Present and Future Suitability of the Lake Tana Biosphere Reserve (LTBR) in Ethiopia for the Nile monitor (*Varanus niloticus*) using the MaxEnt Mode

Dessalegn Ejigu (dessalegn_ejigu@yahoo.com)
Bahir Dar University https://orcid.org/0000-0002-5672-4484
Nega Tassie
Bahir Dar University

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Abstract

Background

The Nile monitor (*Varanus niloticus*) is a reptile native to Sub-Saharan Africa along the Nile River. The species inhabits a wide variety of habitats including woodlands, grasslands, mangroves, and swamps. Although the practice is not common in the Lake Tana Biosphere Reserve (LTBR) , the species is being hunted in Sahelian Africa for its leather, food, pet trade and fat-content. Consequently, the species is listed under the Convention on International Trade in Endangered Species.

Methods

Data collection was based on original onsite GIS aided presence recording. Each record of the species was first vetted for data quality. A multicollinearity analysis was conducted before fitting the MaxEnt model to the 19 bioclimatic variables. Since it provides good coverage for Africa, the Hadley Global Environment Model 2-Atmosphere Ocean (HadGEM2-AO) model was used for extracting future climate scenarios. The jackknife test was selected to measure the contribution of each environmental variable to the MaxEnt model for the species. Area under the curve of the receiver operating characteristic was used to evaluate the performance of MaxEnt model.

Results

on average 2750 individuals were recorded within the LTBR. Mean annual temperature, precipitation and temperature were the most important predictors that limit the potential distribution of *V. niloticus*. Most of its suitable habitats were mainly predicted in the northern and southern parts of the Lake. The ecological niche model produced an average AUC of 0.85. Notable records of the species were found in the vicinity of the lake and wetlands nearby. Future projection of potential suitable areas revealed that the currently available suitable area will decline in both 2050 and 2070 under both RCP 6.5 and RCP 8.5, of which the decline in suitable area under the business as usual scenario is the greatest.

Conclusions

The potential distribution map for *V. niloticus* can help in planning land use management around its existing habitat range, discover new populations or set priorities to restore its natural habitat for more effective conservation. Extensive reductions in the amount of suitable areas under future climate scenarios suggest that the species may become threatened in future if effective conservation measures are not implemented.

Background

The Nile monitor (*Varanus niloticus*: Linnaeus 1758) is a reptile native to Sub-Saharan Africa along the Nile River. Its range encompasses most of sub-Saharan Africa extending northward along the Nile River all the way to Egypt occuring along the periphery of deserts and from grasslands to rainforests in the vicinity of rivers, swamps, ponds, lakes, and seashores (Enge et al. 2004). However, currently the species occurs in North America as a result of the pet trade, and if introduced, it will likely spread into many regions in the Americas, the Caribbean, Madagascar, Southeast Asia, and Australia (Bevan 2016). In its introduced range in Florida, the most suitable habitats include mangrove swamps, edges of freshwater and saltwater marshes, river banks, canals, and lakes (Enge et al. 2004). It has the largest geographic distribution capable of reaching high population density of up to 50/km^2.

The ecology of *V. niloticus* is highly related with the ecology of *Crocodylus niloticus*. However, it seems very unlikely that a true interspecific competition could occur between the two species as they remarkably differ in size and the area where they forage. Crocodiles entirely forage in aquatic habitats whereas Varanids prefer to both terrestrial and aquatic habitats with permanent water bodies to forage and open rooftops and streets to bask (Dowell et al. 2015). Besides, Varanids inhabit a wide variety of habitats including woodland, dry savanna, scrub, evergreen thickets, swamps, mangroves, marshes, creeks, rivers, lakes and in disturbed areas near canals (Luiselli et al. 1999). The Nile monitor has the potential to disperse into ecologically sensitive areas where it could threaten different wildlife species (Enge et al. 2004).

Nile monitor can swim, climb, run, and dig, feed on a wide array of aquatic, terrestrial and arboreal prey, and it is also known to hunt cooperatively (Campbell 2005). Stomach content analyses of the species revealed that its diet is extremely broad including many taxa of invertebrates and vertebrates (Bevan 2016; Campbell 2005). Nile monitor mainly feeds on arthropods, the eggs of birds, alligators, crocodiles, and turtles and could impact many threatened and endangered species, including, owls and sea turtles. Juveniles may be insectivorous (Bennett 2002; Bevan 2016; Enge et al. 2004). The lack of fat accumulation in these animals suggests they do not undergo extended fasting periods (Bennett 2002).

Morphologically, Nile monitor is gray-brown or dark olive with darker reticulation on its dorsal side and with six to nine bands of yellow-golden ocelli in adults, while juveniles are with black and yellow patterns. The tongue is blue (Bennett 1998), and it has large, strong claws. The neck is longer than the narrow-snouted head, and it has a laterally compressed tail. It can grow up to 2.4 m with a body mass of up to 7 kg (Campbell 2005; Enge et al. 2004). Though Nile monitor is poikilothermic, it can tolerate the ecological niche thermal range of beyond expected limits by developing adaptation of living in underground burrows (Bennett 2002; Campbell 2005).

The Nile monitor reaches sexual maturity at one to two years of age and about 50% of mature females reproduce each year (Ahmed et al. 2018; Enge et al. 2004). In Africa, female Nile monitors oviposit in burrows or active termite mounds from August to January (Bennett 2002; Enge et al. 2004). Females oviposit 50 to 60 eggs, and eggs apparently take six to ten months to hatch in the wild (Ahmed et al. 2018; Campbell 2005; Ciliberti et al. 2012; Enge et al. 2004). On average females reach sexual maturity at two years of age.

Although the practice is not common in the Lake Tana Biosphere Reserve (LTBR), the species is being hunted in Sahelian Africa for its leather, food, pet trade and for some medical treatments (Ahmed et al. 2018). Consequently, the species is listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, Appendix II) (Dowell et al. 2015). This study, therefore, has tried to estimate population size, identify potential hotspots, and model the spatiotemporal distribution of Nile monitor (*Varanus niloticus*) within the LTBR, Ethiopia.

Materials And Methods

Description of the study area

The Lake Tana Biosphere Reserve (LTBR) is located in the Amhara National Regional State approximately 565 km northwest of Addis Ababa. Lake Tana surface area is 3156 km² which is stretching approximately 84 km north-south and 66 km east-west. The Lake is located within the watershed, which consists of 137 Administrative Kebeles, 10 Districts, and four Administration Zones (Fig. 1). It is located at 11°25'07” N – 12°29'18”N latitude, and 36°54'01”E – 37°47’20”E longitude with altitude ranging from 1788 to 3712 m a.s.l (Friedrich zur Heide 2012). The total surface area of the reserve is 695,885 ha of which the core area comprises 22,841 ha (terrestrial: 7,699 ha). Its buffer area is 187,567 ha (terrestrial: 30,969 ha), and the transition zone is 485,477 ha (terrestrial: 354,297 ha). Lake Tana has been recognized as UNESCO Biosphere Reserve since 2014.

Lake Tana, the source of the Blue Nile River, is a shallow lake with an average depth of 9 m and its maximum depth is 14 m with a decreasing trend due to siltation and lowering water level. The lake is surrounded by lagoons and wetlands and has more than 40 tributaries of which Gilgel Abay, Ribb, Gumara and Megech Rivers accounting for 93% of the total inflow. The climate around the lake is warm with a mean temperature of 21.7 °C. Rainfall is strongly seasonal with a dry season between November and May and a pronounced rainy season between July and September. The mean annual rainfall ranges from 800 to 2000 mm.

Lake Tana is the largest national freshwater body, accounting for 50% of the total inland water of the country. The Biosphere Reserve is an important fish resource and is home to different species of fish of which 70% are endemic. The barbus species of Lake Tana constitute the only remaining intact species of large cyprinid fish in the world. A large number of wetlands are located all around Lake Tana, some of them being the largest and ecologically most important units in Ethiopia and in the Horn of Africa. These wetlands, dominated by papyrus and typha stands are breeding, nesting and feeding grounds for various bird populations, and provide a source of animal feed, domestic water supply, building material, fuel and food for local communities.

