BIOCLIMATIC SUITABILITY MODELS FOR CURRENT AND FUTURE DISTRIBUTION OF ELONGATED TORTOISE (*Indotestudo elongata*) IN NEPAL

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Submitted To

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Tribhuvan University
Kirtipur, Nepal

May, 2023

DECLARATION

I hereby declare that the work presented in this thesis entitled **"Bioclimatic Suitability Models for Current and Future Distribution of Elongated Tortoise (*Indotestudo elongata*) in 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 the reference to the author(s) or institution(s).

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RECOMMENDATION

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On the recommendation of Supervisor Dr. Bishnu Prasad Bhattarai, this thesis submitted by Mrs. Anita Pandey entitled "**Bioclimatic Suitability Models for Current and Future Distribution of Elongated Tortoise (*Indotestudo elongata*) in 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.

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CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Mrs. Anita Pandey entitled "**Bioclimatic Suitability Models for Current and Future Distribution of Elongated Tortoise (*Indotestudo elongata*) in Nepal**" has been accepted as a partial fulfilment for the requirements of Master's Degree of Science in Zoology with special paper "Ecology and Environment".

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LISTS OF ABBREVIATIONS

AUC	Area under curve
CR	Critically Endangered
EN	Endangered
FCC	Forestry Campus Complex
GBIF	Global Biodiversity Information Facility
IUCN	International Union for Conservation of Nature
PA	Protected Area
ROC	Receiver Operating Characteristics
RCPs	Representative Concentration Pathway scenarios
SSPs	Shared Socio-economic Pathways
SDM	Species Distribution Modelling
SCL	Straight Carapace Lengths
TRCC	Turtle Rescue and Conservation Center
VES	Visual Encounter Surveys
VU	Vulnerable

ABSTRACT

The Elongated Tortoise (*Indotestudo elongata*) is the least known and most threatened species among all the vertebrates in the world. Observation for the previous climatic variation, future prediction on changes, and an exercise to explore the relation of climate change and its distribution has done in this study. The site of occurrence of the species is based on climatic suitability. The study basically focuses on whole lowland Nepal. The present distribution of this species and their further response to future climatic changes was done through Species Distribution Modelling (SDM). Seven environmental variables were analysed against the distribution of elongated tortoise under different climatic conditions; Shared Socio-economic Pathways (SSPs) 245 and 585 for the year 2050 and 2070 with the use of maximum entropy modeling (MaxEnt). A predicted distribution frame maps and estimated area using Arc GIS 10.8 was done for the study. Among seven bioclimatic variables, three variables were considered important factors where average temperature of wettest quarter (Bio8) contributed the highest (77.1%) followed by 8.6% for Bio5 (temperature of warmest month) and 7.4% for Bio12 (annual precipitation). When MaxEnt was used, the average area under the curve high (AUC) for *I. elongata* was 0.926, indicating the accuracy of the climatic suitability modeling. The suitability estimated by Maxent for elongated tortoise was 47,893 km^2 (24.42%) where, highly suitable area was approximately 27,822km^2 (14.19%) and moderately suitable area 20,071 km^2 (10.23%) for current scenario. The study also predicted that suitability will increase along with time as the proportion of moderately suitable areas would decline by 2070 under high emission scenarios SSPs585(2070).

1. INTRODUCTION

1.1 Background of the study

Turtles and tortoise of Asia are among the world's least known and most endangered vertebrate species (Engstrom et al. 2002, Buhlmann et al. 2009). The study of turtles and tortoises is called cheloniology, after the Greek word for turtles. It also sometimes called Testudinology, after the Latin name for turtles. Tortoises and turtles of order Testudines (Dubois and Bour 2010) are mainly covered in Horney shell plates developed from their ribs as a shield (Hutchinson, 1996) and inhibits with a great variety of habitat including terrestrial, semi aquatic and aquatic system (Aryal et al. 2010). Except the land tortoise species, all the turtle species more or less depend on wetlands (Aryal et al. 2009). They are one of the oldest reptile species, having existed on Earth for 157 million years (Joyce 2007). Shah and Tiwari (2004) reported that Nepal is settlement of 138 species of reptiles (80 serpents, 17 turtles and 41 lizards including crocodiles) that are distributed across a wide elevation range <100m to >4000m. The turtles and tortoises in Nepal are classified into three families i.e., hard-shelled Geoemydidae and Testudinidae, and soft-shelled turtles Trionychidae (Shrestha et al. 2021).

Asia contributes the highest number of species of Chelonians, comprising for up to 91%, listed on IUCN Red List, among 300 species of tortoise and turtles. “75% of the species are listed under IUCN either as CR (Critically Endangered), EN (Endangered) or VU (Vulnerable)” (Fund 2002). *Indotestudo elongata* has caused a minimum 80% drop in its populations across its range in the past 90 years, and these populations have been widely and intensely exploited for human consumption and export trade (Rahman et al. 2019). Recently, the IUCN Red List's status of the globally endangered Elongated Tortoise has been changed from Endangered to Critically Endangered, and also included in CITES' Appendix II as a member of the Testudinidae family (Rahman et al. 2019). *Indotestudo elongata* is a medium-sized tortoise. Although most individuals have straight carapace lengths (SCLs) of 280-300 mm, adults can attain SCLs of up to 360 mm (Taylor 1970, Auliya 2007). The habitat of the species includes the lowlands and foothills (above 100m above sea level. Blyth described the Elongated Tortoise as Testudo elongate for the first time in 1853. This species is also commonly referred as Yellow-headed Tortoise and is found throughout southern and southeastern Asia (Das and Gupta 2015, Rahman et al. 2019).

In Nepal *Geochelone elegans* (Schoepf), *Testudo horsjieldii* (Gray) and *Indotestudo elongata* (Blyth) (Frazier 1992) are the main three species of land tortoise reported. The third species, *Indotestudo elongata* found in Nepal, also found in Indochina region at west to Indian subcontinent (Hoogmoed and Crumly 1984). In Nepal, 17 Species of turtles are recorded, among which Elongated Tortoise (*Indotestudo elongata)* is considered as a critically endangered. Tortoises are club-footed, with a hard carapace and plastron covered in horny plates; with fingers and claws seen morphologically (Bhatt 2019). In Nepal, it is widely recorded in Terai region and rarely in midlands (Schleich and Kästle 2002). During rainy season, tortoise remains active and its distribution is high during this period, which eventually decreases during the dry season. Land turtle like *Indotestudo elongata* can be found in the woodlands of Nepal, primarily in the west and center (Aryal et al. 2010). Several vegetation types, such as open deciduous dipterocarp, semi-evergreen, as well as savannah grasslands are hostile to elongated tortoises (Sharma 1998, Schleich and Kästle 2002, Ihlow et al. 2016). In Nepal, *Indotestudo elongata* is commonly found in the forests dominated by Sal (*Shorea robusta*), bushes or bamboo groves (Schleich and Kästle 2002, Kiesl and Schleich 2016) primarily in humid climates and often close to water bodies (Rai 2020). It feeds mostly on fruits, plant flowers, foliage, mushrooms, grasses, and vegetables, as well as smaller creatures such as earthworms, snails, slugs, worms, insects, and animal feces (Sharma 1998, Schleich and Kästle 2002, Ihlow et al. 2016).

The species distribution model uses data from museum info sheet, questionnaire, and environmental factors to develop probability models within landscapes, regions, and continents (Guisan and Thuiller 2005, Gillespie et al. 2008). Environmental indicators can have an impact on a species either directly or indirectly (Guisan and Thuiller 2005). With the use of these models, researchers may better understand the factors that influence species distribution, which is crucial for altering and developing conservation strategies that are successful in both current and future climate conditions (Báez et al. 2012, Karthik et al. 2014).

1.2 Rationale of the study

In Nepal, Turtles and other reptiles were never considered a priority category (Schleich and Kästle 2002). According to Gibbons (2003), the conservation of amphibians and reptiles depends on either their accidental existence in PAs established for other purposes or individual-species action. The most endangered group of vertebrate species are amphibians and reptiles, which are also declining at a rapid rate and will go extinct if conservation efforts are not made (Shah and Tiwari 2004). Terrestrial turtle act as an important species in land ecosystems as they disperse seed and spore for many plants, trees and fungi thus maintaining ecological balance (HOSSAIN et al., 2009). In Nepal, there is a lack of information regarding the elongated tortoise's range. However, relatively few studies on their geographic distribution and status have been performed. Large mammals are the primary concern of Nepal's protected areas. The preservation of turtles and tortoises is not a particularly important issue. This results in information gap on turtle species' occurrence, habitats, and other ecological factors. (Schleich and Kästle 2002). This study provides basic information about the on the major bioclimatic parameters impacting present species distribution and helps to predict their response to future climate change.

1.3 Research Objectives

1.3.1 General Objectives

The main aim of this study was to explore the bioclimatic suitability models for current and future distribution of elongated tortoise (*Indotestudo elongata*) in Nepal.

1.3.2 Specific Objectives

- To assess the current distribution of *Indotestudo elongata* in Nepal.
- To examine the potential distribution of *Indotestudo elongata*, according to the future climate change.

2. LITERATURE REVIEW

2.1 Distribution of Elongated Tortoise

250 different species of turtles have been recorded as of late (www.reptiledatabase.org ; Nov. 2009). Over 75% of the Asian species are threatened, and at least 50% of the 200 species of fresh water turtles are critically endangered (Millennium Ecosystem Assessment; (MEa 2005). There have been 17 turtle species recorded from Nepal thus far (Shah and Tiwari 2004).

Indotestudo elongata species of medium-sized tortoise, sometimes known as the elongated tortoise, is distributed throughout the Southeast Asian continent, including Nepal. According to IUCN, it is a critically endangered species IUCN (2018). *Indotestudo elongata* has a broad geographic range that reaches from southern China through Thailand, Cambodia, and Vietnam as well as Nepal, India, Bangladesh, Bhutan, and Myanmar (Ernst et al. 1989). George R. Zug (1995) showed that this species is the only tortoise confirmed to occurred in Nepal. Shah (1995) conducted a study on histories of turtles in Nepal and discovered 14 species of turtles, including one tortoise and 13 turtles.

Aryal et al. (2010) discovered 9 *Indotestudo elongata* and 19 *Melanochelys tricarinata* in the forests, primarily in the west and central regions, including the PAs. A total of 67 turtle specimens from eight different species were identified., 3 species of *Indotestudo elongata* was observed in Kankai Mai River in Jhapa (Kharel and Chhetry 2012). Kharel and Chhetry (2014) study about some rescued turtles and their traslocation at Turtle Rescue and Conservation Center (TRCC) Five species of turtles were discovered in Sanischare, Jhapa, of which three have hard shells: *Indotestudo elongata*, *Melanochelys tricarinata*, and *Pangshura flaviventer*. The remaining two species, *Lissemys punctata* and *Nilssonia hurum*, have soft shells and have been successfully rescued and relocated to the turtle rescue centre.

