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Present and future suitability of the Lake Tana Biosphere Reserve in Ethiopia for the Nile monitor (*Varanus niloticus*) using the MaxEnt model

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Abstract

Introduction: The Nile monitor (*Varanus niloticus*) is the largest lizard 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, the species is being hunted in Sahelian Africa for its leather, food, and pet trade. Consequently, the species is listed under the Convention on International Trade in Endangered Species.

Methodology: Data collection was based on 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 implementation of change factor was to correct the modeled mean climate from the climate models. The jackknife test was selected to measure the contribution of each environmental predictor variable. Area under the curve of the receiver operating characteristic was used to evaluate the performance of MaxEnt model.

Results: On average 2750 individuals of Nile monitor were recorded within the Lake Tana Biosphere Reserve. Mean annual temperature, precipitation and temperature were the most important predictors that limit the potential distribution of Nile monitor in the area. Most of the suitable habitats of Nile monitor were mainly predicted in the northern parts of Lake Tana. 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 the nearby wetlands. Future projection of potential suitable areas revealed that the currently available suitable area to Nile monitor 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.

Conclusion: The potential distribution map for Nile monitor in the Lake Tana Biosphere Reserve 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.

Keywords: Distribution modelling, Ethiopia, Lake Tana Biosphere Reserve, MaxEnt model, Nile monitor

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Introduction

The Nile monitor (*Varanus niloticus*: Linnaeus 1758) is the largest lizard native to Sub-Saharan Africa and along the Nile River. It is usually brownish in color with yellow spots along its body including the tail, and adult males median size and weight are 155 cm and 5 kg, respectively (Faust 2001). Its range covers most of the sub-Saharan Africa and extending northward along the Nile River to Egypt. It occurs in grasslands, riverine forests, swamps, ponds, lakes, and seashores (Enge et al. 2004). However, the species has been introduced in North America, and it will likely spread into many regions in the Americas, the Caribbean, Madagascar, Southeast Asia, and Australia (Bevan 2016). In its introduced range, the most suitable habitats include mangrove swamps, edges of freshwater and saltwater marshes, river banks, canals, and lakes (Enge et al. 2004).

The ecology of Nile monitor is highly related with the ecology of Nile crocodile (*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. Nile crocodile entirely forages in aquatic habitats whereas Nile monitor prefers to both terrestrial and aquatic habitats with permanent water bodies and open rooftops and streets to bask (Dowell et al. 2015). 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 feed on different types of aquatic, terrestrial and arboreal prey, and it is also known to hunt in groups (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). It mainly feeds on eggs of birds, alligators, crocodiles, and turtles and could impact many threatened and endangered species. Juveniles may be insectivorous (Bennett 2002; Bevan 2016; Enge et al. 2004). The lack of fat accumulation in Nile monitor suggests it does not undergo extended fasting periods (Bennett 2002).

Morphologically, adult Nile monitor is gray-brown or dark olive with darker reticulation on its dorsal side with six to nine bands of yellow-golden ocelli, while juveniles are with black and yellow patterns. The tongue is blue (Bennett 1998), and it has large and strong claws. The neck is longer than the narrow-snouted head, and it has a laterally compressed tail (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). 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).

Nile monitor 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).

Species distribution modeling is commonly used to project the response of species distributions to climate change. A species distribution model functions by deriving a relationship between the known distribution of a species and environmental variables such as rainfall, temperature, soil type, and land use (Beaumont et al. 2008). This relationship is then used as the basis for projecting range shifts under future climate change scenarios (Baek et al. 2013). These projections can help identify species at risk and inform conservation decision-making.

In the last few decades, several approaches have been used for building species distribution models (Elith et al. 2006, 2011). Models may be based on presence–absence data or on presence-only data. Where presence–absence data are available, these generally yield more robust, and accurate models (Elith et al. 2011). In cases where complete field data are scarce and records of organisms are found in the form of presence-only data, models predicting species ranges from presence-only data can be applied. One type of these models is Maximum Entropy models (MaxEnt) (Elith et al. 2011). MaxEnt is a multipurpose model which has been shown to outperform other modelling procedures in delimiting species boundaries and ecological niches (Phillips and Dudik 2008; Elith et al. 2011). It models the distributions of species by calculating the maximum entropy given the input data (Phillips and Dudik 2008). This results in a probability distribution grid describing probability of occurrence of a species in each grid cell as a function of the values of the environmental variables (Hodkinson et al. 2011).

MaxEnt has numerous advantages including the input species data can be presence points only, both categorical and continuous environmental layers can be applied, its prediction is stable and reliable with a great accuracy even if low sample sizes are undertaken, thus can predict distribution of threatened species, it creates a spatially explicit map for habitat suitability with an easy interpretation, it enables replicated runs to test model robustness, the importance of each environmental variable can be measured using jackknife test, it can be used to project into the future under climate change to predict habitat losses and gains within species range and thus help in planning appropriate conservation measures (Phillips et al. 2006; Elith et al. 2011).

Understanding species sensitivities to climate change and other anthropogenic factors, population structure as a function of these environmental factors, and how their distributions will be affected with such impacts is an important step in developing mitigation strategies for species conservation. This study, therefore, has tried to model the spatiotemporal distribution of Nile monitor (*Varanus niloticus*) within the Lake Tana Biosphere Reserve, Ethiopia.

Methodology

Description of the study area

The Lake Tana, part of the Biosphere Reserve is located in the Amhara Region approximately 565 km to the northwest of Addis Ababa. Lake Tana has a surface area of 3156 km^2 stretching approximately 84 km from north to south, and 66 km from east to west. The Lake is located within the watershed, which consists of 137 Administrative Kebeles, 10 Districts, and four Administration Zones. 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 (Zur Heide 2012). The total surface area of the Lake Tana Biosphere Reserve is 695,885 ha of which the core area comprises 22,841 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 maximum depth of 14 m. The lake is surrounded by lagoons, wetlands and more than 40 tributaries. The climate around the lake is warm with a mean temperature of 21.7 °C and a mean annual rainfall range of 800 to 2000 mm. Rainfall is strongly seasonal with a dry season between November and May, and a pronounced rainy season between July and September.