The LTBR consists of four terrestrial and three freshwater ‘key biodiversity areas’. The area is internationally renowned as Important Bird Area and the highest abundances of wetland birds qualify areas around the lake as Ramsar site. Many Palaearctic migrant water birds depend on the lake as feeding and resting grounds, including the common crane (*Grus grus*), Northern shoveller (*Anas acuta*), Black-tailed Godwit (*Limosa limosa*), and ruff (*Philomachus pugnax*) (Tassie and Bekele 2008). Few patches of original forest vegetation and mountain ecosystem remain in the biosphere reserve that has high plant endemism of global importance. Indigenous trees found in the biosphere reserve include but not limited to *Albizia gummifera*, *Millettia ferryginea*, and *Cordia africana*. The region is a gene centre for indigenous agricultural crops such as *Guizotia abyssinica*, and *Eragrostis tef*. Wild coffee (*Coffee arabica*) occurs naturally in the area, especially in the Zegie Peninsula. Four major wetland ecosystem types such as riverine freshwater wetlands, lacustrine freshwater wetlands, palustrine freshwater wetlands, and agricultural flooded freshwater wetlands have been identified.

The LTBR comprises Lake Tana, which is the main source of the Blue Nile that provides important ecosystem services to the region. The LTBR is a hotspot of biodiversity, and it is part of the two biodiversity hotspots i.e., Eastern Afromontane and Horn of Africa biodiversity hotspots. It is internationally known as an Important Bird Area (Aynalem and Bekele 2008; Tassie and Bekele 2008), and is of global importance for genetic diversity. The area is characterized by an enormous heterogeneity of land uses and natural ecosystems.

The reserve is known for mammal species including Hippopotamus *(Hippopotamus amphibious)*, black and white colobus monkeys *(Colobus guereza*), aardvark (*Orycteropus afer)*, crested porcupine *(Hystrix cristata)*, Grimm's duiker *(Sylvicapra grimmia)*, leopard *(Panthera pardus)*, honey badger *(Mellivora capensis)*, African civet cat *(Civettictus civetta)*, Bailey´s shrew (*Crocidura baileyi*), foxes, highland hyenas, rabbits and other rodents. Besides Nile monitor, other reptiles recorded within the biosphere reserve are crocodile (*Crocodyla niloticus)*, and python *(Python sebae).*

Methodology

Data Collection

The survey areas for spotting Nile monitor were selected based on the nature of potential habitats of the species. For example, habitats such as swamp forests, river banks, dry land forests in the vicinity of water bodies, shrub lands, farmlands, cultivations, and urban and suburb areas were considered during the survey. In the reserve, the Lake itself and associated wetlands and rivers that drain to the lake (Fig. 2) and the lake shore areas suspected for the presence of *V. niloticus* were surveyed for the presence data. The study was carried out for four consecutive months, July to October 2018. Although the survey was conducted in the aforementioned habitats, focal group discussants and key informants from different woredas and kebeles within the survey area were also consulted prior to the commencement of the actual filed data collection. The study had invested all possible effort to address all known and suspected potential habitats of the species within the biosphere reserve.

Distribution data

Distribution data collection was mainly based on original on site GIS aided locality recording for ground truth. The ground truth includes the aforementioned habitats. However, prior to GIS recording, the general whereabouts of the species was obtained by consulting key informants and focal group discussants from different woredas and kebeles within the study area. In addition to field observation, the locality records were collected from literature sources and correspondents in the field. Each record of the species was first vetted for data quality. Records lacking high range of uncertainty or insufficient information to consider credible were eliminated. In such cases, anecdotal observations were excluded and we focused on credible and confirmed observations for the analysis to prevent distortion in statistical analysis or over-fitting of models. A total of 307 presence records for *V. niloticus* in LTBR were used in subsequent analyses.

Although the focus area of our survey was on the entire lake and its lush shore, every potential habitat of the species got due emphasis during the survey. Field trips carried out on either sunny or rainy days. The field observation was conducted from 08:00am to 6:00 pm. Materials and equipments used during this study include binoculars; digital photographing camera; GPS; data sheets; notebooks; Push-wheel switch counter; motor boats and papyrus boats. Random routes were followed to observe animals throughout each habitat type (Luiselli et al. 1999). The distribution map is mainly plotted on the basis of the field observation data (Fig. 3).

Environmental data layers

Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These are often used in species distribution modeling and related ecological modeling studies. Ninteen bioclimatic variables used in this study were downloaded from WorldClim database (www.worldclim.org) (Hijmans et al. 2005). To account for the effect of anthropogenic activities on the distribution of the target species (Pulliam 2000; Soberon 2007), the study also included variables that are associated with human influences on ecosystems or landscapes. In this regard we incorporated human population density figures from World Pop database (http://www.afripop.org/) and land use classes for Ethiopia which were downloaded from http://due.esrin.esa.int/globcover/.

Before fitting the MaxEnt model to the variables, a multicollinearity analysis was performed using ENM tools 1.44, to ensure that correlated variables were removed in the same model. For pairs of variables that had a high correlation (≥ 0.75) (Stiels et al. 2015) only one of the variables was retained (Guisan and Thuiller 2005) based on its biological significance to the species. After correlation analysis only 6 variables were retained namely; Annual Mean Temperature (Bio1), Temperature Seasonality (Bio4), annual precipitation (Bio12), precipitation seasonality (Bio15), Human population density and land cover.

When modelling species distribution, it is important to ensure that the environmental variables have the same spatial extent and resolution. However, the downloaded environmental layers had different resolutions; consequently, this mismatch in resolution was corrected, using GIS such that all environmental variables had a resolution of 1 km^2. Processing of all the environmental layers was done using ArcGIS 10.5.1.

Climate scenarios

To extract future climate scenarios the Hadley Global Environment Model 2-Atmosphere Ocean (HadGEM2-AO) from Worldclim database was used (Collins 2008). This climate projection model was chosen for this study because it provides good coverage for Africa (Davis et al. 2012; Jaramillo et al. 2011). From this model four climate scenarios were extracted – 2050 RCP6.0, 2050 RCP8.5, 2070 RCP6.0 and 2070 RCP8.5. The climate scenarios for 2050 represent averages for 2041–2060 while the scenarios for 2070 represent averages for 2061–2080 (*IPCC*2013). The RCPs used in this study signify two possible greenhouse emission scenarios ranging from moderate (RCP 6.0) to high (RCP 8.5); corresponding to increases in global radiative values in the year 2100 relative to preindustrial values (6.0 and 8.5 w/m^2, respectively) (Wei et al. 2017). This study assumed that human population density and land cover will remain constant in the future as such they were not projected to 2050 and 2070, however all the other variables were projected to 2050 and 2070. The assumption made for population density and land cover classes has limitations as it is expected that human population density and land cover classes will change in future.

Modelling the distribution of Nile monitor using MaxEnt

Applications of SDMs include predicting impacts of climate change and habitat loss, identification of corridors and reserve areas for conservation, and predicting the spread of invasive species (Elith et al. 2011). To date, no studies have applied SDMs to study the distribution of *V. niloticus* in the LTBR. Predictions of potential current and future distribution of *V. niloticus* were made using MaxEnt version 3.3.3; a software based on maximum entropy method (Phillips et al. 2006). MaxEnt was chosen for this study because it has proven to perform better among species distribution modeling algorithms using presence only datasets (Elith et al. 2006; Wei et al. 2017). MaxEnt models for all the species were calibrated with similar settings. We used a regularization value of 1 which has been shown to perform well across a variety of organisms and regions (Phillips and Dudik 2008).

The jackknife test was selected to measure the contribution of each environmental variable to the MaxEnt model for the species. The default convergence threshold value was adopted, while the maximum number of iterations was set to 5000 and maximum number of background points was set to 10000. We selected sub-sample run type and we performed 10 replicate runs and averaged the results. During the runs, 75% of the species occurrence records were used for training the model and the remaining 25% for validation.