One *Indotestudo elongata* during a herpetofaunal survey in Parsa National Park has been discovered from Ghodemasan Bhattarai et al. (2018). Before being released inside the park in its latter phases, two further rescued individuals of the same species were held in Amlekhgunj-Hattisar.

Four turtle species *Lissemys punctata*, two *Melanochelys tricarinata* , two *Indotestudo elongata* and one *Melanochelys trijuga*, and were found higher in areas with dense vegetation cover and sandy soils in lakes of Chitwan National Parks (CNP) (Bhattarai et al. 2017).

The presence of 16 species of turtles in the Tarai region of Nepal was confirmed at 161 study locations including wetlands, woods, and in captivity of 20 districts (Aryal and Suwal 2019). The species composition is: Bataguridae 11, Testudinedae-1 (*I. elongata*) and Trionychidae-4 (Aryal and Suwal 2019). Luitel et al. (2021) made a study at Forestry Campus Complex (FCC), Nepal and six Elongated Tortoises, *Indotestudo elongata* (Blyth 1854) were found in canopy forest, grassland and along the forest-settlement area during Visual Encounter Surveys (VES).

The spread of *Indotestudo elongata* on the larger Asian subcontinent has also been researched, in addition to Nepal. Das (2015) studied that the spread of *Indotestudo elongata* on the larger Asian subcontinent has also been researched and For instance, in India, the species can be found in the Andaman and Nicobar Islands, Assam, Meghalaya, Mizoram, and Tripura in the northeastern regions Similar to this, *Indotestudo elongata* may be found in Bangladesh's Sundarbans and Chittagong Hill Tracts (Khan 2010). Wangyal et al. (2012) found have a report of *Indotestudo elongata* individuals in Bhutan's Royal Manus National Park, although the population there is low.

2.2 Species Distribution Modeling

Species Distribution Modelling (SDM) have been widely used to refer to correlative analyses of species environmental associations and the connection between those associations and their geographic distributions (Araújo and Peterson 2012). Since last two decades, the usage of species distribution models has grown significantly, and in recent years, a number of innovative modelling methodologies have been developed (Phillips et al. 2006). Even though there are hundreds of models available, which predict distribution of various species in the world but very few work has been done in Nepal. In Nepal, the works related to distribution modeling of *Indotestudo elongata* have not done yet.

“Precipitation has been identified as a significant factor affecting turtle life-history features such as development of egg and hatchling success” (Santidrián Tomillo et al. 2015), and provision of food resources (Mondal et al. 2016). Ward (2018) studied about the habitat selection of *I. elongata* in Sakaerat biosphere reserve in Northeast Thailand and detected selection for dry dipterocarp forest and edge habitat at the landscape scale and dry evergreen forest at home range scale.

Using Maxent, the probable ranges and ecological requirements of the indigenous Bulgarian Freshwater Turtle was discovered that the two turtles, *Emys orbicularis* and *Mauremys rivulata*, are locally available and prevalent with a high degree of predictability in parts of Bulgaria (Kornilev et al. 2017).

An ecological niche model and protected area analysis was used to examine the current and future distribution of appropriate habitat for the internationally endangered wood turtle (*Glyptemys insculpta*) across its range in the northeastern United States and determined that just 5% of suitable habitat and 8% of optimal habitat are protected, with the overall area of protected suitable habitat being only 5% of the entire area of protected suitable habitat (Mothes et al. 2020).

The distribution of *Indotestudo elongata* in the Indian subcontinent is estimated using a species distribution model, which considers annual precipitation, Isothermality, and elevation as the main determinants of this species' distribution. The model predicts that the species will occur in at least 5.2 percent of the predicted area. (Khan et al. 2020).

The distribution and potential limiting factors of the European Pond Turtle (*Emys orbicularis*) was investigated across Eastern Europe using GIS modeling and a CliMond database of 55 preselected variables and the species distribution model's habitat for *E. orbicularis* was discovered (Nekrasova et al. 2021).

Ecological niche modeling was employed to predict the prospective changes in nesting beaches of green turtle (*Chelonia mydas*) in the Mediterranean based on future climatic scenarios developed with ArcGIS v10 and generated past, current, and future nesting site forecasts by analyzing 19 bioclimatic factors with Pearson Correlation Analysis and Representative Concentration Pathway scenarios (RCP2.6 and RCP8.5) (Arslan et al. 2023) .

3. MATERIALS AND METHODS

3.1 Study Area

Geographically, Nepal is situated at 26^0 to 30^0 North and 80^0 to 88^0 East, between India and China, covering an area of 147,516 km^2. According to Shrestha et al. (2013) based on the elevation, there are five regions: the Terai , Chure range, Middle Mountains , High Mountains and High Himalayas. Nepal has a subtropical monsoon climate, characterized by frequent change in temperature, precipitation, and humidity (Nayava 1975). At the local scale, the climate of Nepal is controlled by the north-south elevation gradient. The Terai is hot for most of the year, and the temperature gradually decreases as increase in altitude. Nepal experiences an average annual rainfall of 1600 mm every year and almost 80-90% of which occurs within the month of June to September. There are 14 National Parks, one wildlife reserve, six conservation areas, and one hunting reserve which contribute for country's 25% land designated as Protected Area (PA) (Central Bureau of Statistics, 2020; Ministry of Forest and Soil Conservation, 2009).

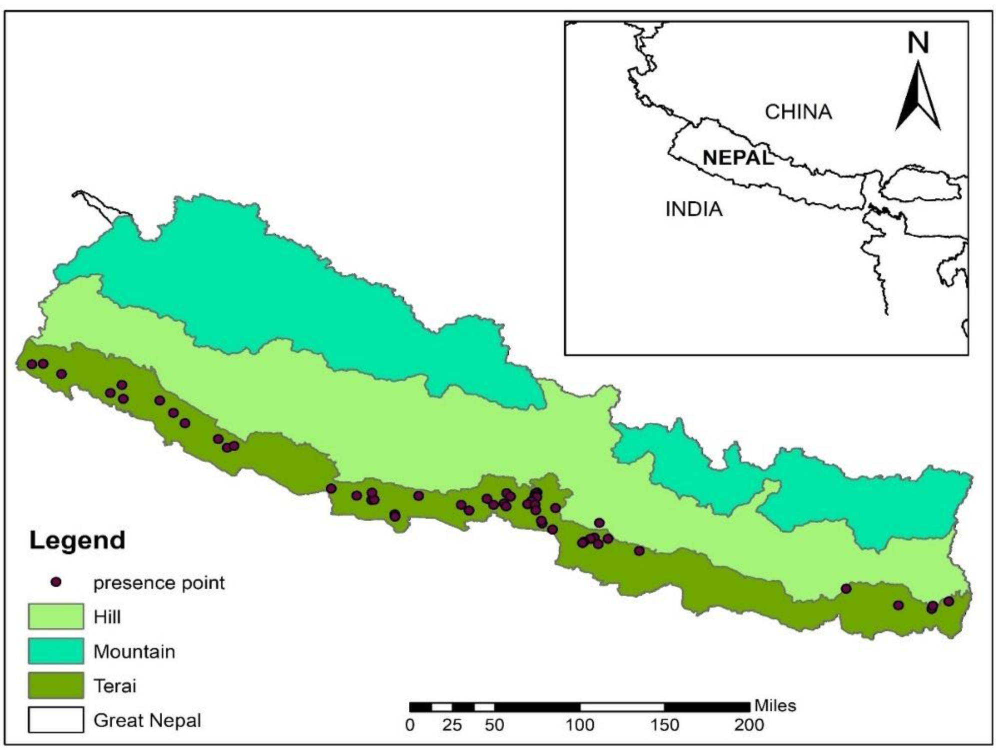


Figure 1. Study area showing geographic region and location of distribution of *I. elongata* in Nepal.

3.2 Methods

3.2.1 Species Occurrence

The presence locations of elongated tortoise were based on the field survey and opportunistic records. Incidental observations of tortoise and carapace of tortoise that were obtained during the questionnaire with the locals and within the forest area were done. During this study, there were five presence locations of elongated tortoises reported from Division Forest Office records in Kapilvastu, Rupandehi, and Nawalparasi (west). Other presence locations of elongated tortoises from different places in Nepal were collected from various published (Bista and Shah 2010, Kharel and Chhetry 2012, Khan et al. 2020, Rawat et al. 2020, Luitel et al. 2021), iNaturalist.org, GBIF (http://www.gbif.org), Reptile Database (http://www.reptile-database.org)) and unpublished sources (Baral unpublished data, Bhattarai unpublished data, Adhikari unpublished data) from the early 2010s to the late 2020s.

Altogether, 53 occurrence records (coordinates) for *Indotestudo elongata* were obtained. Each presence site within a distance of 1 km was eliminated in order to prevent spatial auto-correlation between the presence locations. A kernel density based bias file was created that was used for background point selection. SDM Toolbox v2.4 was used for spatial filtering and making bias file for background point selection (Brown 2014) which can effectively erase sampling bias for MaxEnt. There were no any removal of occurrence data, So the final occurrences coordinate of 53 entries of elongated tortoises in Nepal were taken (Annex VI) resulting in a detailed distribution map (Figure 1) that were imported into Microsoft Excel and saved as ".CSV" format which was used for further modelling.

3.2.2 Environmental Layer

Environmental layers are the pre-requisite for predicting suitable areas. A total of 19 bioclimatic variable layers (Bio1 to Bio19) (Table 1) which are more informative than other climatic variables and have been shown to be effective predictors of species distribution (Fortini et al. 2022) of spatial resolution 30 arc-second available in worldclim.org (version 2.1) (Fick and Hijmans 2017) was obtained for the period of 1970-2000 to design the species distribution models of *Indotestudo elongata* for the recent scenario. These information include physiologically important factors that include annual ranges, seasonality, and limiting constraints for the purpose of simulating species distribution (Hijmans et al. 2005). The WorldClim data sets were downloaded in "tiff" format, and in order to utilise them in MaxEnt, ArcGIS 10.8's "Raster to ASCII" function transformed them into ASCII files.

