Pleistocene localities. *International Journal of Primatology* **14**:765–795.
- Nix, H. 1986. A biogeographic analysis of the Australian elapid snakes. In ‘Atlas of Elapid Snakes of Australia’. (Ed. R. Longmore.) pp. 4–15. Australian Flora and Fauna Series No. 7. Australian Government Publishing Service: Canberra.
- Oates, J. F. 2013. Primate Conservation: Unmet Challenges and the Role of the International Primatological Society. *International Journal of Primatology* **34**:235–245.
- Pearson, R. G., Raxworthy, C. J., Nakamura, M. and Townsend Peterson, A. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography* **34**:102–117.
- Peterson, A., Soberón, J. and Sánchez-Cordero, V. 1999. Conservatism of ecological niches in evolutionary time. *Science* **285**:1265–1267.
- Peterson, A. T. 2003. Predicting the geography of species’ invasions via ecological niche modeling. *The Quarterly Review of Biology* **78**:419–433.
- Phillips, S. J. 2005. A brief tutorial on Maxent. *AT&T Research* **190**:231–259.
- Phillips, S. J., Anderson, R. P. and Schapire, R. E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190**:231–259.
- Phillips, S. J. and Dudík, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* **31**:161–175.
- Phillips, S. J. and Elith, J. 2010. POC plots: calibrating species distribution models with presence-only data. *Ecology* **91**:2476–2484.
- Pulliam, H. R. 2000. On the relationship between niche and distribution. *Ecology Letters* **3**:349–361.

- Pyritz, L. W., Buntge, A. B., Herzog, S. K. and Kessler, M. 2010. Effects of Habitat Structure and Fragmentation on Diversity and Abundance of Primates in Tropical Deciduous Forests in Bolivia. *International Journal of Primatologist* **31**:796–812.
- Raxworthy, C. J., Martinez-Meyer, E., Horning, N., Nussbaum, R. A., Schneider, G. E., Ortega-Huerta, M. A., et al. 2003. Predicting distributions of known and unknown reptile species in Madagascar. *Nature* **426**:837–841.
- Regmi, G. R., Huettmann, F., Suwal, M. K., Nijman, V., Nekaris, K., Kandel, K., et al. 2018. First open access ensemble climate envelope predictions of Assamese macaque *Macaca assamensis* in Asia: a new role model and assessment of endangered species. *Endangered Species Research* **36**:149–160.
- Regmi, G. R. and Kandel, K. 2008. Population status, threats and conservation measures of Assamese macaque (*Macaca assamensis*) in Langtang National Park, Nepal. *Primates* **96**:19–20.
- Roos, C., Boonratana, R., Supriatna, J., Fellowes, J. R., Groves, C., Nash, S. D., et al. 2014. An updated taxonomy and conservation status review of Asian primates. *Asian Primates Journal* **4**(1):2–20.
- Sarkar, P., Srivastava, A., Dasgupta, S. and Bhattacharjee, P. 2012. Activity profile of free ranging forest group of Assamese macaque. *The Clarion-International Multidisciplinary Journal* **1**:59–67.
- Schloss, C. A., Nuñez, T. A. and Lawler, J. J. 2012. Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. *Proceedings of the National Academy of Sciences* **109**:8606–8611.
- Schülke, O., Psek, D., Whitman, B. J. and Ostner, J. 2011. Ecology of Assamese macaques (*Macaca assamensis*) at Phu Khieo Wildlife Sanctuary, Thailand. *Journal of Wildlife in Thailand* **18**:1–15.
- Scott, J. M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., et al. 1993. Gap analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs* **3**:41.
- Sharma, C. 1999. *Physiography: Nepal nature's paradise*. Hari Devi, Gwalior, India.
- Shcheglovitova, M. and Anderson, R. P. 2013. Estimating optimal complexity for ecological niche models: A jackknife approach for species with small sample sizes. *Ecological Modelling* **269**:9–17.

- Stewart, B. M., Turner, S. E. and Matthews, H. D. 2020. Climate change impacts on potential future ranges of non-human primate species. *Climatic Change* **162**:2301–2318.
- Stoms, D. M. and Estes, J. 1993. A remote sensing research agenda for mapping and monitoring biodiversity. *International Journal of Remote Sensing* **14**:1839–1860.
- Suwal, M. K., Huettmann, F., Regmi, G. R. and Vetaas, O. R. 2018. Parapatric subspecies of *Macaca assamensis* show a marginal overlap in their predicted potential distribution: Some elaborations for modern conservation management. *Ecology and Evolution* **8**:9712–9727.
- Ter Braak, C. J. and Verdonschot, P. F. 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**:255–289.
- Thorn, J. S., Nijman, V., Smith, D. and Nekaris, K. 2009. Ecological niche modelling as a technique for assessing threats and setting conservation priorities for Asian slow lorises (Primates: Nycticebus). *Diversity and Distributions* **15**:289–298.
- Upreti, D. 1999. Rising Atmospheric CO and crop response. SASCOM Scientific Report 1–8.
- Voskamp, A., Rode, E. J., Coudrat, C. N. Z., Coudrat, C. N. Z., Coudrat, C. N. Z., Wilson, R. J., et al. 2014. Modelling the habitat use and distribution of the threatened Javan slow loris *Nycticebus javanicus*. *Endangered Species Research* **23**:277–286.
- Wada, K. 2005. The distribution pattern of rhesus and Assamese monkeys in Nepal. *Primates* **46**:115–119.
- Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J., et al. 2002. Ecological responses to recent climate change. *Nature* **416**:389–395.
- Wang, Y.-S., Xie, B.-Y., Wan, F.-H., Xiao, Q.-M. and Dai, L.-Y. 2007. The potential geographic distribution of *Radopholus similis* in China. *Agricultural Sciences in China* **6**:1444–1449.
- Weiskopf, S. R., Rubenstein, M. A., Crozier, L. G., Gaichas, S., Griffis, R., Halofsky, J. E., et al. 2020. Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Science of the Total Environment* **733**:137782.
- Wilson, J. B., Rapson, G. L., Sykes, M. T., Watkins, A. J. and Williams, P. A. 1992. Distributions and climatic correlations of some exotic species along roadsides in South Island, New Zealand. *Journal of Biogeography* 183–193.
- Worth, J. R., Harrison, P. A., Williamson, G. J. and Jordan, G. J. 2015. Whole range and regional-based ecological niche models predict differing exposure to 21st century

- climate change in the key cool temperate rainforest tree southern beech (*Nothofagus cunninghamii*). *Austral Ecology* **40**:126–138.
- Yang, X.-Q., Kushwaha, S., Saran, S., Xu, J. and Roy, P. 2013. Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. *Ecological Engineering* **51**:83–87.
- Zhou, Q., Wei, H., Huang, Z. and Huang, C. 2011. Diet of the Assamese macaque *Macaca assamensis* in limestone habitats of Nonggang, China. *Current Zoology* **57**:18–25.
- Zhou, Q., Wei, H., Huang, Z., Krzton, A. and Huang, C. 2014. Ranging behavior and habitat use of the Assamese macaque (*Macaca assamensis*) in limestone habitats of Nonggang, China. *De Gruyter*.
- Zhou, Q., Wei, H., Huang, Z., Krzton, A. and Huang, C. 2014. Ranging behavior and habitat use of the Assamese macaque (*Macaca assamensis*) in limestone habitats of Nonggang, China. *Mammalia* **78**:171–176.