Boolean maps for suitable and unsuitable areas for the species

Classification of suitable and unsuitable areas for the species was done by converting the probability distribution values which range from 0 to 1 (Pearson et al. 2007). A 10th percentile training presence logistic threshold value obtained from MaxEnt model results was used to classify suitable and unsuitable areas for the species (Hao et al. 2012; Liu et al. 2005). Pixels with values above the 10th percentile training presence logistic threshold were classified as suitable areas while pixels with values below the threshold value were classified as unsuitable areas (Hao et al. 2012). All the suitability maps were produced and calculation of the amount of suitable areas under current and future climate scenarios were done using ArcGIS 10.5.1.

MaxEnt model performance evaluation

Area under the curve (AUC) of the receiver operating characteristic (ROC) was used to evaluate the performance of MaxEnt model. High AUC values imply that the model performance is good; in general AUC values within the range 0.5–0.7 signify poor model performance, while values ranging between 0.7 and 0.9 indicate good performance, and values greater than 0.9 indicate excellent performance (Wei et al. 2017).

Results

Population size estimate of Nile monitor

Field survey and interview with the local communities about the population size estimate of Nile monitor within the Hotspots of the LTBR showed that the northern part of Lake Tana harbours more Nile monitors, while relatively the least number of individuals were recoreded in the southern part of the Lake. The average population was estimated at 2750 individuals (Fig. 4).

Distribution of Nile monitor

Most suitable habitat for *V. niloticus* was mainly predicted in the northern and southern parts of the Lake and the eastern and western parts of the Lake were also predicted to be suitable for the species (Fig. 5). Besides, fragmented distributions are predicted following the presence of tributaries of the Lake Tana.

The Maxent model's internal jackknife test of variable importance showed that mean annual temperature (bio1), Precipitation seasonality (coefficient of variation) (bio15), and temperature seasonality (standard deviation) (bio4) were the three most important predictors that limit the potential distribution of *V. niloticus* (Table 1). These variables presented the highest gain that is contained most information compared to other variables (Fig. 6).

Table 1
Mean AUC value and percent contribution of the most important variables influencing the distribution of the species

Species	Mean AUC	Variable	Contribution to MaxEnt model (%)	Remark
Varanus niloticus	0.85	Annual Mean Temperature	45.9	
		Precipitation Seasonality	28.4	
		Temperature Seasonality	15.8	
		Population density	6.3	
		Land use	3.4	
		Annual precipitation	0.1	

The ecological niche model constructed from this species occurrence records (n = 307) produced an average test AUC of 0.85 (Table 1). Projecting the species onto the study area showed that the vast majority of the currently suitable areas is predicted to be highly unsuitable. Aggregated observation records illustrate water body centered occurrence of *V. niloticus* in the study area. Notable records of the species were found in the vicinity of the lake and wetlands nearby. Likewise, the northern and eastern parts of the Lake are observed to host large number of individuals of the species. There were also clustered sightings closer to ponds.

Model performance and variable importance for the specie's distribution

The prediction accuracy of the MaxEnt models for the species was good, as the mean AUC values is greater than 0.8. The highest AUC value observed here indicates that the model performed well in predicting potential suitable habitats for the species.

Jackknife analysis of the environmental predictor variables suggests Annual Mean Temperature to be the greatest predictor of *V. niloticus* presence. Precipitation seasonality, averaged across replicate runs, is responsible for a 28.4% contribution to the output of the model, identifying it as the most significant predictor. Temperature seasonality was calculated to contribute 15.8% to the model, followed in relative importance by the population desnsity 6.3%, land use 3.4%, and Annual Precipitation 0.1%. The last three variables were found to be of less important in the predictions of the Maxent model.

The sensitivity of the species to the variables that greatly influenced the distribution varied greatly. For example, the probability of occurrence for the species increased with increase in annual mean temperature from 12 to 21 °C, with an optimum annual temperature of 21 °C that favored the species to occur in the study area, while the probability of occurrence rapidly declined as the temperature goes above 21 °C (Fig. 7).

Precipitation seasonality, the Coefficient of Variation, is the standard deviation of the monthly precipitation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean). The larger the standard deviation, the greater the variability. It is the tendency of a place to have more precipitation in certain months or seasons than in others. Large values show high seasonality and small values low. For this species, precipitation seasonality was found to be the second important factor to determine its distribution. This index provides percentage of precipitation variability where larger values indicate greater variability of precipitation. In other words, while increase in precipitation seasonality up to 118% led to an increase in the probability of occurrence for the species, but seasonality increase above 130% led to a decrease in the probability of occurrence (Fig. 8). This result shows the presence of high precipitation variability in the study area where precipitation amounts that favored the occurrence of the species ranged from 118–130%.

Likewise, precipitation seasonality was found to be the third important factor to determine *V. niloticus* distribution. If there is a high variation then the seasonality is high, but if low, then there is less extreme difference through the year, resulting in no pronounced season, but rather an even and mild climate range. So it is not indicating when the season is. This index provides percentage of temperature variability where larger values indicate greater variability of temperature. While increase in temperature seasonality up to 11% led to an increase in the probability of occurrence for the species, a seasonality increase above 14% led to a decrease in the probability of occurrence. This result shows the presence of high temperature variability in the study area where temperature amounts that favored the occurrence of the species ranged from 11–14% (Fig. 9).

Since intensity of land-use change in Ethiopia is expected to increase in the future, the assumption of constant land-use classes over time gives conservative estimates of changes in the species distributions. Nevertheless, the species favored more land use category of water bodies coded as 210 followed by rain fed, post flooding, irrigated or aquatic croplands coded as 14 and mosaic vegetation coded as 30 (Fig. 10). This finding is counter intuitive because it is commonly expected that change in land use type should lead to a change in the probability of occurrence of the species.

Current and future distribution of *V. niloticus*

MaxEnt model predictions for the current distribution of suitable areas for the species indicated that the species had a wide range of suitable areas across the study area. Despite the species having a wide range of current suitable areas, future projections revealed that the amount of suitable areas will reduce greatly. Generally, the more extreme global climate change scenario (RCP 8.5) predicted a larger loss of suitable area than the other (RCP 6.0). The area predicted to be suitable for *V. niloticus* as a whole became more restricted under future climate projections, with the more extreme scenarios (RCP 8.5) showing extremely smaller predicted ranges (Fig. 11). Largely, our findings revealed that areas very close to water bodies such as the Lake and rivers were predicted to be suitable for the species or the species is least affected by range losses as a result of climate change, thus it can be said that the ranges for the species are shifting towards areas where water is available. For all RCP scenarios, areas of probable presence suggest reduction of suitable areas. The findings are not surprising as it was observed that the species was very sensitive to increases in temperature, and since the species might use water bodies to regulate the body temperature such findings are logical. Nile monitors are usually found near water, including rivers and lakes. They are both terrestrial and aquatic which allows them for great adaptability to different environments (Szczepaniuk, 2011).

Generally, the range loss for the species is huge under future climate change scenarios; it ranged from 54.93 to 98.70% (Table 2). The highest percentage of range loss was observed in 2070 under the business as usual climate change scenario (2070RCP8.5), while the least range loss was observed in 2050RCP6.0. These results indicate that potentially suitable areas for this species are declining as time goes by in years and climate changes under scenarios used.

Table 2
Current and projected suitable area left and percent loss of the specie's suitable area under different climate scenarios

		Current and future climate scenarios				
Species	Area category	Current	2050 RCP 6.0	2050 RCP 8.5	2070 RCP 6.0	2070 RCP 8.5
V. niloticus	Suitable area(Km^2)	3011	1357	474	277	38
	Range loss (%)	0	54.93	84.26	90.80	98.70

Discussion

The distribution of records suggests water bodies are corridors for *V. niloticus*. Indeed, the riverine areas are home to a notable proportion of records. GPS coordinates place an additional majority of records in wetlands that physically flank habitats of the riverine areas and the Lake. *V. niloticus* prefers to live near permanent bodies of water in its native range (Pianka et al. 2004) confirming that the species' home range contains at least a permanent source of water. It inhabits mainly vegetated spots and gallery forests in the vicinities of rivers and water bodies (Luiselli et al. 1999). As has been noted during our observations, rivers serve the species as convenient means of retreat, feeding and breeding ground. Furthermore, river banks and sidewalks lining rivers offer attractive basking sites.