The future bioclimatic variables were based on CMIP6, obtained from WorldClim 2.1. For the future projection of climate suitability of *Indotestudo elongata* in Nepal, the datasets were GCMs (General Circulation Models) MPI-ESM1-2HR (CMIP6) projections from Worldclim 2.1 was obtained. MPI-ESM1-2HR is low-bias and high-sensitivity model with a relatively high spatial resolution compared to many other climate models (Sanderson et al. 2015) that include two climate change scenarios Shared Socio-economic Pathways (SSPs) 245 and 585 for the years 2050 and 2070 was done. By selecting these two scenarios, a wide range of possible future outcomes can be investigated, ranging from a more sustainable and climate-friendly future to a future with major negative effects from climate change (Riahi et al. 2017).

Table 1. List of bioclimatic variables derived from monthly temperature and precipitation values.

Code	**Bioclimatic Variables Name**
Bio1	Annual Mean Temperature
Bio2	Mean Diurnal Range (Mean of monthly (max temp-min temp)
Bio3	Isothermality (BIO2/BIO7) (*100)
Bio4	Temperature Seasonality (standard deviation *100)
Bio5	Max Temperature of Warmest Month
Bio6	Min Temperature of Coldest Month
Bio7	Temperature Annual Range (BIO5-BIO6)
Bio8	Mean Temperature of Wettest Quarter
Bio9	Mean Temperature of Driest Quarter
Bio10	Mean Temperature of Warmest Quarter
Bio11	Mean Temperature of Coldest Quarter
Bio12	Annual Precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality (Coefficient of Variation)
Bio16	Precipitation of Wettest Quarter
Bio17	Precipitation of Driest Quarter
Bio18	Precipitation of Warmest Quarter
Bio19	Precipitation of Coldest Quarter

For the further selection of bioclimatic variables, Pearson Correlation Coefficient of above mentioned 19 bioclimatic variables were performed using R which helps to identify and remove highly correlated variables (r > 0.75). From the pairs of variables, the significant variables that were more meaningful and simple to interpret for the study species were chosen in case of collinearity between two variables to minimize the over-fitting of the model (Wei et al. 2017). In the end, seven final sets of variables were selected to show the impacts on the potential distribution of *I. elongata* (Table 2).

Table 2. Relative contribution of the environmental variables to the Maxent model built for current climatic conditions.

Variable	**Environmental Variables**	**Percent contribution**
Bio8	Mean Temperature of Wettest Quarter	77.1
Bio5	Max Temperature of Warmest Month	8.6
Bio12	Annual Precipitation	7.4
Bio17	Precipitation of Driest Quarter	3.5
Bio14	Precipitation of Driest Month	1.5
Bio6	Min Temperature of Coldest Month	1.2
Bio3	Isothermality	0.7

3.2.3 Species Distribution Modelling

MaxEnt version 3.4.4 was used to explore the present and future distribution ranges of *Indotestudo elongata* using Species Distribution Modelling (SDM) (Phillips et al. 2004) with GCS_WGS_1984 as the Geographic Coordinate System. Maxent is frequently used to predict species distribution using presence-only data collected with inconsistent sample numbers and minor location errors (Persoons et al. 2005, Elith et al. 2011, Kramer-Schadt et al. 2013). The appropriateness value varied from 0 (unsuitable) to 1 (suitable), and Maxent was run with seven variables included, ten repetitions, and 10,000 randomly selected background locations from covariate grids. To evaluate model performance and produce habitat suitability maps, 10 repetitions of each model scenario were carried out using a subsample of 30 randomly selected test data.

3.2.4 Model Evaluation

By contrasting the model's capacity to forecast with random predictions, higher Area Under Curve (AUC) values of the receiver operating characteristic ROC statistics values were utilised to assess the model's predictive performance (Figure 2). If the AUC value is closer to 1.0, the predicting model outperforms the random prediction and suggests high probability appropriateness for AUC values > 0.70 towards 1.0 (DeLeo 1993). The maximum test sensitivity plus specificity logistic threshold strategy was proven to be suitable for the conversion of the continuous predicted output probability to binary response to presence or absence (Liu et al. 2005). To evaluate the impact of variables, the Jackknife test and variable contribution table was implemented in MaxEnt (Phillips et al. 2004). The method compares the gain of the model using a single variable, without the variable, and with all other variables in order to forecast the significance of one particular variable (Torres et al. 2010). Using the logistic output, MaxEnt was used to create a continuous map with an estimated chance of existence between 0 and 1.

4. RESULTS

4.1 Model Performance and Contribution of Environmental Variables

The ROC curve describes the relationship between sensitivity and false positive predictions at various decision thresholds. The modelling of species was found using the ROC area under the curve (AUC) data. During present investigation, the AUC showed that the Maxent model provided the potential favorable habitat for *Indotestudo elongata* with satisfactory statistical accuracy for the replicate runs, with an AUC value of 0.924 and the standard deviation of 0.019 in the given study (Figure 2).

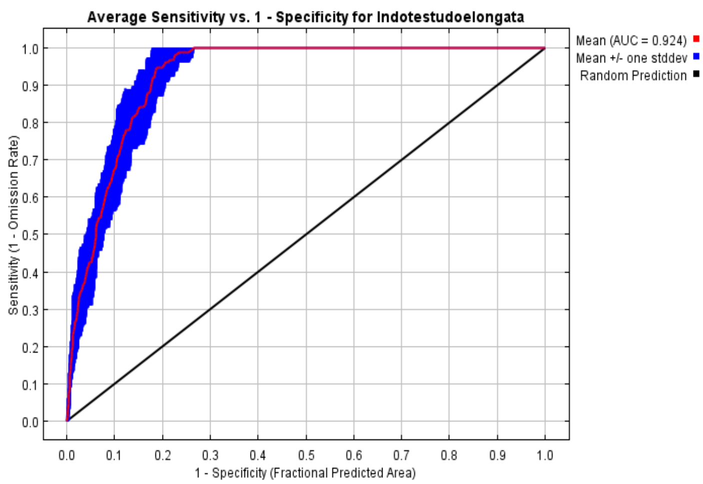
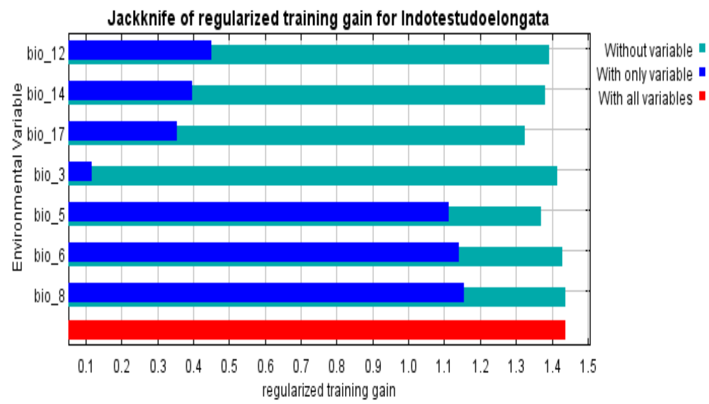


Figure 2. Receiver operating characteristic (ROC) average area under curve (AUC) for 10 replicates MaxEnt run.

The Pearson correlation coefficient was used to filtered 19 climatic variables and finally seven variables were used to frame the final model remained. The percentage contribution of bioclimatic variables in the distribution of *I. elongata* are shown in Table 2. Out of seven predictor variables used for modelling, each individual variable has a different contribution value to the model prediction, where mean temperature of wettest quarter (Bio8) contributed the most (77.1%) followed by 8.6% for Bio5 (maximum temperature of warmest month), 7.4% for Bio12 (annual precipitation) were the main factors for its distribution. Isothermality (Bio3) had the lowest contribution (0.7%) (Table 2).

The important variables balancing the *I. elongata* distribution were identified, along with their contribution rates, using the Jackknife study findings and the relative contributions of environmental variables to the model created by Maxent iterative computing. Based on the results of the jackknife tests in Maxent, it was determined that only three out of seven environmental factors were significant, with Bio8 having the highest gain and AUC when utilized alone, followed by Bio5 and Bio6 (Figure 3).

A. Jackknife of regularized training gain



B. Jackknife of AUC

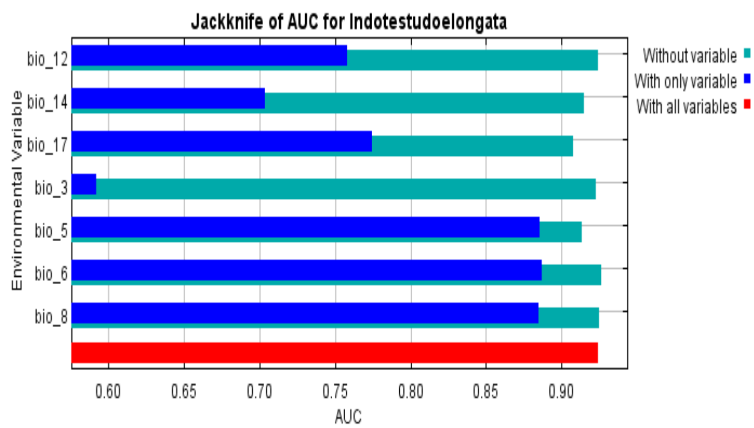


Figure 3. Results of jackknife test of relative importance of predictor variables for *Indotestudo elongata* for the current distribution. (A) Jackknife of regularized training gain. (B) Jackknife of AUC. Predictors used: Bio3 Isothermality; Bio5 Maximum Temperature of Warmest Month; Bio6 Minimum temperature of coldest month; Bio8 Mean Temperature of Wettest Quarter; Bio_12 Annual precipitation; Bio_14 Precipitation of driest month; Bio_17 Precipitation of driest quarter.

Response curves display the association between probability of occurrence for a species and each bioclimatic variable. The species response curve explains the link between bioclimatic conditions and the likelihood of a species' existence. This illustrates the impacts of each variable on the Maxent prediction. The x-axis in the response curves shows the range of environmental variable values, while the y-axis reflects the likelihood of occurrence on a scale from 0 (low probability) to 1 (high probability). The response curves of Maxent model of *I. elongata* for current and future emission scenario were represented (Annex I-V).

According to the Average Temperature of Wettest Quarter (Bio8) response curves, the area between 25°C and 30°C was the best habitat for the species. As the temperature rose or fell from this ideal, the climatic suitability deteriorated significantly. The temperature range that this species could tolerate in its ideal habitat was between 20°C and 35°C (Figure 4).

According to the Maximum Temperature of Warmest Month (Bio5) response curves, the region between 35°C and 40°C was the best habitat for the species. As the temperature rose or fell from this ideal, the climatic suitability deteriorated significantly. The temperature range that this species could tolerate in its ideal habitat was between 25^0C and 45^0C (Figure 4).

According to the response curves for mean annual precipitation (Bio12), the area between 1800 and 2300 mm was the best habitat for the species. As precipitation increased or fell from this optimum, the habitat's suitability deteriorated sharply. The acceptable range of precipitation in the habitat that was favorable for this species was between 1000mm and 3000mm (Figure 4).