The Lake Tana Biosphere Reserve 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).The Biosphere Reserve including Lake Tana is an important home to different fish species. Besides, the biosphere reserve is home to various species of mammals, reptiles and amphibians.

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.

Data collection

The survey areas for spotting Nile monitor were selected based on the nature of potential habitats of the species. Thus, habitats such as swampy 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 Lake Tana Biosphere Reserve, the lake itself and associated wetlands and rivers that drain to the lake (Fig. 1) and the lake shore areas suspected for the presence of Nile monitor 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 afromentioned habitats, focal group discussants and key informants from different districts within the survey area were also consulted prior to the commencement of the actual filed data collection. All possible effort has been invested to address all known and suspected potential habitats of the species within the biosphere reserve.

Distribution data

Presence data for modelling the distribution of Nile monitor were collected using GIS aided locality recording for ground truth. However, prior to GIS recording, the general whereabouts of the species was obtained by consulting key informants and focal group discussants from different districts 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 with high range of uncertainty or insufficient information to consider credible were eliminated. In such cases, anecdotal observations were excluded and credible and confirmed observations were used for the analysis. A total of 307 presence records for Nile monitor in Lake Tana Biosphere Reserve were used in subsequent analyses.

Although the focus area of our survey was on the entire lake and its shore, every potential habitat of the species got due emphasis during the survey. The field observation was conducted from 08:00 a.m. to 6:00 p.m. 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. 2).

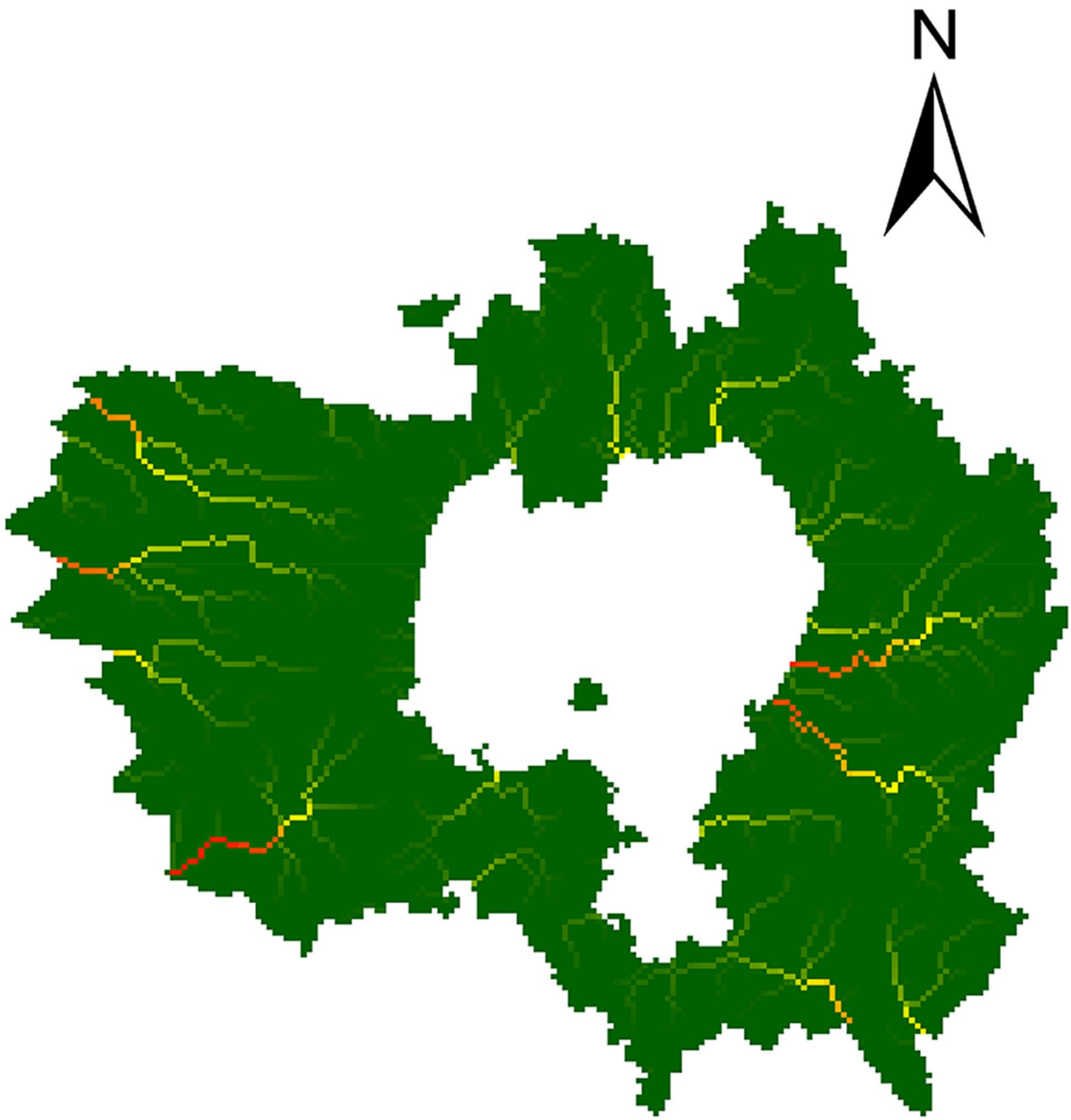

Fig. 1 Tributaries of Lake Tana

Environmental data layers

Biologically meaningful bioclimatic variables were derived from the monthly temperature and rainfall values. 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 the ecosystems. In this regard we incorporated human population density figures from World Pop database (https://www.afripop.org/) and land use classes for Ethiopia which were downloaded from https://due.esrin.esa.int/globcover/.