MaxEnt predictions for the current distribution of *V. niloticus* revealed that overall this species occurs in the immediate vicinity of water bodies. Thus, suggesting that the MaxEnt models correctly predicted the current distribution of the species as the species tends to choose aquatic habitats compared with terrestrial (Noah 2017). Predictably, the entire lush shore of the Lake Tana is identified by Maxent as the area with the highest probability of *V. niloticus* presence in the study area. More interesting is the identification of rivers that flow to the lake as sites of highly probable presence. Credible sighting of *V. niloticus* on areas outside of rivers have been rare, which might further confirm the preference of the species to aquatic habitats. However, since the species is not entirely aquatic, it is possible that the lack of records from the terrestrial areas is the result of survey efforts that mainly focused on the shore of the lake and rivers that drain to the Lake.

The mapping of potential distribution of species offers a number of advantages for conservation (Elith et al. 2011). The present study showed that SDMs can be used to predict current and potential species distribution in current and future climatic condition in an area of high biodiversity using species occurrence and environmental variables. The AUC value was above 0.80 for the species Maxent models provided new information about the future distribution of the species with a fairly good accuracy..

Future projections of the distribution of the species portrayed huge losses in the amount of suitable areas for the species. The species had a maximum range loss of greater than 50% in 2050 and greater than 90% in 2070 under the two scenarios used (Table 2). Since the species was less sensitive to population density, land use change and annual precipitation than temperatures, it can be supposed that the declines in suitable areas are due to increases in annual mean temperatures and seasonality under future climate scenarios (Parmesan 2006). Nevertheless, the potential effects of these factors cannot be ignored as population density leads to loss of habitats or change in land use and rainfall affects the availability of water resources and consequently food productivity for this species.

Average temperatures in Ethiopia for 2070 under RCP 8.5 will increase by 4.1^{0}C (Tassie 2016), as such huge declines in the amount of suitable areas for the species as observed in this study can be expected. Increased temperatures have the potential of not only affecting energy expenditure but also egg production (Pendlebury et al. 2004), consequently threatening the survival of a given species. Therefore, our findings suggest that even though this species is presently under least concern category (DeLisle 1996) it may become threatened or endangered soon, due to habitat loss which will result from increases in temperatures.

Further, the results showed that human population density, land use and annual precipitation played no important role in predicting the distribution of the species. The lack of response to the human population density might be attributed to the ability of the species to adapt areas where human population density is high. For example, the species is observed to feed on cow milk. Such feeding behavior implies that the presence of humans provides vast opportunities to this species for finding food hence occurrence near human settlement is expected. Monitor Lizards are well known to people inhabiting small villages and towns (Angelici and Luiselli 1999). Moreover, our observation and interviews with the local community had confirmed that the species is known for sucking cow milk directly from cow’s nipple in rural villages where cattle are being reared. Additionally, the species has been reported to regularly visit towns and villages in association with churches, large buildings, roads and bridges, for instance the species is enormous at the junction where Nile River leaves Lake Tana in the southern part of the Lake. These findings suggest that the species have adapted to human or anthropogenic landscapes either through increased encroachment of their habitats by humans or through the species frequent visits to human habitats in search for food. Therefore, it is not surprising that some of the variables selected to predict the spatiotemporal distribution of the species are not invaluable for predicating the potential suitable areas of the species.

Conclusion

In this study we modeled the current and potential future distribution of *V.niloticus under* RCP 6.0 and RCP 8.5 scenarios in 2050 and 2070. The findings of this study indicate that the most important factors that determine the distributions of these species are annual mean temperature, temperature and precipitation seasonality. Future projection of potential suitable areas revealed that the currently available suitable geographic area will decline in both 2050 and 2070 under both climate scenarios of RCP 6.5 and RCP 8.5, of which the decline in suitable area under the business as usual scenario is the greatest. The potential habitat distribution map for *V. niloticus* can help in planning land use management around its existing populations, discover new populations, identify top-priority survey sites, or set priorities to restore its natural habitat for more effective conservation. Extensive reductions in the amount of suitable areas under future climate scenarios suggest that the species may become threatened or endangered in future if effective and sustainable conservation measures are not implemented. Although the general characteristics of the distribution of *V. niloticus* is addressed quite satisfactorily from the present study, more detailed surveys throughout the study area are necessary to reliably depict the distribution of the species.

Declarations

Ethics approval

Not applicable

Consent for Publication

Not applicable

Availability of data and materials

The authors declare that data is available on the hands of the corresponding author, and can be avilable on request for the corresponding author.

Competing interests

The Authors declare that there is no competing interest in publishing this manuscript.

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Authors' contributions

Ejigu D and Tassie N conceptualized this study, collected, analyzed, interpreted the data and wrote, read and approved the final manuscript.