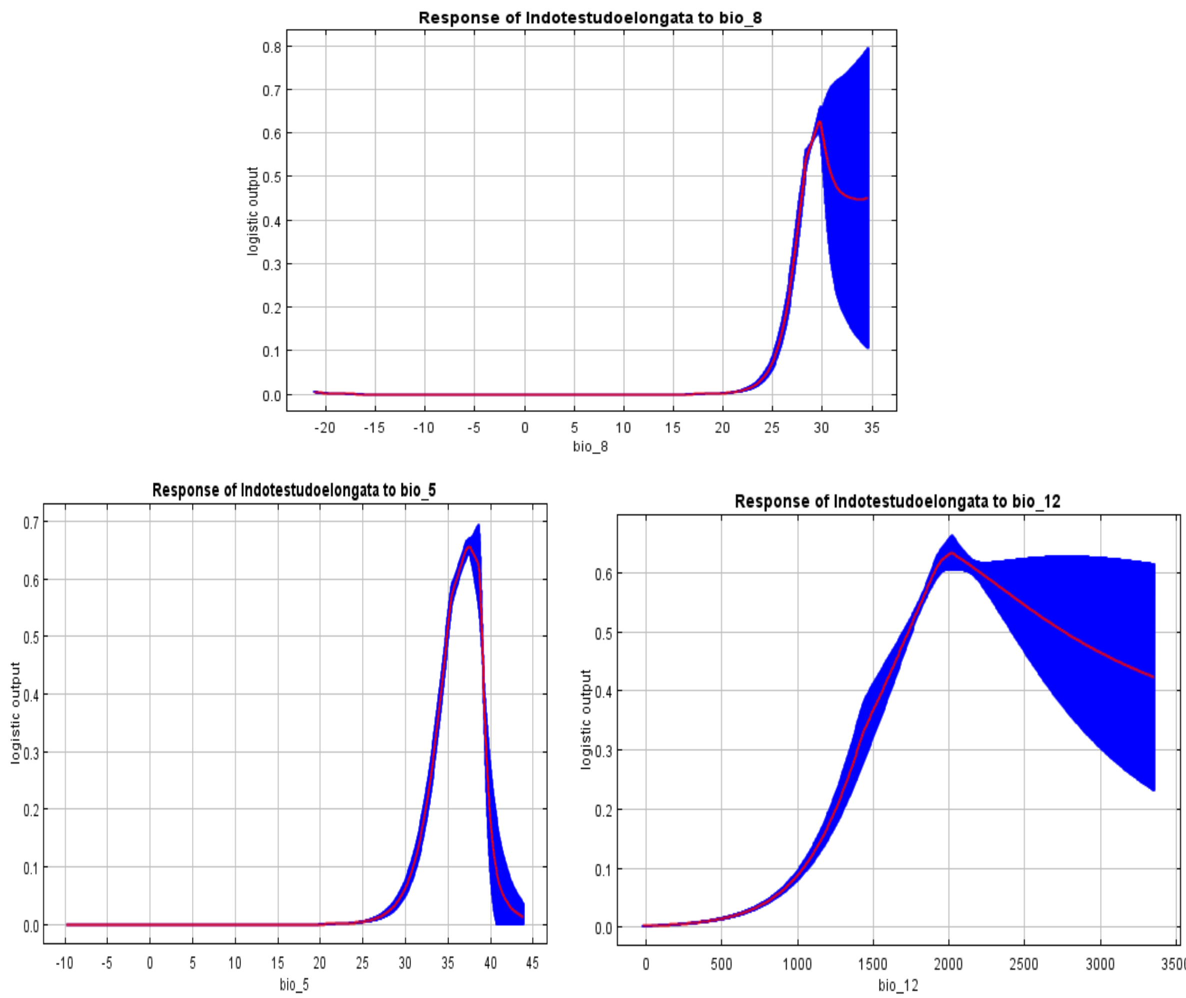


Figure 4. Principal factors for the distribution of the *I. elongata* in Nepal.

Based on 53 distribution points and 7 climate variables for *Indotestudo elongata*, a climate suitability map was created and reclassified into highly suitable (> 0.464), moderately suitable (0.113-0.464), and unsuitable (<0.113) climate areas for *I. elongata* in Nepal (Figure 5). This classification was based on the 10th percentile presence threshold (0.464) (Slater and Michael 2012). This model estimates that approximately one-fourth (24.42%) of the country is currently climatically favorable for the distribution of *I. elongata* (10.13% moderately suitable, and 14.19% highly suitable), whereas the remaining 75.57% is not favorable.

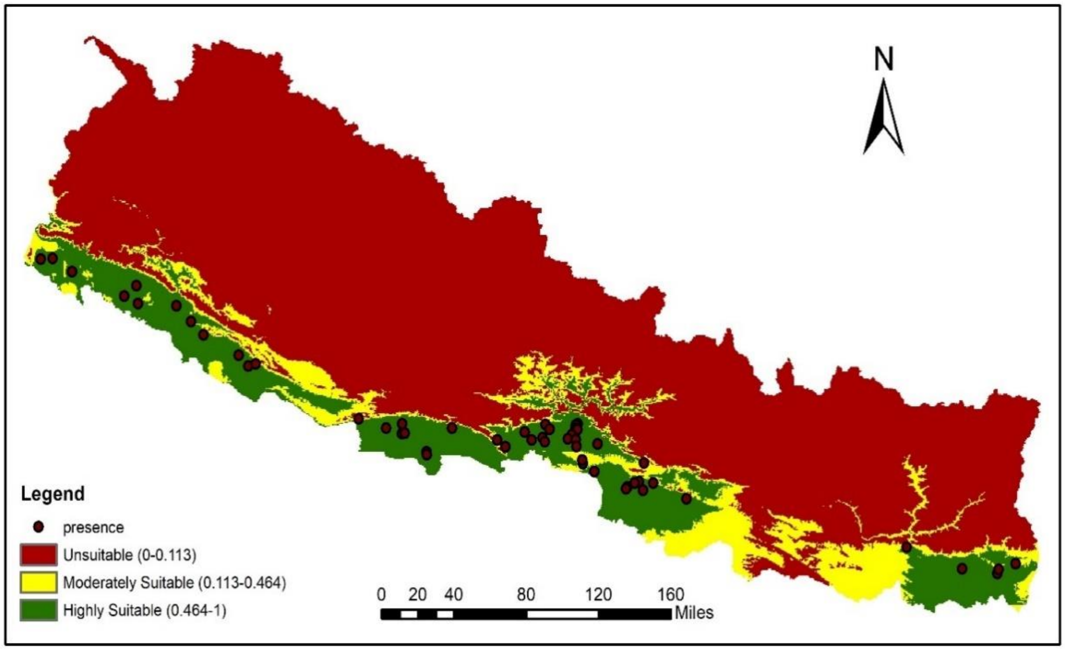


Figure 5. Spatial distribution of present day climatically suitable areas of *I. elongata* in Nepal obtained from MaxEnt modelling approach.

4.2 Bioclimatic Suitability for *Indotestudo elongata* Current and Future

The four future MaxEnt models have an AUC value ranging from 0.926 - 0.939 (Table 3). The highest percentage of contribution is Mean Temperature of Wettest Quarter (Bio8) followed by highest temperature of warmest month (Bio5) and annual precipitation (Bio12) for all four maxent models. Similarly, Maximum Temperature of Warmest Month (Bio5) has the maximum permutation of importance for both the present and future models. The jackknife shows some difference in the outcomes for the current and future models where Mean Temperature of Wettest Quarter (Bio8) has the maximum training gain when used in isolation for current model while Minimum temperature of coldest month (Bio6) has the highest training gain for future model when used in isolation (Annex VI). The prediction accuracy details of the individual models are given in Table 3.

Table 3. Prediction accuracy with important variables

S. N			AUC	Percentage Contribution		Permutation importance		Jackknife training gain	
				Variable	Value	Variable	Value	In Isolation	In absence
1	Current		0.924	Bio8	77.1	Bio5	50.6	Bio8	Bio12
2	2050	SSPs 245	0.926	Bio8	71.8	Bio5	35.7	Bio6	Bio12
		SSPs 585	0.939	Bio8	74.8	Bio5	29.8	Bio6	Bio12
3	2070	SSPs 245	0.957	Bio8	75.3	Bio5	35.8	Bio6	Bio12
		SSPs 585	0.932	Bio8	75.7	Bio5	37.7	Bio6	Bio12

The climatic suitability of the current distribution is demonstrated in Figure 5 and Figure 7 shows the climatic suitability for the years 2050 and 2070 under various emission scenarios. Under both SSPs, the climatically suitable area of distribution of *I. elongata* would increase in the 2050s and 2070s, however the increment amount would depend on the time period and emission scenario (Figure 6). In comparison to the medium emission scenarios (SSPs245), the overall amount of climatically suitable areas would grow under the extremely high emission scenarios (SSPs585). Under the SSPs585, the proportion of moderately suitable places would rise, while the fraction of highly appropriate areas would fall in 2050. SSPs585, however, would result in a drop in the number of moderately suitable places and an increase in highly suitable areas by 2070. However, for the years 2050 and 2070, the proportions of moderately appropriate places would stay the same while those that are extremely suitable would rise, according to the SSPs245 emission scenario.