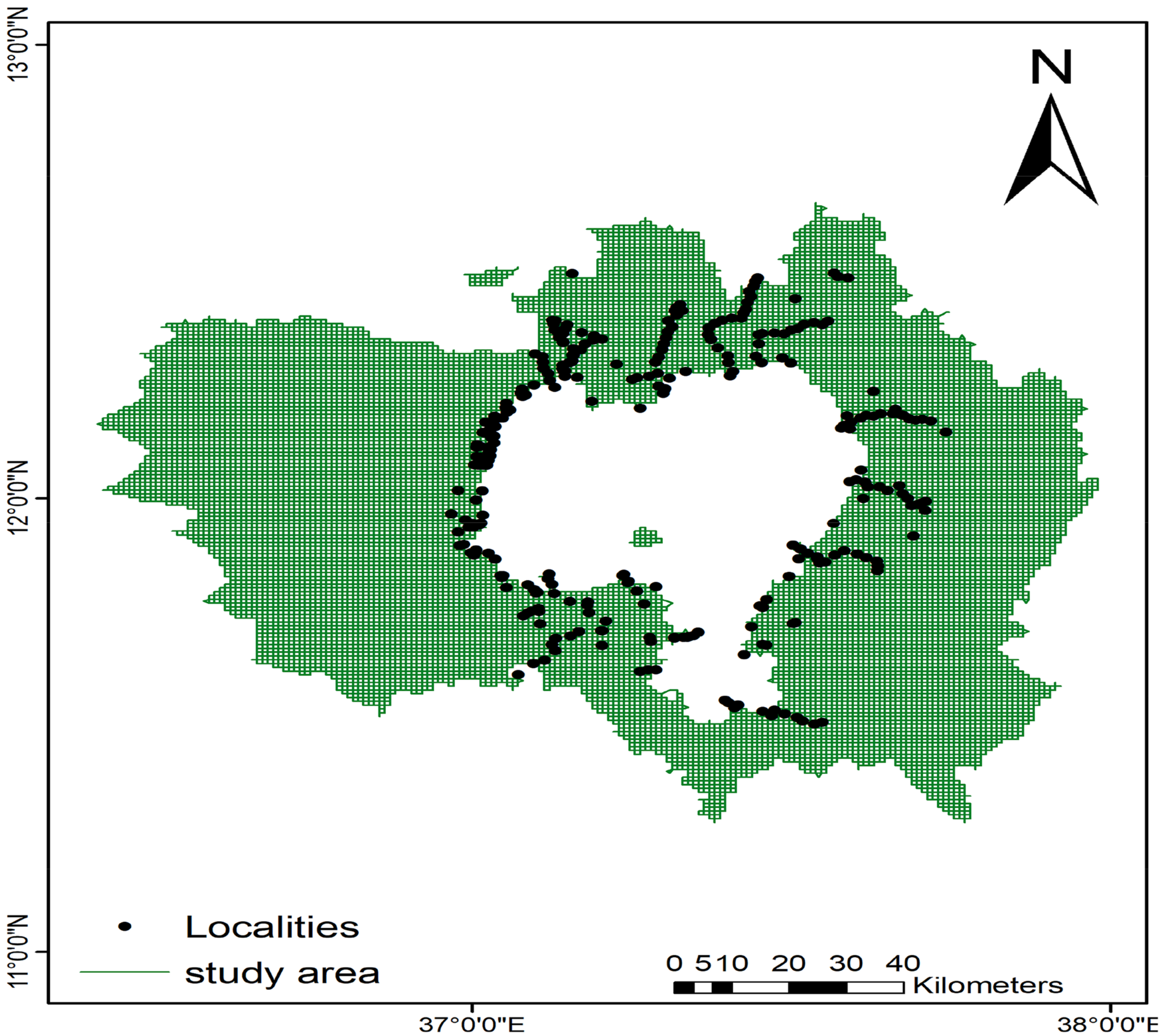

Fig. 2 Sightings of the Nile monitor (n = 307) in the study area

Before fitting the MaxEnt model to the variables, a multicollinearity analysis was performed using ENM tools 1.44, to ensure that correlated variables are removed in the same model. For highly correllated pairs of variables (≥ 0.75) (Stiels et al. 2015) only one of the variables was retained based on its biological significance to the species (Guisan and Thuiller 2005). 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 modeling 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

Climate anomalies were first calculated using general circulation model (GCM) output as the difference between future and historical periods, and then interpolated onto a 30 arc-s grid. The interpolated anomalies were then applied to the baseline climate of the WorldClim high resolution (30arc-s) surfaces for consistency with WorldClim (Hijmans et al. 2005). The implementation of change factor was to correct the modeled mean climate from the climate models, which is a critical aspect in understanding species distributions under climate change, while also providing results at high spatial resolution.

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. 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.

Modeling 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 Nile monitor in the Lake Tana Biosphere Reserve Predictions of potential current and future distribution of Nile monitor 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. A regularization value of 1 was used so that models are not over fit to achieve balance between complexity and parsimony (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 10,000. The sub-sample run type was selected and 10 replicate runs were carried out. 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 threshold were classified as suitable areas, while pixels with values below the threshold value were classified as unsuitable (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 Lake Tana Biosphere Reserve 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. 3).

Distribution of Nile monitor

Most suitable habitat for Nile monitor was mainly predicted in the northern parts of the Lake, and the western, eastern and southern parts of the Lake were also predicted to be suitable for the species (Fig. 4). 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 Nile monitor (Table 1).

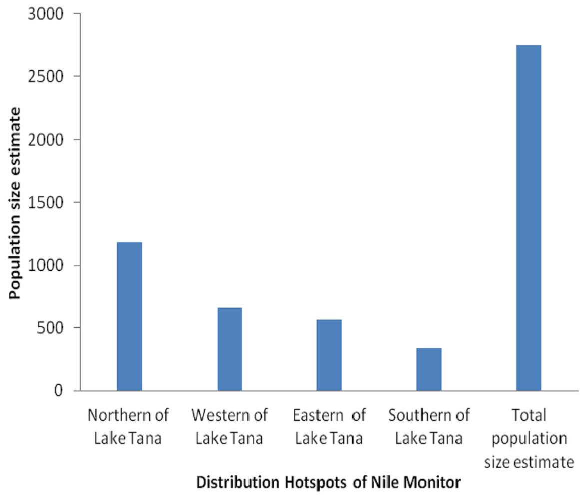

Fig. 3 Population size estimate of Nile monitor within the Lake Tana Biosphere Reserve

These variables presented the highest gain that is contained most information compared to other variables (Fig. 5).