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Authors information

Affilations

Bahir Dar University, Department of Biology, P. O. Box 79, Bahir Dar, Ethiopia

Dessalegn Ejigu

Bahir Dar University, Department of Biology, P. O. Box 79, Bahir Dar, Ethiopia

Nega Tassie

Corresponding Author

Dessalegn Ejigu

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Figures

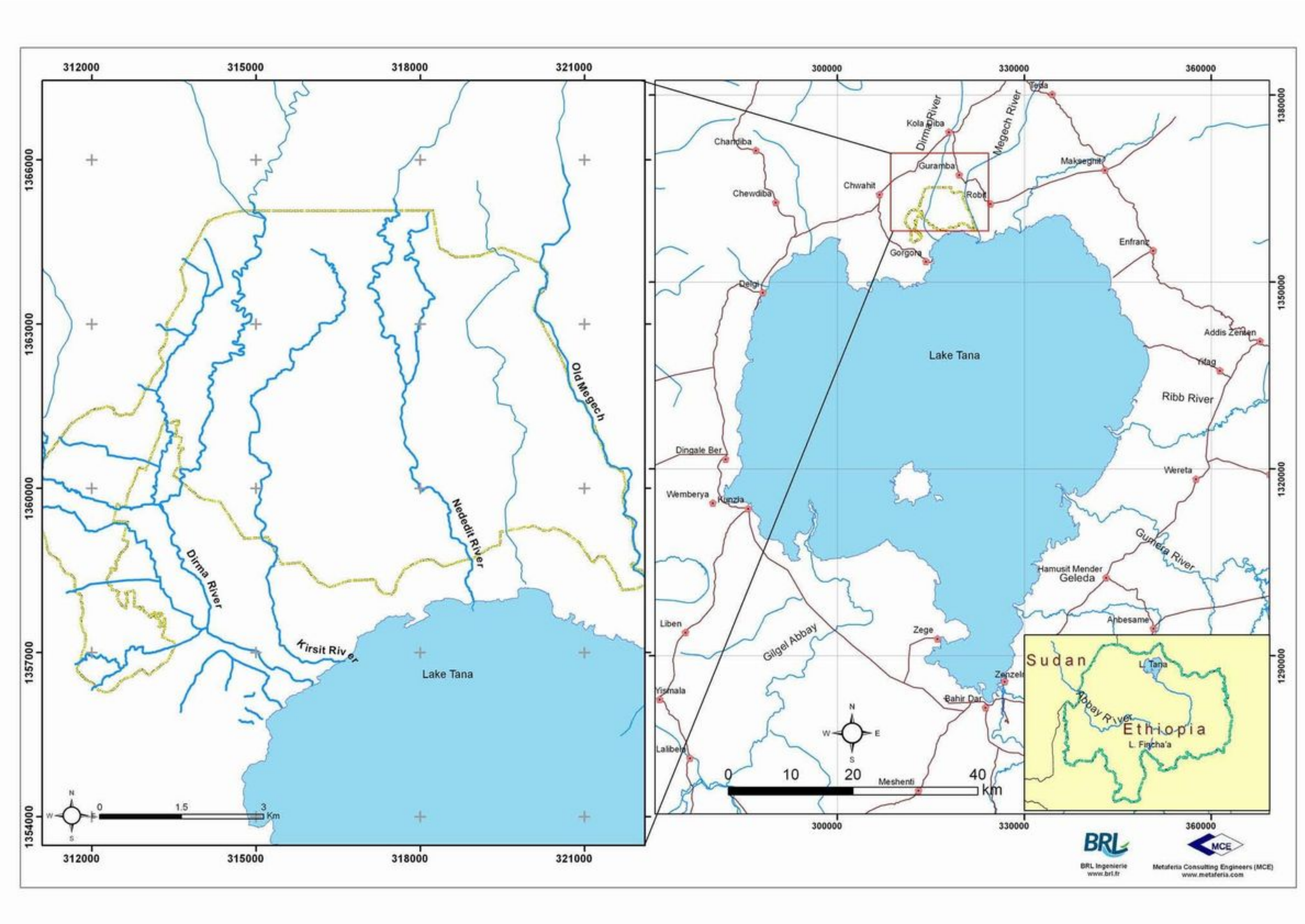

Figure 1

Lake Tana Biosphere Reserve

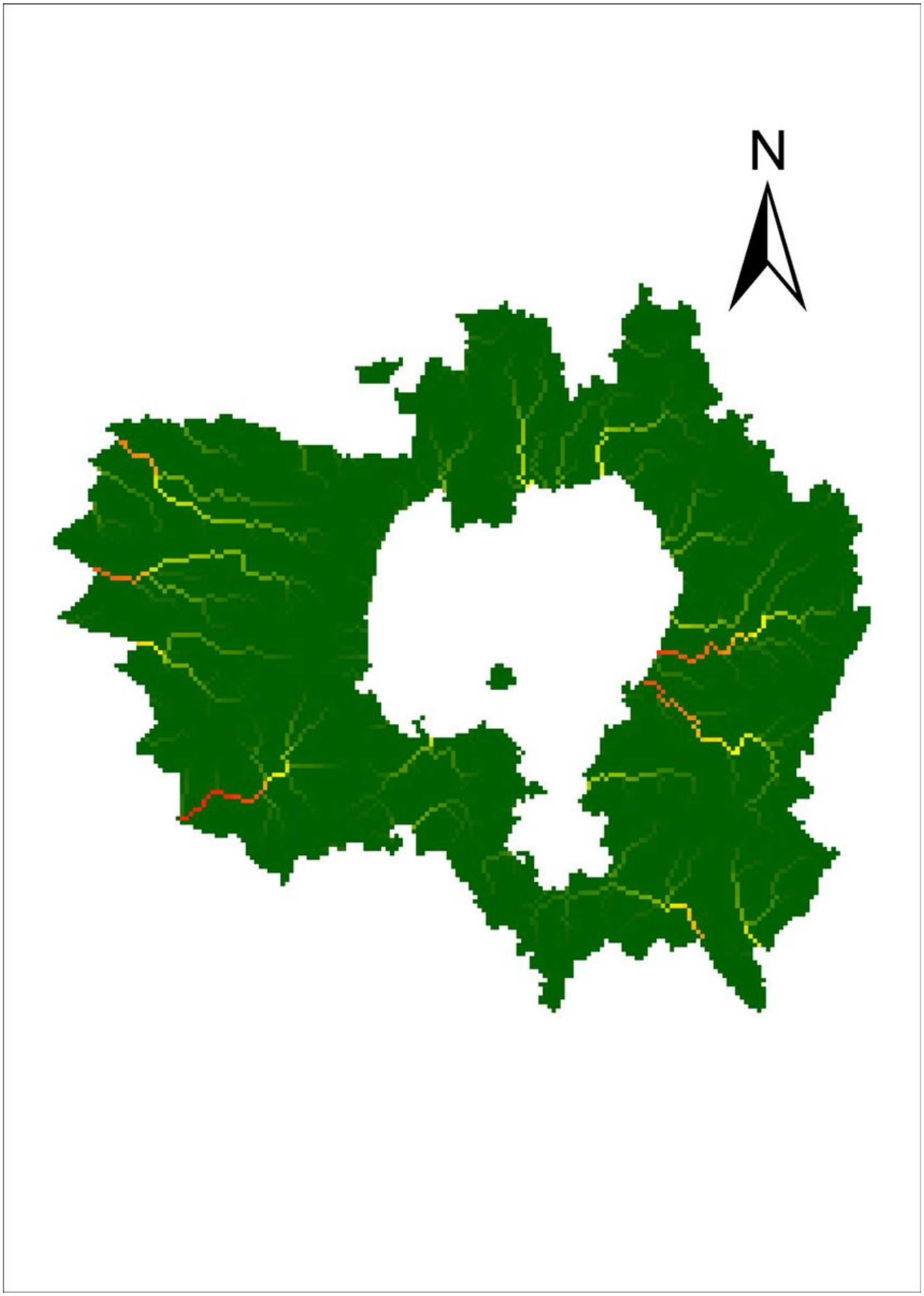

Figure 2

Tributaries of Lake Tana.

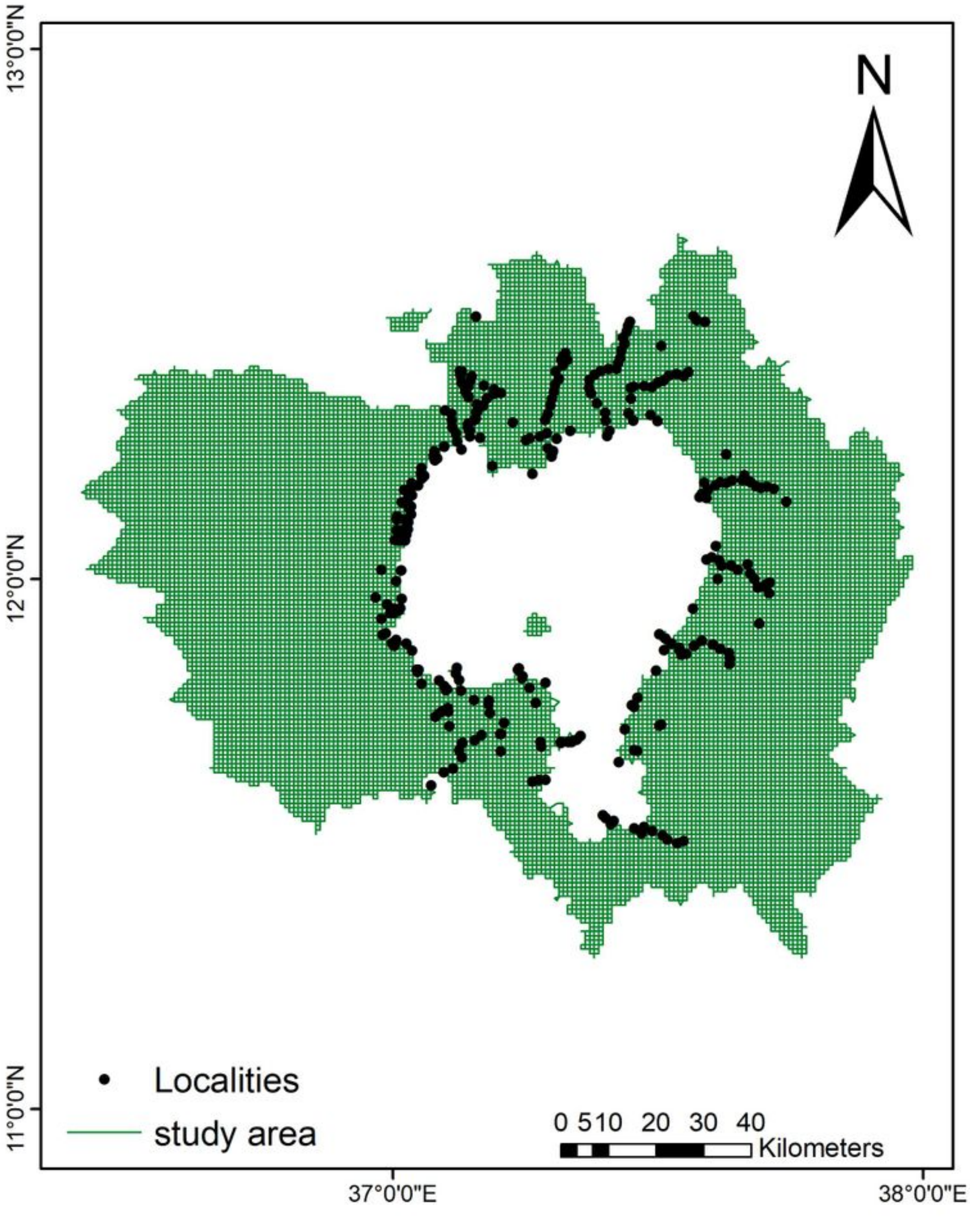

Figure 3

Sightings of the Nile monitor (n = 307) in the study area.