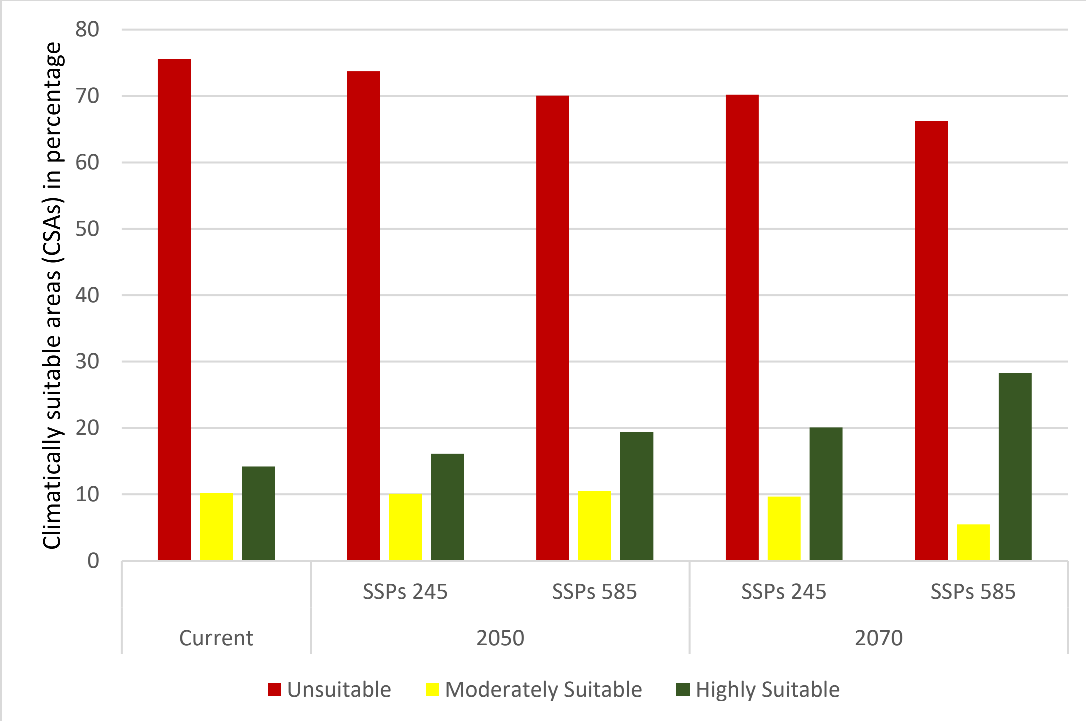


Figure 6. The predicted distribution of areas in Nepal climatically suitable for distribution of *I. elongata* at present and in the future. Red yellow and green bars represent unsuitable, moderately suitable and highly suitable area, respectively.

Currently, highly suitable area for *I. elongata* was approximately 27,822km^2 (14.19%), moderately suitable area 20,071 km^2 (10.23%) and unsuitable area for *I. elongata* suitability was approximately 148,160km^2 (75.57%) (Table 4).

Table 4. Predicted suitable area in km^2 for *I. elongata* habitat suitability under current and future climate.

Suitability	Current	%	SSPs 245 2050	%	SSPs 245 2070	%	SSPs 585 2050	%	SSPs 585 2070	%
Unsuitable	148160	75.57	144566	73.72	137668	70.22	137331	70.05	129853	66.23
Moderately Suitable	20071	10.23	19873	10.13	18986	9.69	20733	10.57	10747	5.48
Highly Suitable	27822	14.19	31614	16.12	39399	20.09	37989	19.37	55473	28.28

(Note: The area calculated is climatically suitable projection but not actual occupying area.)

According to the model, the species' distribution range could expand by a maximum of around 5% (37,989 km^2) and 15% (55,473km^2) under SSP5–8.5 scenarios in 2050 and 2070 respectively.

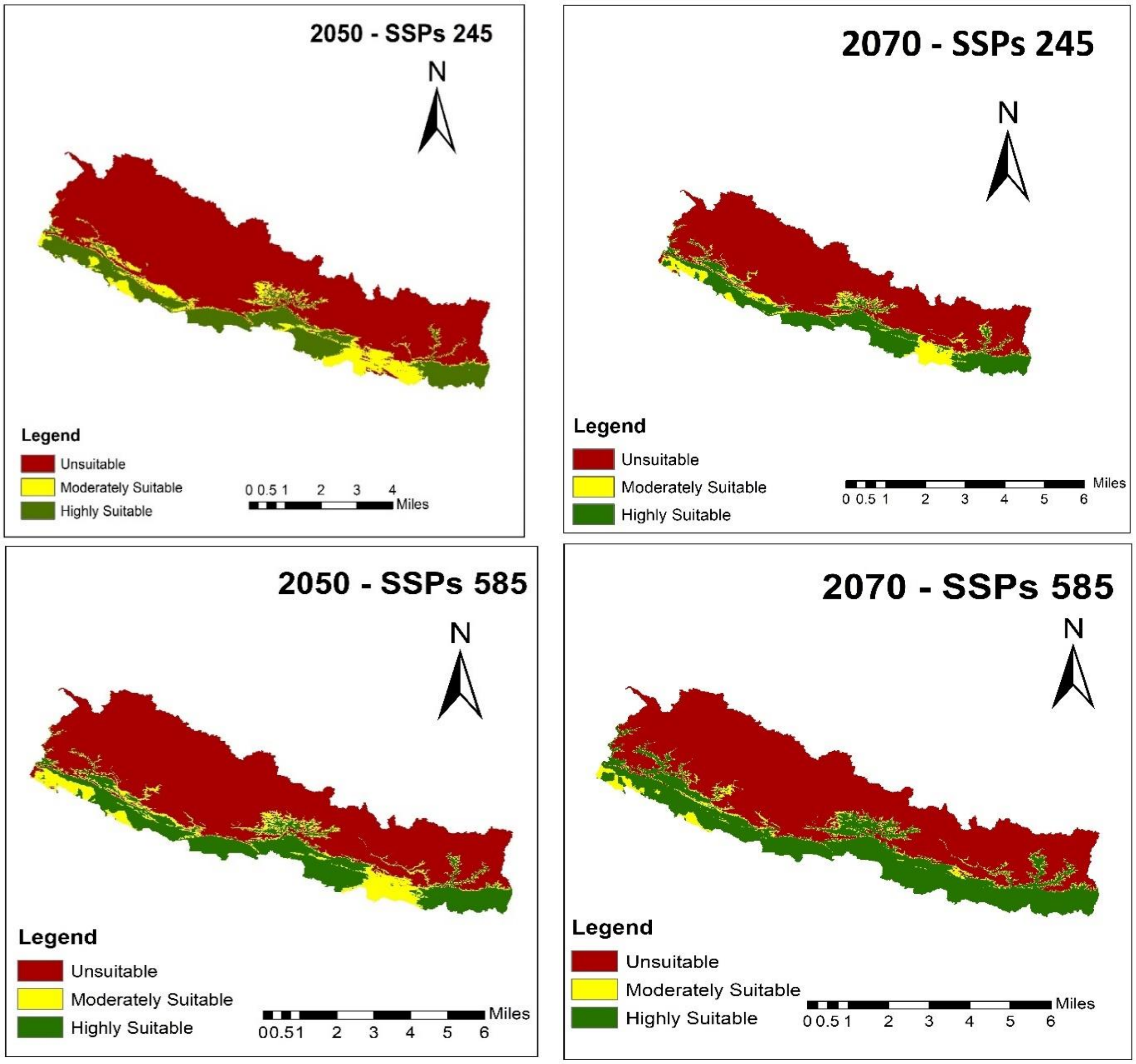


Figure 7. Spatial distribution of future climatically suitable areas of *I. elongata* in Nepal in 2050s and 2070s under the various emission scenarios.

5. DISCUSSION

The present study illustrates the distribution of habitat of *Indotestudo elongata* in current and future climate scenarios. In this study, we used the discovered occurrence locations and a list of bioclimatic factors based on MaxEnt species distribution modeling approach to map the current and future climatically suitable areas of *I. elongata* in Nepal. Maxent (Fourcade et al. 2014) has been the most extensively utilized since it can quickly and readily provide detailed findings on a target species current and past occurrences. MaxEnt generates output with a value ranging from 0 (least suitable) to 1 (most suitable) by predicting likely distributions using presence-only data and a set of climatic grids (Phillips et al. 2006). Then, we calculated the predicted suitable area in km^2 for *I. elongata* habitat suitability under current and future climate. Under the current and future scenarios, potential distribution of *I.elongata* for the all aspects of suitability (highly suitable, moderately and unsuitable) were done. The findings for the current scenario are supported by the other publications like, (Swets 1988) classified model as failing (0.5-0.6), terrible (0.6-0.7), reasonable (0.7-0.8), good (0.8-0.9), or excellent (0.9-1), On the basis of AUC value. Similarly, in current study, climatically suitability was reclassified into highly suitable (> 0.464), moderately suitable (0.113-0.464), and unsuitable (<0.113) therefore, as a result only about 24.42% (10.23% moderately suitable, and 14.19% highly suitable) of the total study area was determined to be suitable habitat for *I. elongata* with high AUC (0.924) as in the study of *H. darjeelingense*, the suitable area was observed to be 13.21% of the total study area with the AUC value of 0.986 (high) (Boral and Moktan 2022).

The findings of this study demonstrated that *I. elongata* observed distribution in Nepal was successfully represented by the locations currently expected to have suitable climates. The Terai region of Nepal was identified by our model as a climatically favorable place for the distribution of *I. elongata*. The potential distribution of *I. elongata* was modeled in this study, and how it is affected by present and future climatic conditions was projected. Their occurrences and the current scenario's potential distribution region overlap each other (Figure 5). The average test AUC for red panda throughout the 10 duplicate runs was 0.920, with a standard deviation of 0.022, demonstrating Maxent's superior predictive capacity (Su et al. 2021). Similarly, the current model was well-performing, with high AUC (0.924) and the standard deviation (0.019) suggesting it is reliable (Ferson et al. 2000) as models with predictive values > 0.9 are considered outstanding (Hosmer et al. 2000). The current model is successfully verified using AUC and offers a better insight of the probable distribution of *I. elongata.*

The optimum temperature for slider activity and for embryo development is 25–26 ° C (Cagle 1950, Morreale and Gibbons 1986). Our model also approximately represents these requirements, and maximum suitability for elongated tortoise was the area ranging between 25℃ and 30℃. Among the 7 variables considered for predicting the climatic suitability of *I. elongata*, Mean Temperature of Wettest Quarter (Bio8) was the major driver of its distribution in Nepal. Moreover, maximum temperature of warmest month (Bio5) and annual precipitation (Bio12) also contributed to its distribution. Meanwhile, Isothermality (Bio3) had the lowest contribution to its distribution as in the study of Pike (2013) where, distribution of six sea turtle species was impacted by the maximum temperature of the warmest month, as well as by Isothermality in five of them. After removing auto-correlated features, MaxEnt discovered that two temperature variables (Bio8 and Bio5) and two precipitation factors (Bio12 and Bio17) contributed 95% more to the current distribution of *I. elongata*. The environments where *I. elongata* is likely to be found were mostly defined by temperature and precipitation as in the study done by Santidrián Tomillo et al. (2015), where precipitation has been identified as a significant factor affecting turtle life-history features such as egg development and hatchling success. It was found that western, mid-western and eastern regions with mean temperature ranging between 25℃ and 30℃ have a higher chance of high habitat suitability in natural condition. The lowland terai regions of Bagmati, Lumbini and Sudhur Paschim province represent more than 75% of total suitable habitat for *I. elongata* in Nepal (Annex VI). In summary, compared with the current conditions, climate change in the future may have a positive impact on highly suitable area that will increase suitable area, especially in Madhesh province (Figure 7).