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 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 Nile monitor presence. Precipitation seasonality, averaged across replicate runs identified as the main predictor accounting for a 28.4% contribution. Temperature seasonality was found to contribute 15.8% followed by 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 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. 6).

Precipitation seasonality was found to be the second important factor to determine the distribution of the species. This index provides percentage of precipitation variability where larger values indicate greater variability of precipitation. In other words, increase in precipitation seasonality up to 118% has led to an increase in the probability of occurrence of the species, but seasonality increase above 130% led to a decrease in the probability of occurrence (Fig. 7). This result shows the presence of high precipitation variability in the study area where precipitation favored the occurrence of the species ranged from 118 to 130%.

Likewise, temperature seasonality was found to be the third important factor to determine Nile monitor distribution. If there is a high variation then the seasonality is high, but if low, then there is less extreme difference throughout 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. An increase in temperature seasonality up to 11% has led to an increase in the probability of occurrence for the species, but 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 favored the occurrence of the species ranged from 11 to 14% (Fig. 8).

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 (210) followed by rain fed, post flooding, irrigated or aquatic croplands (14) and mosaic vegetation (30) (Fig. 9). 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 Nile monitor

MaxEnt model predictions for the current distribution of suitable areas for Nile monitor indicated that the species had a wide range of suitable areas across the Lake Tana Biosphere Reserve. Despite the species having a

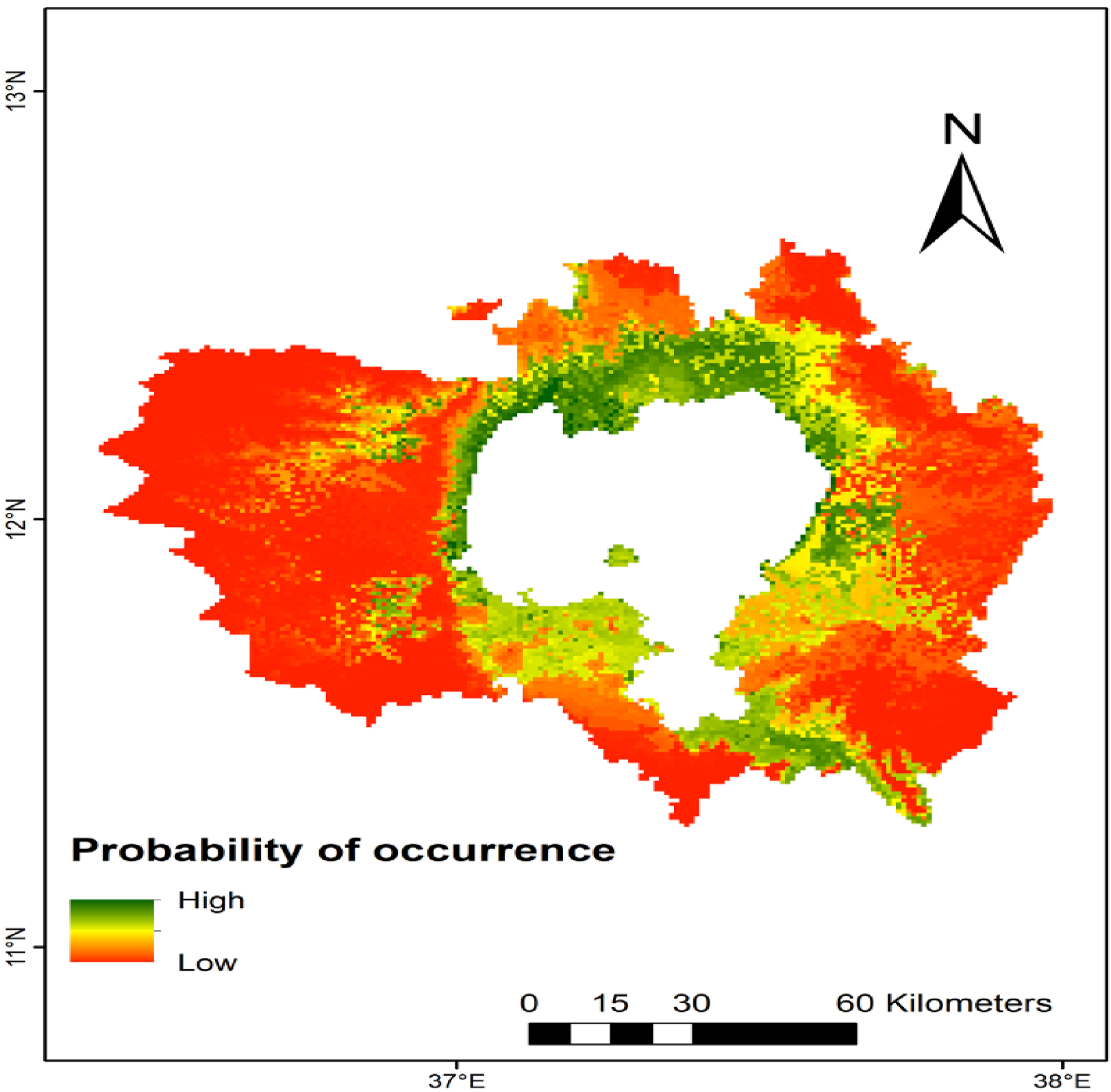

Fig. 4 Distribution map of the Nile monitor within the Lake Tana Biosphere Reserve

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 (%)
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