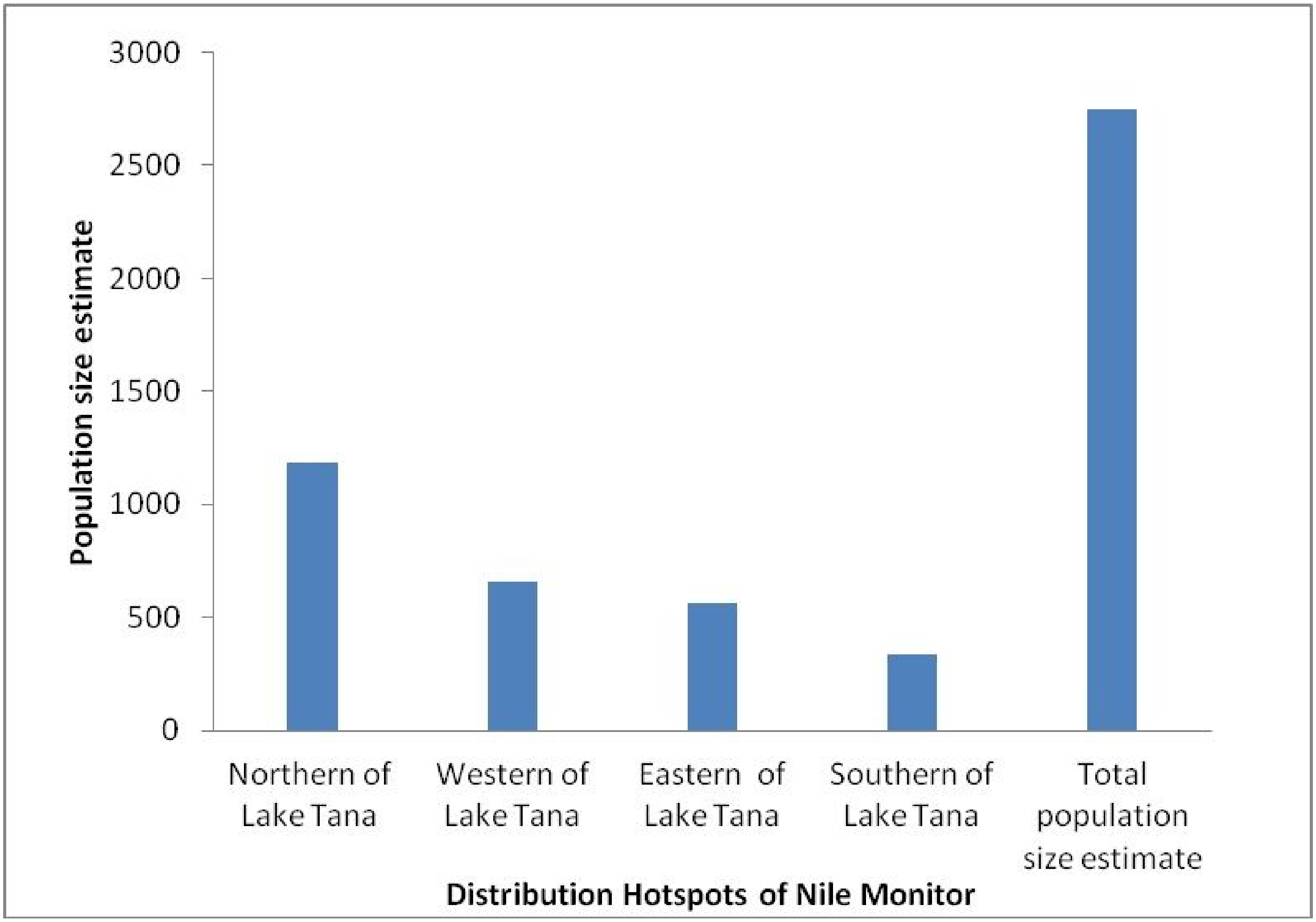

Figure 4

Population size estimate of Nile monitor within the LTBR

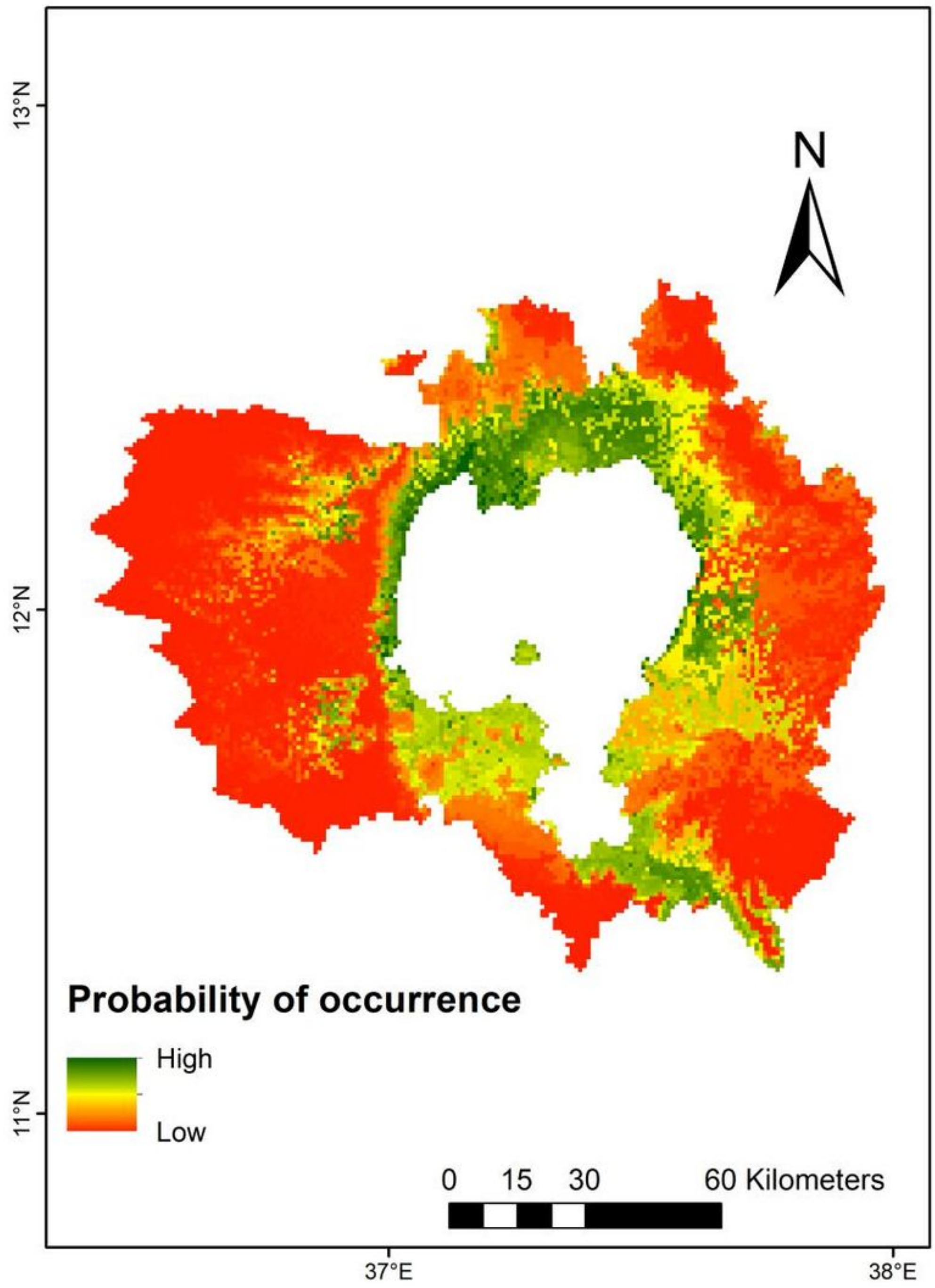

Figure 5

Distribution map of the Nile monitor within the LTBR

Figure 6

Jackknife test of variable importance in modeling distribution of Nile monitor