Assessing the effects of climate change on species distribution is difficult due to the uncertainty of the future climate (Xiao et al. 2018). Numerous studies in the past demonstrated that ecosystems and species would suffer as a result of global warming (Thomas et al. 2004). This study established the current and future spatial limits of *I. elongata* climatic suitability in Nepal. As a result, this study provides critical baseline information required for monitoring the conservation methods of *I. elongata*. Under the future scenarios, classification based on the distribution of *I. elongata* for the highly suitable, moderately suitable and unsuitable area was done. In the future model prediction, climatically suitable area for *I. elongata* would be approximately double as compared to current distribution. Under both SSPs, the climatically suitable area of distribution of *I. elongata* would increase in the 2050s and 2070s.Under, High emission scenarios (SSPs585), the observation directs for the increase in larger amount in climatically suitable compared to the medium emission scenarios (SSPs245). Moderately appropriate regions becoming highly suitable places suggests that the spread of *I. elongata* there may grow in the future. The number of moderately appropriate places would, however, decline under SSPs585, while the percentage of very suitable areas would rise to 28.28% in 2070 (Table 4). As in the study by Zhao et al. (2021), under the high emission scenario SSP585, there are adverse climate impacts in 2070 that identify the areas that can be used for expanding distribution, while the newly increased suitable areas with great potential distribution are expected to be approximately 90% continuous from the east to the west of Terai region in 2070s (Figure 7).

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, using a MaxEnt species distribution modelling technique, this study evaluated *Indotestudo elongata* climatic suitability under present and projected climatic scenarios. The Terai region was selected as a climatically favorable environment for the species, and the study indicated that just 24.42% of the total area of Nepal was assessed to be a suitable habitat for *I. elongata*. While temperature and precipitation both had a significant influence on identifying the likely habitats for *I. elongata* spread in Nepal. According to the study, moderately appropriate places will eventually become highly suitable areas, expanding the range of *I. elongata* climate-friendly habitat. However, in 2070, the fraction of moderately appropriate places would decline and the proportion of highly suitable areas would rise under high emission scenarios. This study offers vital baseline data necessary for tracking *I. elongata* conservation efforts. The results are confirmed by AUC, showing that the current projected climate-suitable regions successfully reflected the actual distribution of *I. elongata* in Nepal. In order to develop successful conservation measures and track the range of *I. elongata* in the face of anticipated climate change, policymakers and conservationists would benefit greatly from the knowledge provided by this study.

6.2 Recommendations

- Species distribution models perform better with a large number of occurrences points, resulting in a more accurate prediction. The study does, however, have several drawbacks, such as a lack of occurrence data, which would have resulted in an underestimate of the climatically suitable areas. To improve the precision of the findings, future research should concentrate on gathering more occurrence data.
- The distribution of *I. elongata* may be impacted by a variety of variables, including habitat fragmentation, changes in land use, and human activities, which were not taken into account in this study. Therefore, future studies should take these aspects into account to have a more thorough picture of *I. elongata* distribution in Nepal.

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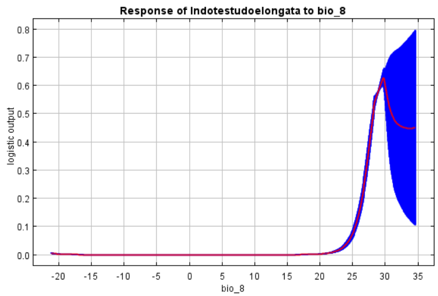
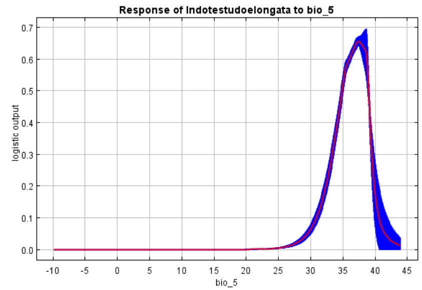
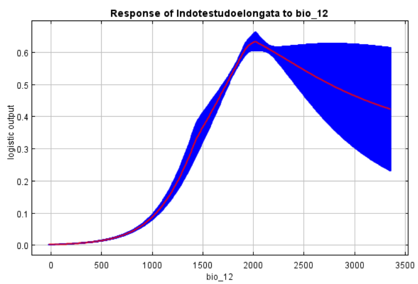
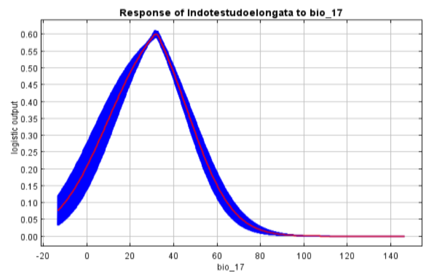
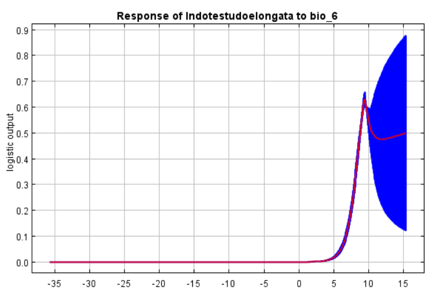
Annex I: Response curves of predictor variables for current senario

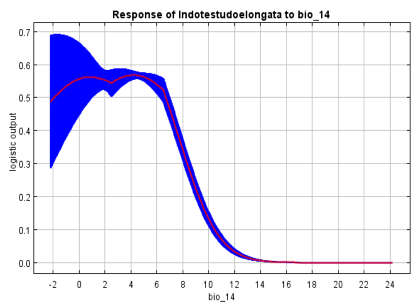


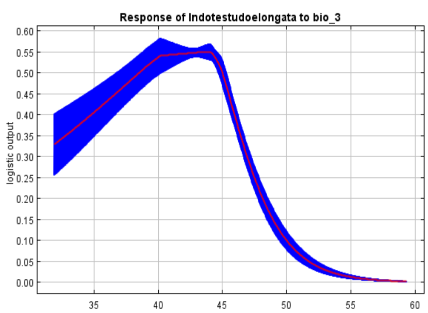




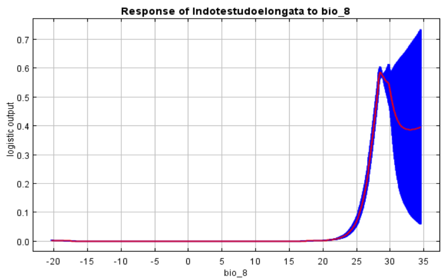


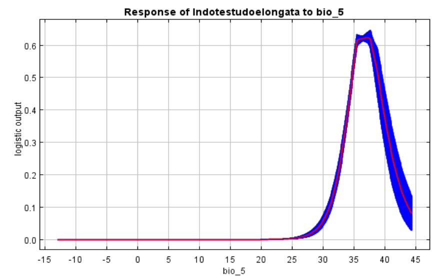


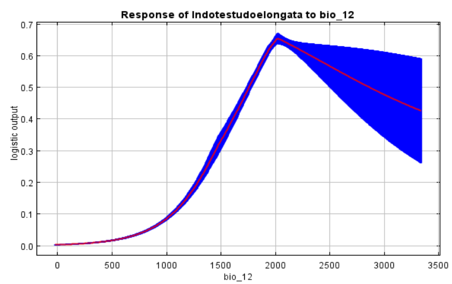


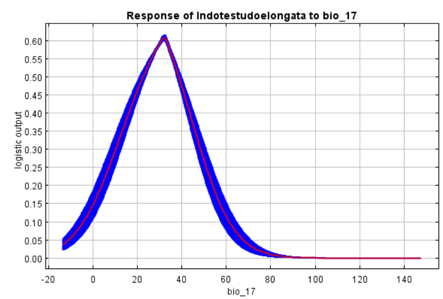


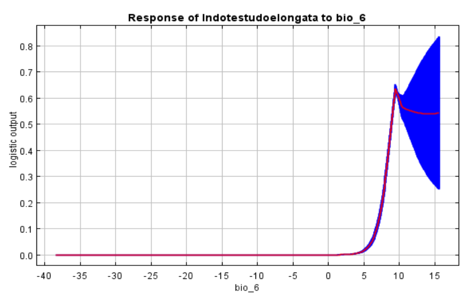
Annex II: Response curves of predictor variables for SSPs 245 (2050)

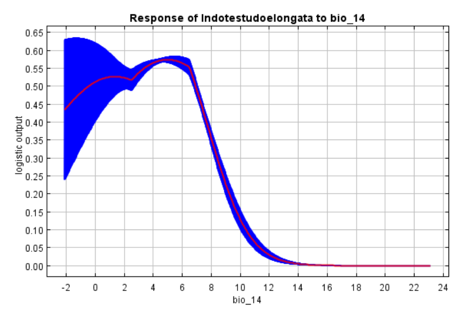


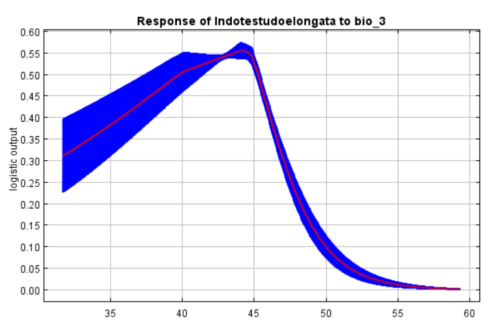




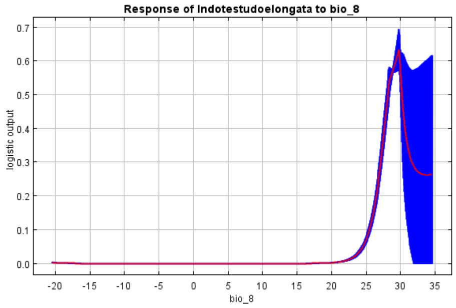


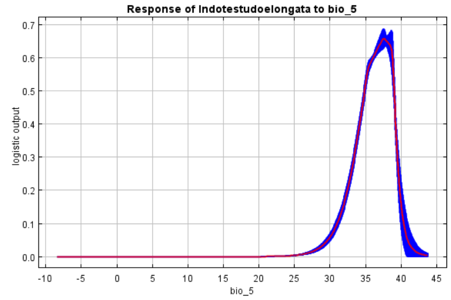


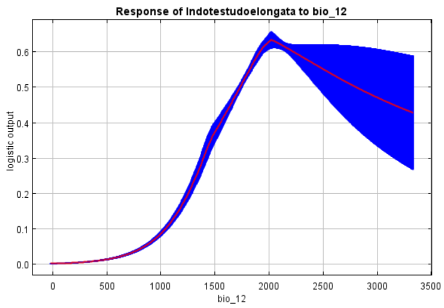


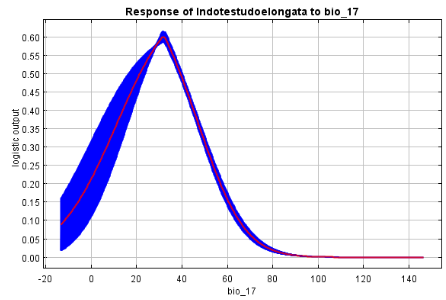


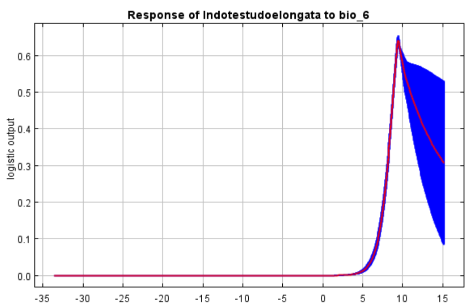
Annex III: Response curves of predictor variables for SSPs 245 (2070)