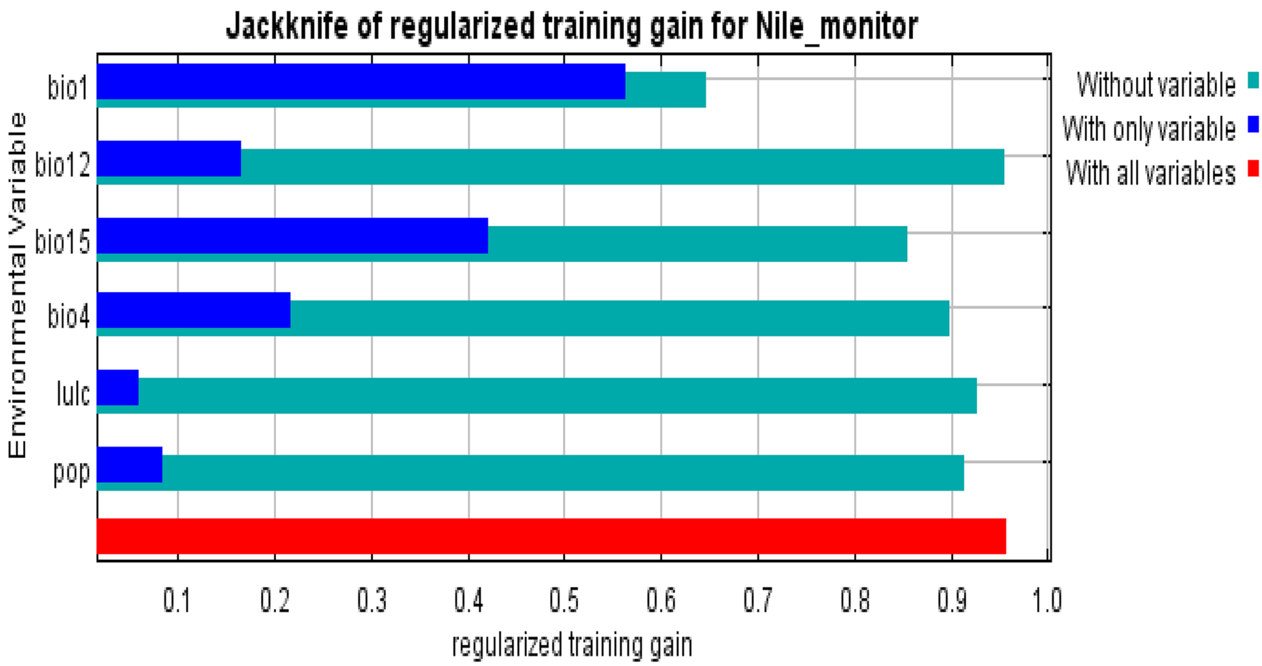

Fig. 5 Jackknife test of variable importance in modeling distribution of Nile monitor

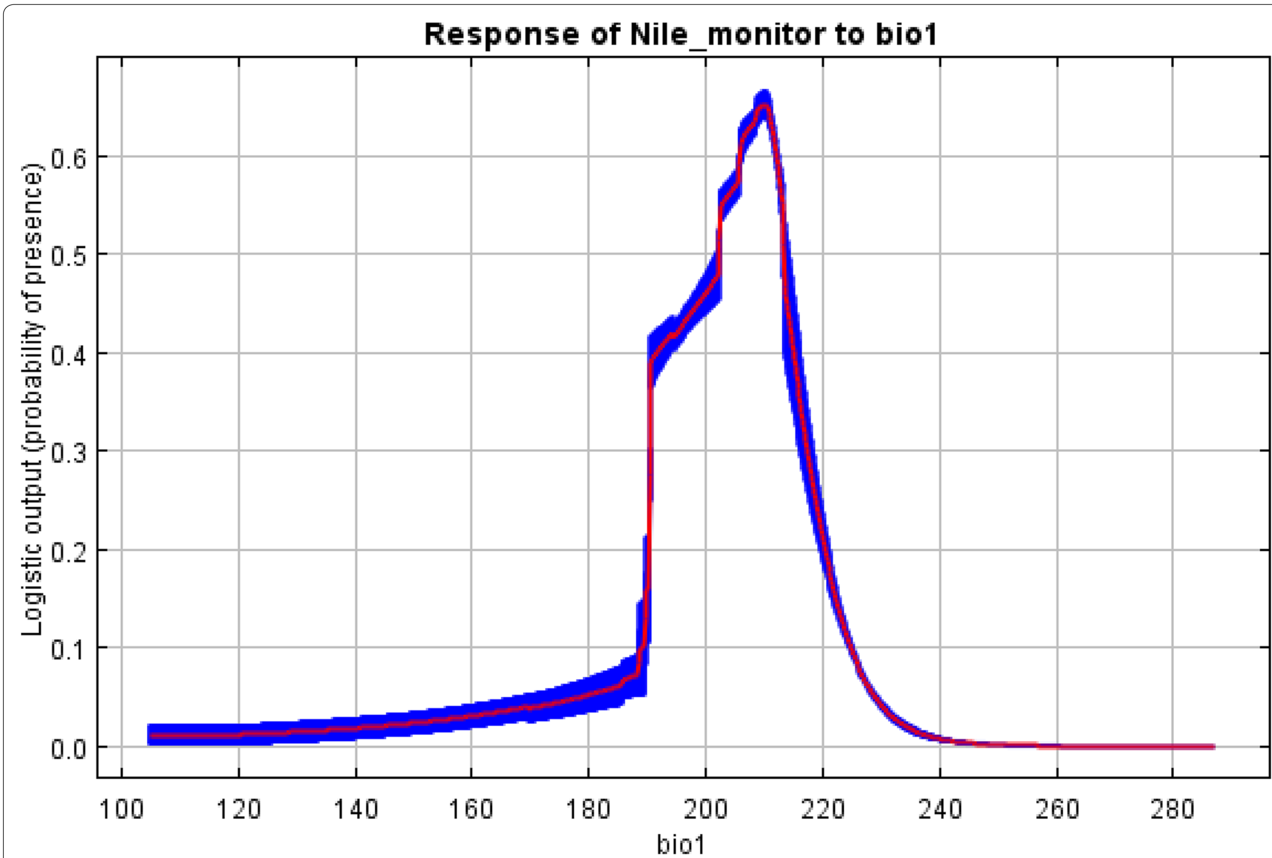

Fig. 6 The dependence of predicted suitability of the species on annual mean temperature