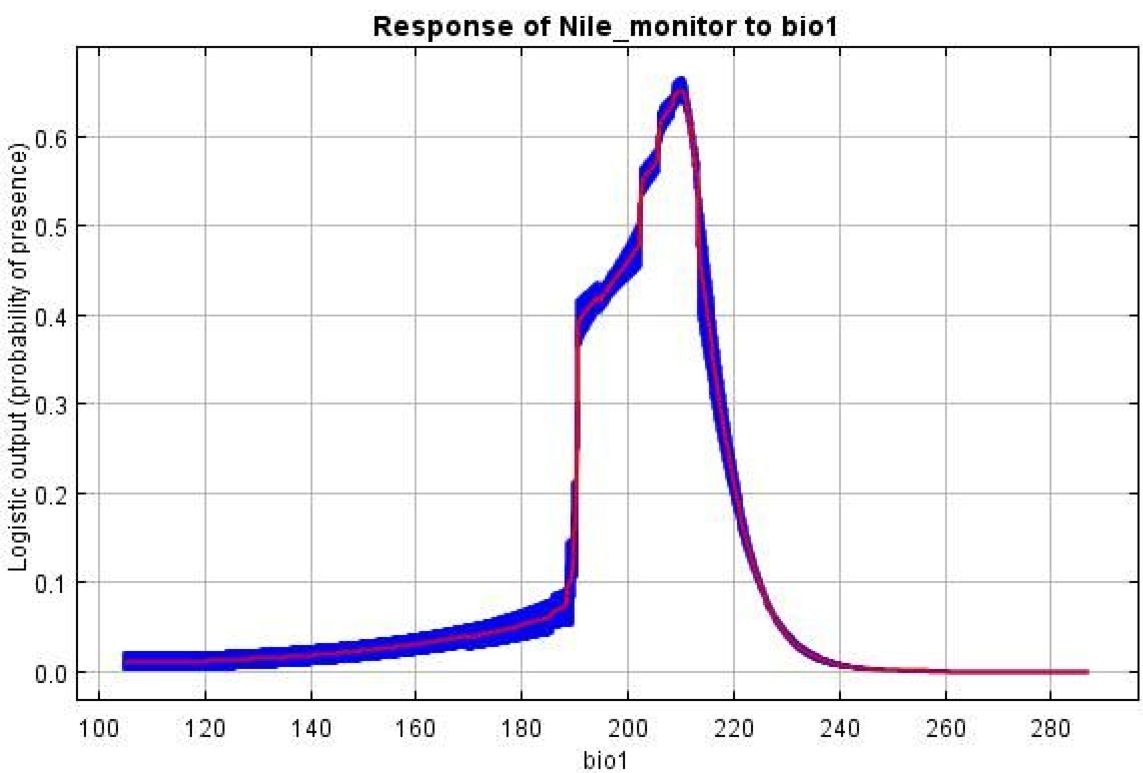

Figure 7

The dependence of predicted suitability of the species on annual mean temperature

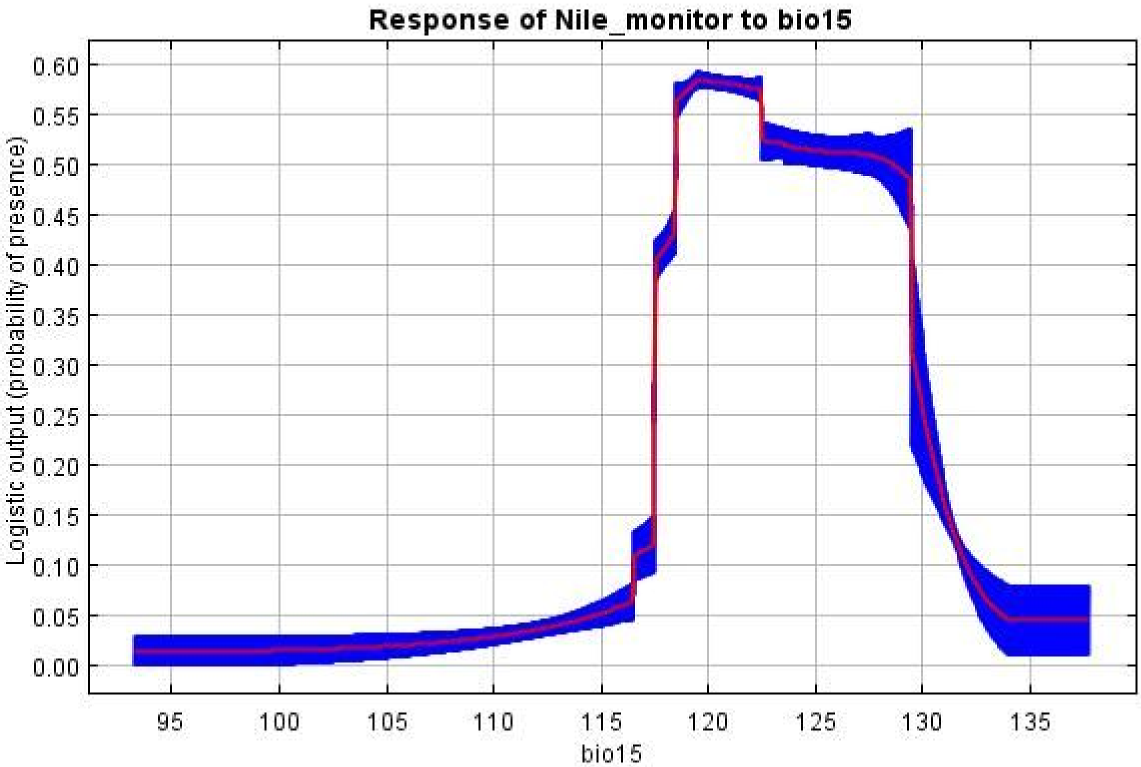

Figure 8

The dependence of predicted suitability of the species on precipitation seasonality