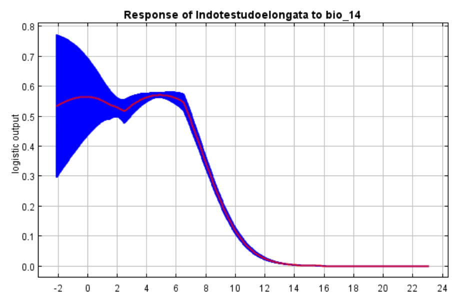


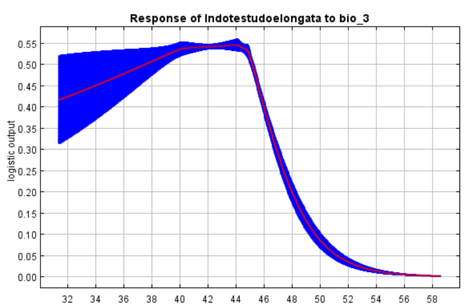




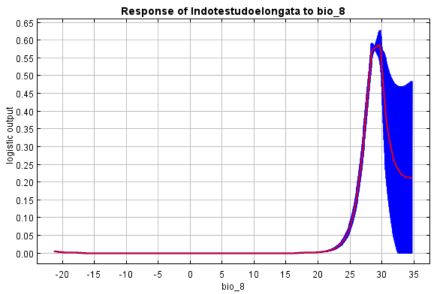


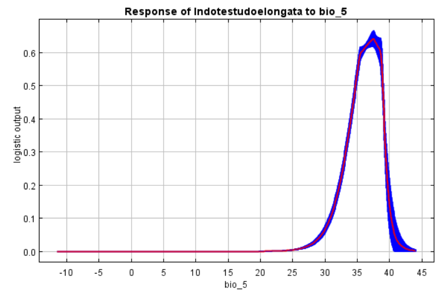


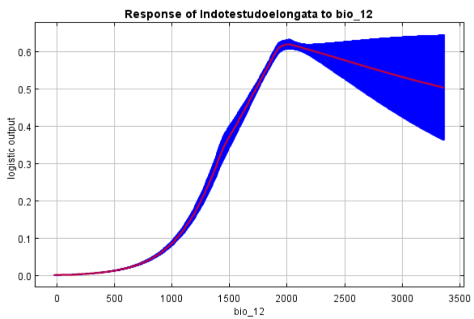


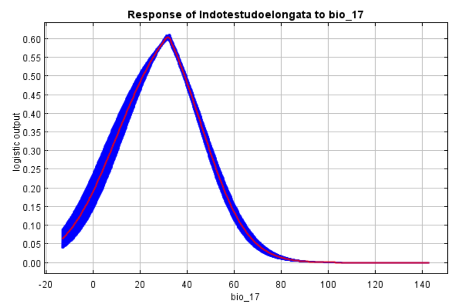


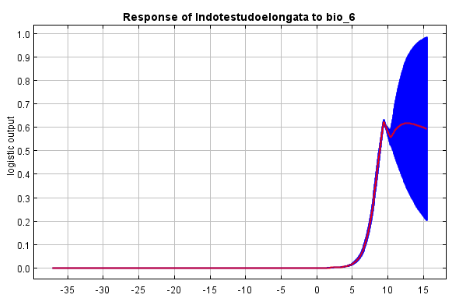
Annex IV: Response curves of predictor variables for SSPs 585 (2050)

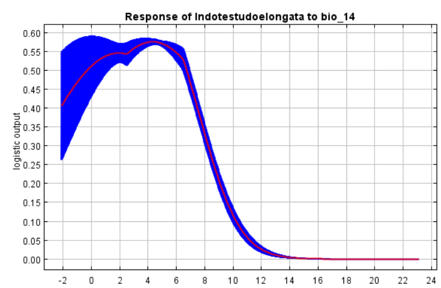


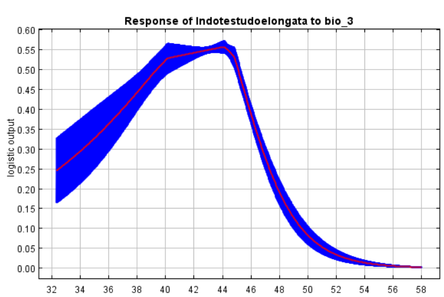




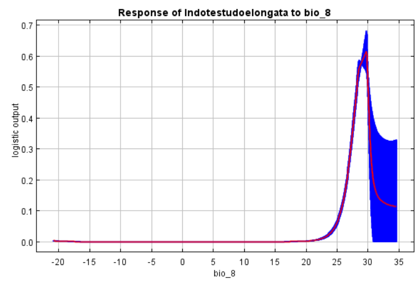


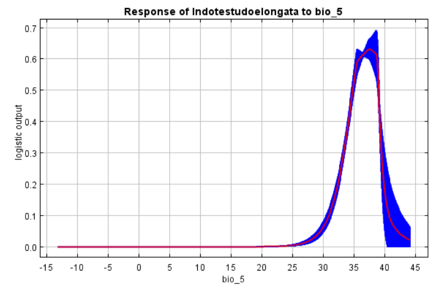


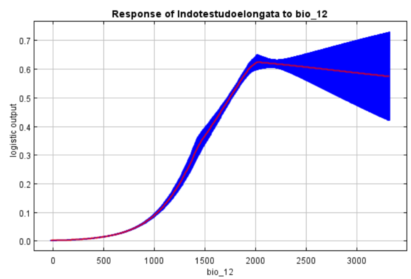


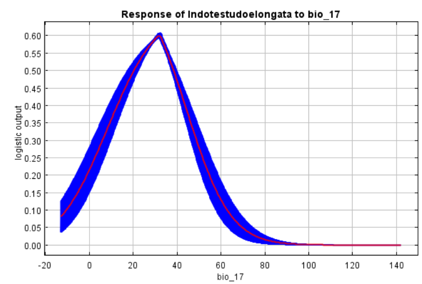


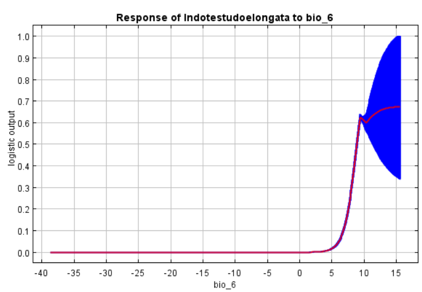
Annex V: Response curves of predictor variables for SSPs 585 (2070)

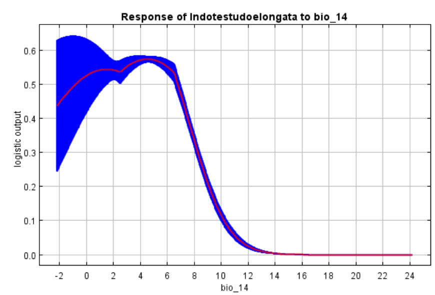


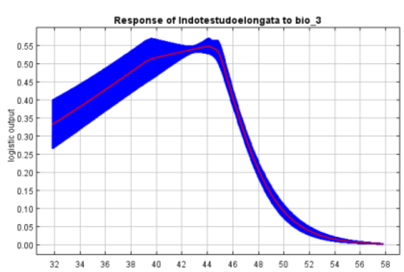




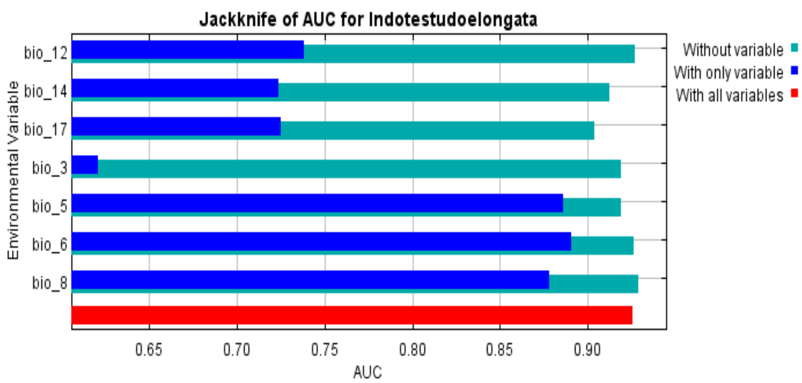




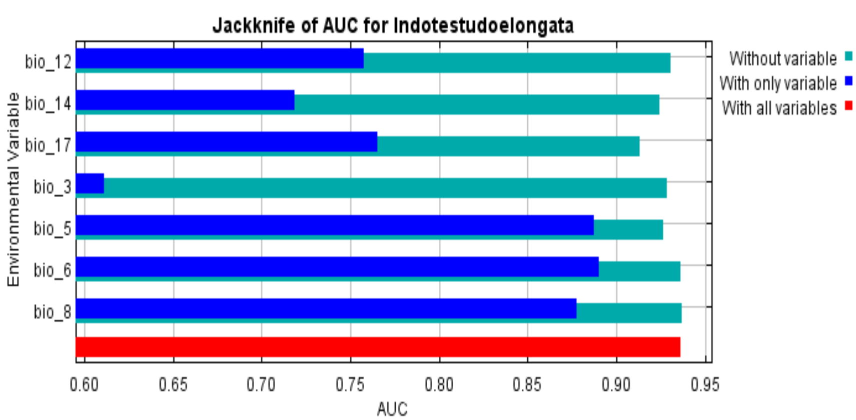




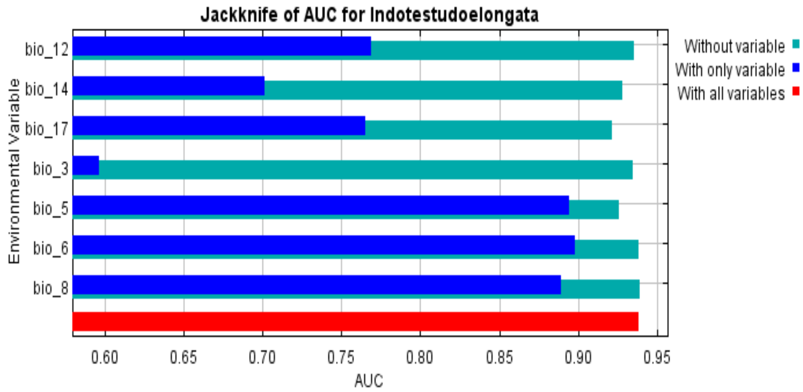
Annex VI: Jackknife of AUC for *Indotestudo elongata* for different future emission senario