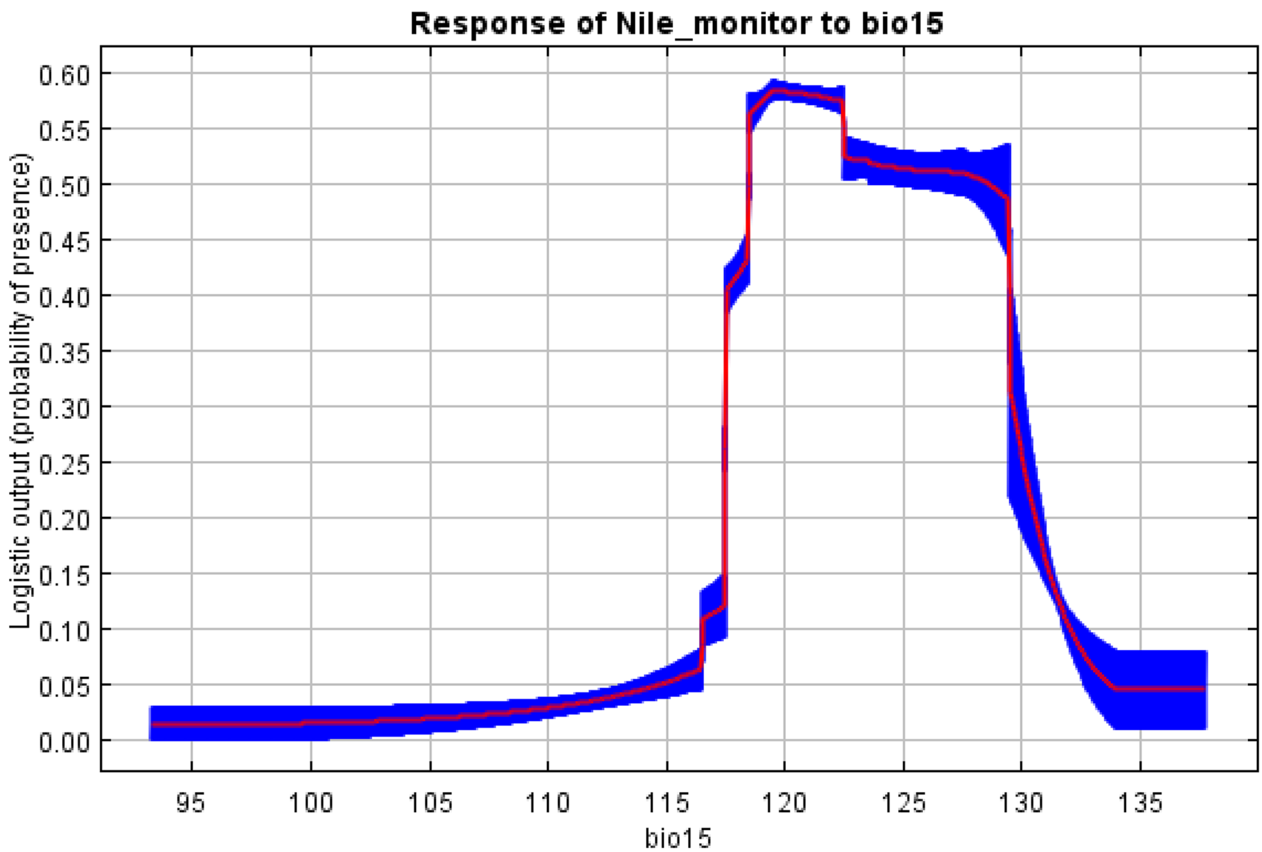

Fig. 7 The dependence of predicted suitability of the species on precipitation seasonality

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 RCP 6.0. The area predicted to be suitable for Nile monitor as a whole became more restricted under future climate projections, with the more extreme scenarios (RCP 8.5) showing extremely smaller predicted ranges (Fig. 10). Largely, findings revealed that areas very close to water bodies were predicted to be suitable for the species, 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 its body temperature. Nile monitors 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 and climate changes under scenarios used.

Discussion

The distribution of records suggests water bodies are corridors for Nile monitor. Indeed, the riverine areas are home to a notable proportion of its records. GPS coordinates place an additional majority of records in wetlands that physically flank habitats of the riverine areas and the Lake. Nile monitor prefers to live near permanent bodies of water in its native range. Pianka and King 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 other water bodies (Luiselli et al. 1999). As has been noted during our field 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 for the species.