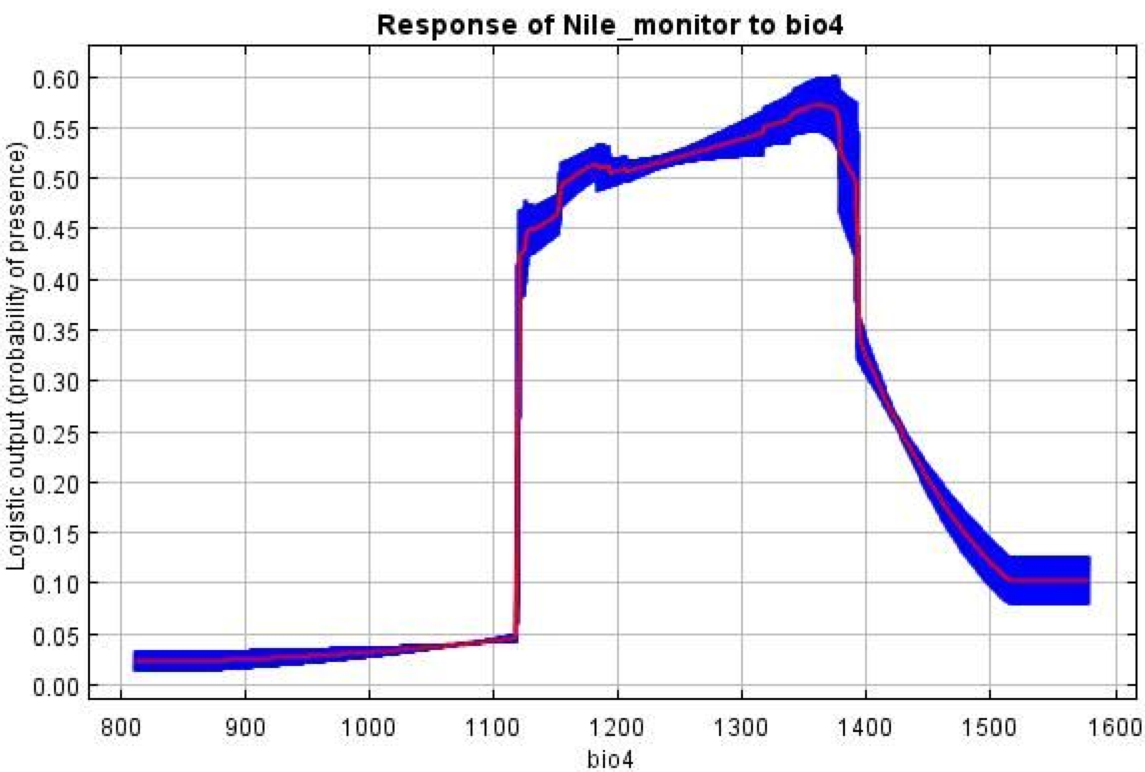

Figure 9

The dependence of predicted suitability of the species on temperature seasonality

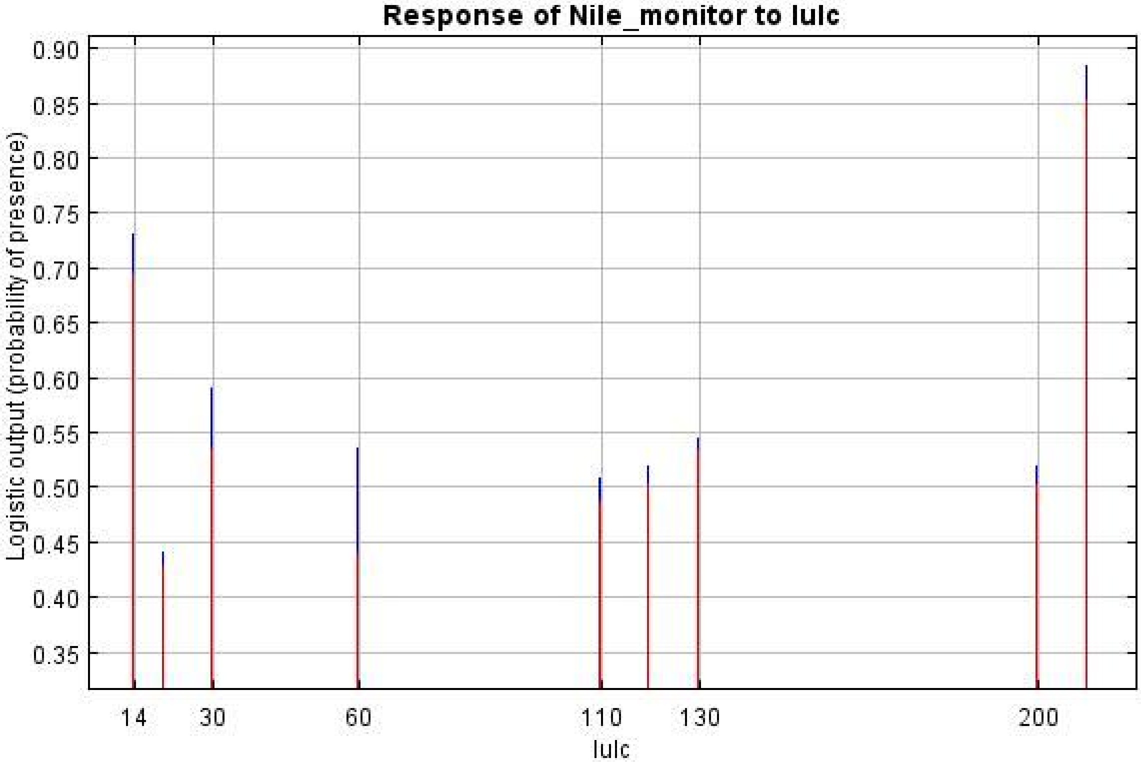

Figure 10

The dependence of predicted suitability of the species on land use types of the study area.

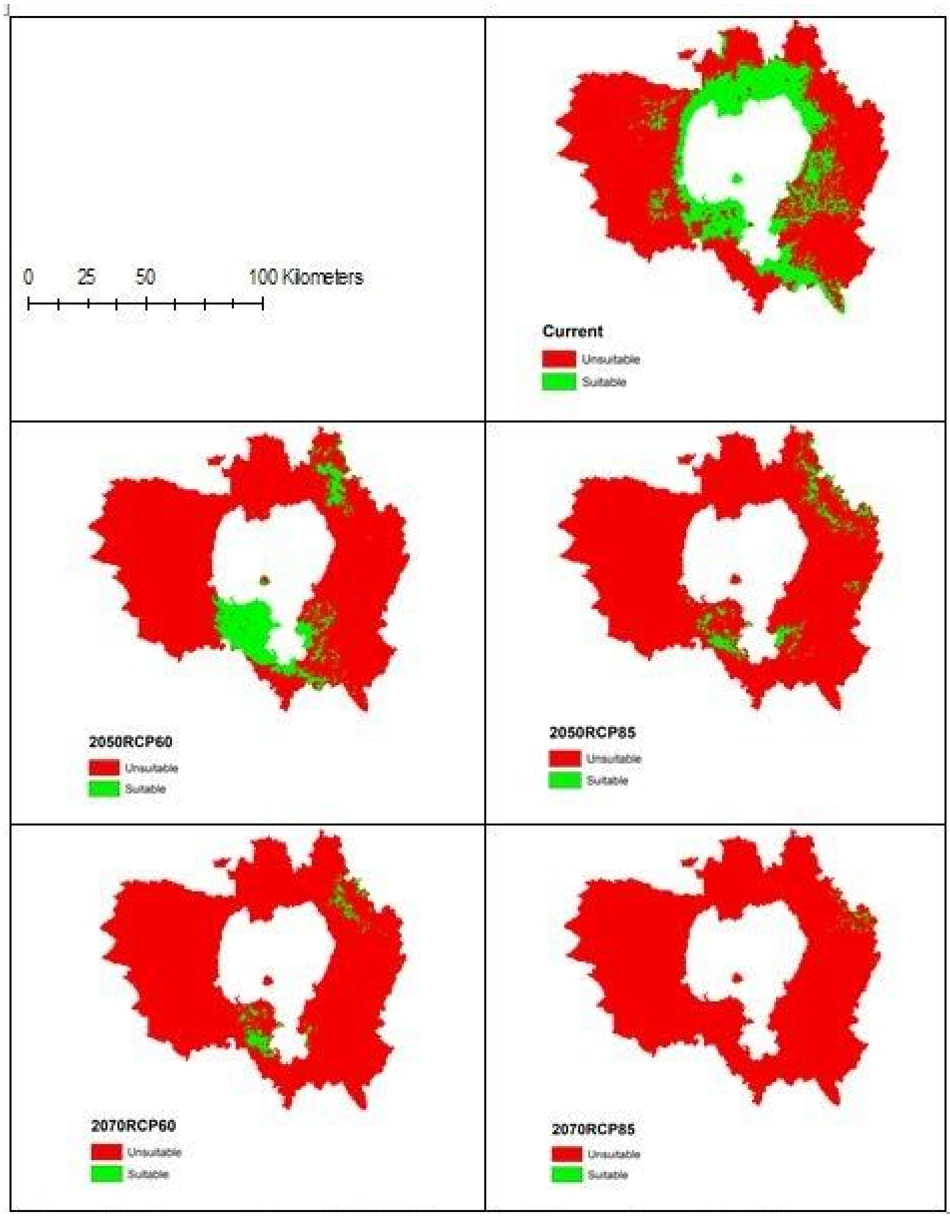

Figure 11

Current and potential suitable areas of Nile monitor under different climate scenarios.