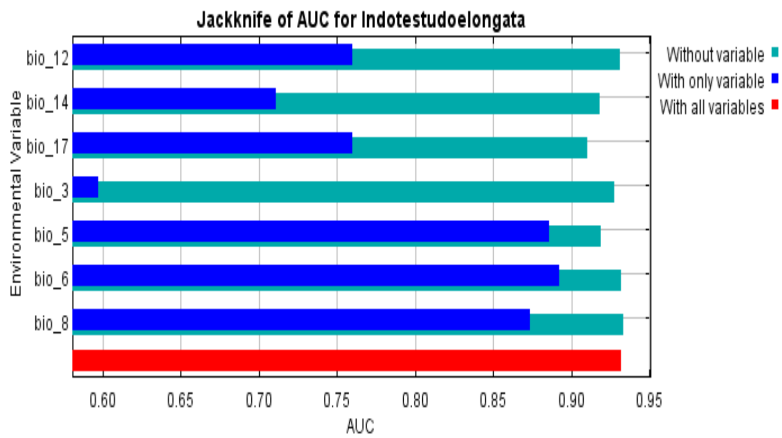
Jackknife of AUC for SSPs 245 (2050)



Jackknife of AUC for SSPs 245 (2070)



Jackknife of AUC for SSPs 585 (2050)



Jackknife of AUC for SSPs 585 (2070)

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Annex VII: Occurrence records of Elongated Tortoises (*Indotestudo elongata*) from different provinces of Nepal

S.N.	District	Province	Occurrence Point	Sources
1.	Jhapa, Koshi	Koshi	6	(Chhetry 2010, Kharel and Chhetry 2012)
2.	Chitwan and Nawalpur	Bagmati	13	(Bhattarai Unpublished data; Adhikari Unpublished data)
3.	Hetauda	Bagmati	6	(Luitel et al. 2021)
4.	Bara, Parsa	Madesh	4	(Kharel and Chhetry 2014, Bhattarai et al. 2018, Khan et al. 2020)
5.	Kanchanpur, Kailali	Sudhur Pashchim	7	(Bista and Shah 2010, Rawat et al. 2020)
7.	Jhapa	Koshi	1	GBIF database
8.	Chitwan, Kathmandu and Lalitpur	Bagmati	4	GBIF database
9.	Kapilvastu, Rupandehi, and Nawalparasi (west)	Lumbini	5	Division Forest records
10.	Dang, Banke and Bardiya	Lumbini	7	(Bhattarai Unpublished data; Adhikari Unpublished data).

नेपाल सरकार
वन तथा वातावरण मन्त्रालय
राष्ट्रिय निकुञ्ज तथा वन्यजन्तु संरक्षण विभाग

फोन नं. : ४२२०८५०
: ४२२०९१२
: ४२२७९२६
फ्याक्स नं. : ४२२७६७५

पत्र संख्या : - 068/80/968 .... इकोलोजी .... शाखा)
चलानी नं. : - 2256

पो.ब. नं. - ८६०
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मितिः २०७९/११/१७

विषयः अध्ययन-अनुसन्धान अनुमति सम्बन्धमा ।

श्री पर्सा राष्ट्रिय निकुञ्ज कार्यालय, आधाभार, बारा
श्री चितवन राष्ट्रिय निकुञ्ज कार्यालय, कसरा, चितवन
श्री बर्दिया राष्ट्रिय निकुञ्ज कार्यालय, ठाकुरद्वारा, बर्दिया
श्री शुक्लाफाँटा राष्ट्रिय निकुञ्ज कार्यालय, मझगाँउ, कञ्चनपुर ।

प्रस्तुत विषयमा तहाँ निकुञ्ज क्षेत्रहरुमा निम्नानुसारको अध्ययन अनुसन्धानको अनुमति प्रदान गरिएको व्यहोरा आदेशानुसार अनुरोध छ ।

अनुसन्धानकर्ताको नाम	अनिता पाण्डेय			
ठेगाना	वेलवास, बुटवल	इमेल : anitapandey2052@gmail.com		फोन नं: ९८६०२३५२१५
सम्वद्ध संस्था	Central Department of Zoology, Kirtipur, Kathmandu, Nepal			
अनुसन्धानको प्रकृति	व्यक्तिगत			
पद	विद्यार्थी			
अनुसन्धानको तह	स्नाकोत्तर			
अनुसन्धानको शीर्षक	**Distribution and Conservation Threats of Elongated Tortoise (*Indotestudo elongata*) in Nepal**			
अनुसन्धान विधि	Direct Observation, Field Survey, Structured and semi-structured interview, Questionnaire Survey		नमूना संकलन	नमूना परिक्षण कहाँ गर्ने
			नगर्ने	
अनुसन्धानको अवधि	२ मार्च २०२३ देखि ३० मे २०२३ सम्म			

शर्त :

१. अनुसन्धानकर्ताले राष्ट्रिय निकुञ्ज तथा वन्यजन्तु संरक्षण ऐन, २०२९ र नियमावली, २०३० तथा मातहतका सबै नियमावलीहरुको पूर्ण पालना गर्नु पर्नेछ ।
२. अनुसन्धानकर्ताले आफ्नो अनुसन्धानको प्रस्ताव सम्बन्धित निकुञ्ज कार्यालयमा समेत पेश गर्नु पर्नेछ ।
३. अध्ययन अनुसन्धान गर्दा सम्बन्धित निकुञ्ज कार्यालयसँग समन्वय गरी गर्नु पर्नेछ ।
४. अनुसन्धानकर्ताले अनुसन्धान समाप्त भएपछि प्राप्त तथ्यांक, एक प्रति कागजी प्रतिवेदन र एक प्रति इलोक्ट्रोनिक प्रतिवेदन यस विभाग र सम्बन्धित निकुञ्ज कार्यालयमा बुझाउनु पर्नेछ ।
५. अनुसन्धानकर्ताले नतिजाहरु प्रकाशित गर्दा अनुसन्धानमा संलग्न यस विभाग र अन्तरगतका कर्मचारीको योगदानको आधारमा सहलेखकको रुपमा समावेश गराउनु पर्नेछ ।
६. तोकिएका शर्तहरुको पालना नगरेमा विभागले कुनै पनि समयमा अनुमतिपत्र रद्द गर्न सक्नेछ ।

(प्रकाश शाह)
सहायक इकोलोजिष्ट

बोधार्थः
श्री अनिता पाण्डेयः सम्बन्धित निकुञ्ज कार्यालयसंग समन्वय गरी अध्ययन अनुसन्धान गर्नु हुन ।

नेपाल सरकार
वन तथा वातावरण मन्त्रालय
वन तथा भू-संरक्षण विभाग

फोन नं. ४-२२७५७४, ४-२२०३०३
फ्याक्स: ४-२२७३७४

(कृपया पत्रोत्तरमा प्राप्त पत्र संख्या र मिति उल्लख गर्नुहोला ।
बबरमहल, काठमाडौं, नेपाल

प्राप्त पत्र संख्या र मितिः-
पत्र संख्याः- 069/80
च. नं.:- 922

मिति : २०७९/११/१६

विषयः अनुसन्धान अनुमति सम्वन्धमा ।

श्री अनिता पाण्डे,
बुटवल, नेपाल ।

प्रस्तुत विषयमा Central Department of Zoology ,Tribhuvan University, Kirtipur Kathmandu मा M.sc. 4th Semester मा अध्ययनरत तपाईले "Distribution and Conservation Threats of Elongated Tortoise(*Indotestudo elongata*) in Nepal" को विषयमा अध्ययन अनुसन्धानका लागि अध्ययन अनुमति उपलब्ध गराइदिनु हुन भनि मिति २०७९/11/16 गते यस विभागमा दिनु भएको निवेदन साथ प्रपोजल प्राप्त भयो । सो सम्बन्धमा कारवाही हुँदा उक्त प्रपोजलमा उल्लेखित Methodology(Species occurrence by field visual survey) अनुसार तपसिलको शर्तहरुको अधिनमा रही डिभिजन वन कार्यालयहरुसँग समन्वय गरि सन् २०२३, मे सम्मका लागि अनुसन्धान गर्नु हुन निर्देशानुसार अनुरोध छ ।

<u>शर्तहरु</u>

१. अनुसन्धानकर्ताले वन ऐन २०७६ तथा वन नियमावली २०७९, राष्ट्रिय निकुञ्ज तथा वन्यजन्तु संरक्षण ऐन, २०२९ र नियमावली २०३० तथा यस मातहतका नियमावलीहरुको पूर्ण पालना गर्नुपर्नेछ ।
२.अनुसन्धान कार्य डिभिजन वन कार्यालयसँगको समन्वयमा गर्नुपर्नेछ ।
३. नमुना संकलन गर्न पाइने छैन ।
४.अनुसन्धानको क्रममा प्राप्त भएको जैविक विविधता संरक्षणसँग सम्बन्धित संवेदनशिल सूचनाहरु गोप्य राख्नु पर्नेछ अनाधिकृत रुपमा त्यस्ता सूचनाहरु कसैलाई पनि उपलव्ध गराउन पाइने छैन ।
५.अनुसन्धान कार्य समाप्त भए पश्चात एक प्रति रिपोर्ट/प्रतिवेदन (कागजी तथा विद्युतिय) यस विभागमा अनिवार्य रुपमा बुझाउनु पर्नेछ ।
६.तोकिएका शर्तहरुको पालना नगरिएमा विभागले कुनै पनि समयमा अनुसन्धान अनुमति रद्द गर्न सक्नेछ ।

(सबनम पाठक)
सहायक वन अधिकृत

<u>बोधार्थ</u>
श्री डिभिजन वन कार्यालय, पर्सा, चितवन, नवलपरासी, रुपन्देही, कपिलवस्तु, दाङ्ग, बर्दिया, कैलाली र कञ्चनपुर । : जानकारी तथा आवश्यक सहयोगका लागि अनुरोध छ ।