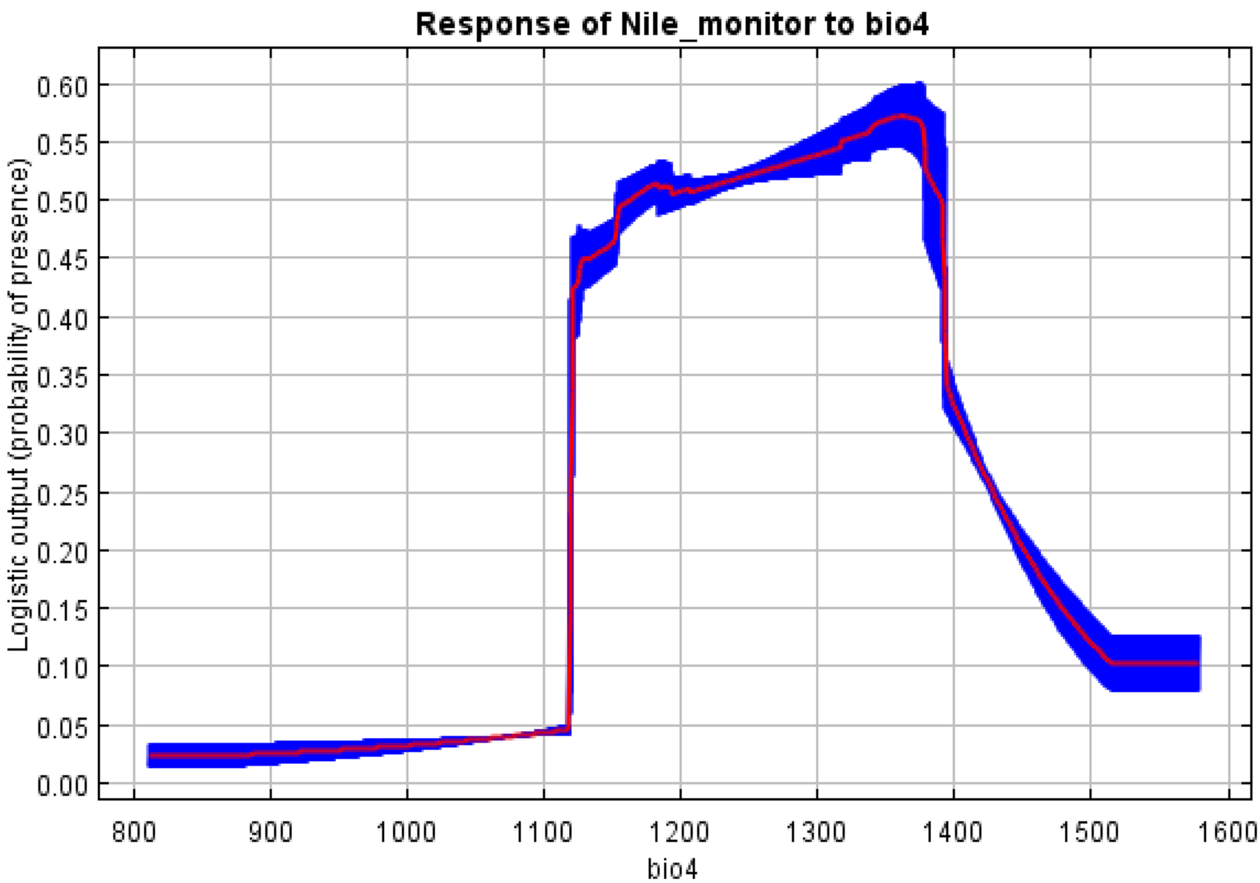

Fig. 8 The dependence of predicted suitability of the species on temperature seasonality

MaxEnt predictions for the current distribution of Nile monitor revealed that overall this species occurs in the immediate vicinity of water bodies suggesting that models correctly predicted the current distribution of the species as the species tends to choose aquatic habitats (Noah 2017). Predictably, the entire lush shore of the Lake Tana is identified by Maxent as the most suitable area for the Nile monitor. More interesting is the identification of rivers that flow to the lake as sites of highly probable presence. Credible sighting of Nile monitor 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.

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 is 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 the species.

Average temperatures in Ethiopia for 2070 under RCP 8.5 will increase by 4.1 °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, this study argue that even though this species is presently under least concern category (De Lisle 1996) it may become threatened or endangered soon due to habitat loss which will result from an increase in temperatures.

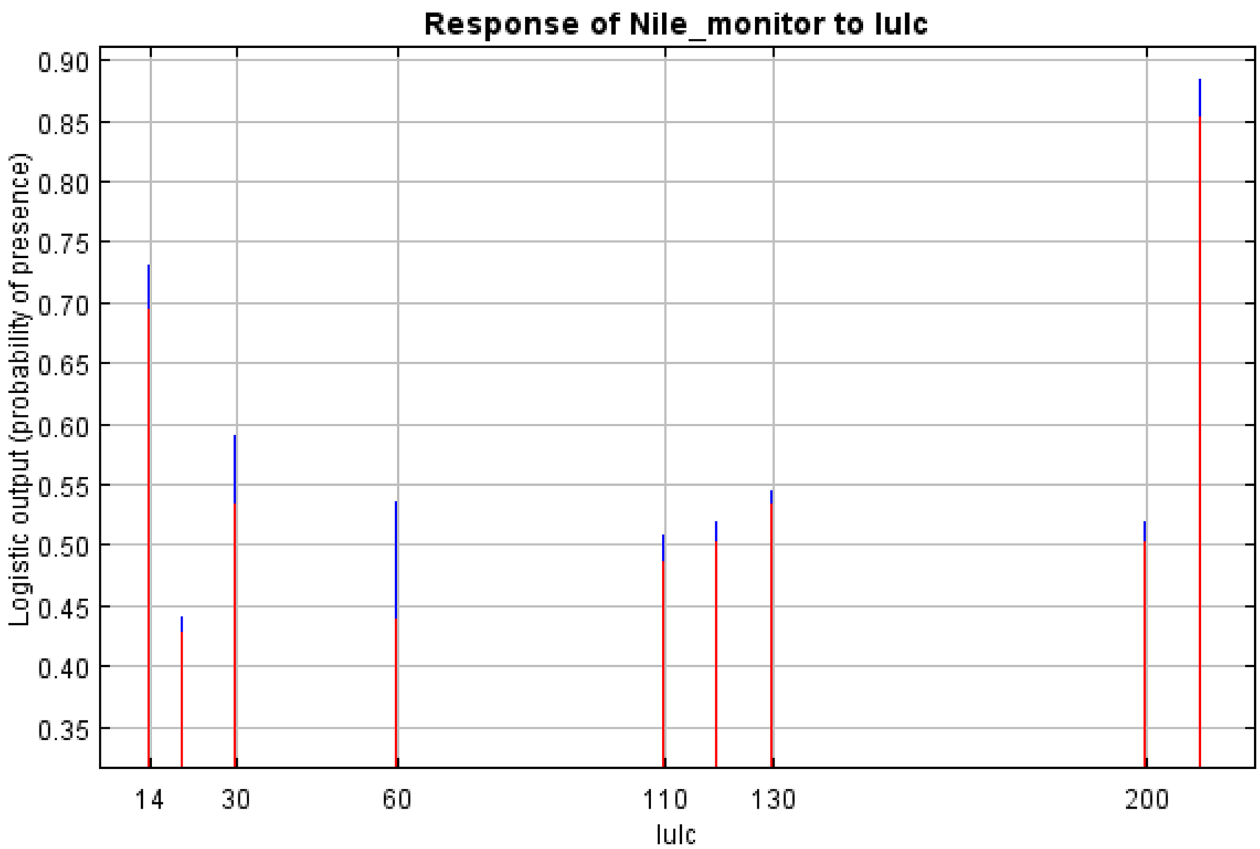

Fig. 9 The dependence of predicted suitability of the species on land use types

Furthermore the results showed that human population density, land use and annual precipitation played no important role in predicting the distribution of Nile monitor. 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 instancce, the species is observed to feed on cow milk. Such feeding behavior implies that the presence of livestock 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, observation and interviews made 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, and they are common in 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 has adapted to human or anthropogenic landscapes either through increased encroachment of their habitats by humans or through the species frequent visits to human settlements in search for food. Therefore, it is not surprising that some of the environmental variables selected to predict the spatiotemporal distribution of the species are not invaluable for predicating the potential suitable areas of Nile monitor in the Lake Tana Biosphere Reserve.

Conclusion

The findings of this study indicate that the most important factors that determine the distributions of the 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 Nile monitor can help in planning land use management around its existing 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

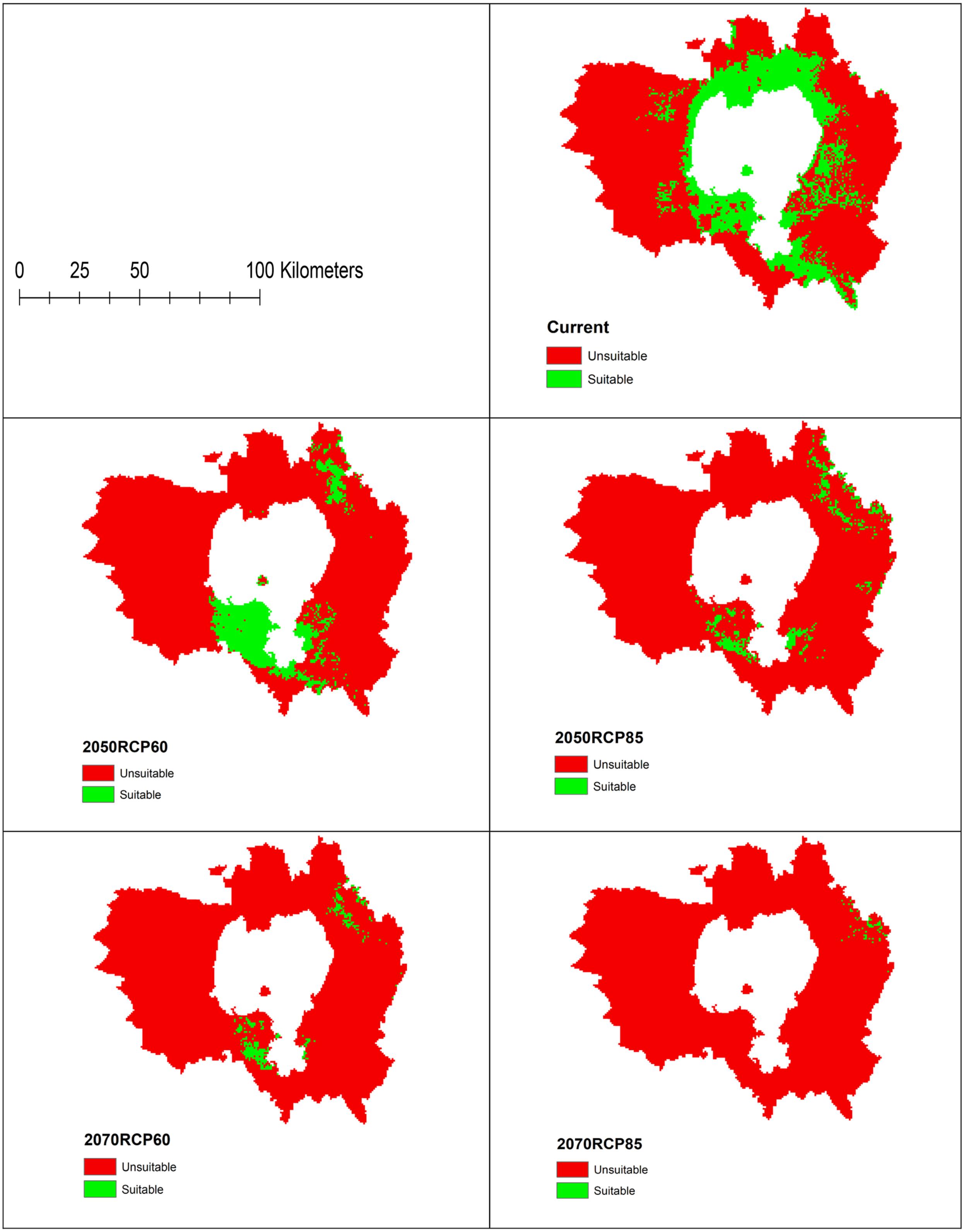

Fig. 10 Current and potential suitable areas of Nile monitor under different climate scenarios

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

Species	Area category	Current and future climate scenarios				
		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

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 Nile monitor 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.

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Authors' contributions
ED and TN conceptualized this study, collected, analyzed, interpreted the data and wrote the final manuscript. Both authors read and approved the final manuscript.

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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.

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Not applicable.

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The authors declare that they have no competing interests.

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