

Research article

Predicting the current and future suitable habitats for endemic and endangered Ethiopian wolf using MaxEnt model

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ABSTRACT

The Ethiopian wolf, endemic to Ethiopia, is the most endangered species in the world. As flagship species, a wide range of studies has been conducted on the Ethiopian wolf. However, there is scanty information about the impact of climate change on this globally important species. Thus, this study aimed to predict the current and future suitable habitats of the species based on four Representative Concentration Pathway scenarios of IPCC for the years 2050 and 2070 by using the MaxEnt model. A total of 479 species occurrence records were obtained from the field survey and Global Biodiversity Information Facility. The 19 bioclimatic variables and altitude were downloaded from worldclim and extracted for the study area using GIS software. The Pearson correlation analysis was employed to detect correlation among variables and maintained 10 variables. The prediction potential of the model was evaluated and found excellent to predict the distribution of the species. The result depicted that suitable habitats for Ethiopian wolves will be badly affected by climate change. Currently, about 9.4% of the total landmass of Ethiopia is suitable for wolves. However, it will be lost in the forthcoming couple of decade under all scenarios of global climate change. Consequently, the Ethiopian wolf is highly suspected to be extinct globally in the mid of 21st century, unless corrective measures are done in time. Therefore, enhancing the adaptive capacity of species as well as genetic resource preservation and captive breeding is advisable.

1. Introduction

The Ethiopian wolf (*Canis simensis*) is one of the five *Canis* species in Africa [1]. It is endemic to Ethiopia, the most endangered carnivore in Africa, and the rarest canid in the world [2]. The Ethiopian wolf is a very distinctive medium-sized, terrestrial and social animal [3] mainly feeds Afroalpine rodents [4]. As a unique species, the Ethiopian wolf has local, regional, and global significance [5]. The Ethiopian wolf is one of the top priorities for conservation and research [6], as the result, it has an important role in regional and global cooperation and collaboration. The Ethiopian wolf is the flagship species [5] and contributed to the conservation of the largest Afroalpine ecosystem in Africa [7]. The afro-alpine ecosystem is one of the most important ecological regions in sub-Saharan Africa [8]. As a top predator, the Ethiopian wolf control and regulate the function, integrity, and productivity of the ecosystem [9]. Besides, it has a significant role in the national economy being a potential source of tourism attraction [10]. The aforementioned evidence

pinpoints that the wolf has a huge role to maintain ecosystem function and integrity, promoting social benefit and economic development.

So far, a wide range of studies has been conducted on species biology, ecology, human interaction, and diseases [4, 9, 11, 12, 13]. The findings of the previous studies paved the way and set the foundation for the conservation of species and their ecosystem. However, regardless of the effort of the scientific community, the Ethiopian wolf population has been declining to the extent that it declines locally in some parts of the country [2]. Currently, Ethiopian wolves are confined to a few isolated mountains of Siemen and Bale Mountains National Parks in Ethiopia [14]. The most recent estimate indicated that the total population of Ethiopia wolves is not more than 500 across species [4, 15, 16].

Habitat contraction and fragmentation with the limited altitudinal ranges are one of critical problems for wolf conservation in Ethiopia [12]. On top of that, with global climate change, suitable habitat is expected to decline and lead to total habitat loss [6]. This also harms biodiversity and may lead to the total extinction of the species. Moreover, the ecosystem

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services associated with the existence of the species, for example, checks and balances on the food web and chain [17], can be altered. Consequently, the ecological process of the ecosystem is expected to be affected badly. Hence, understanding how and to what extent climate change affects the Ethiopian wolf distribution in advance, is crucial for setting proper climate change adaptation and mitigation strategies to conserve the species. However, there is limited information on the impact of global climate change on the current and future suitable habitat distribution for Ethiopia wolves. Therefore, this study is designed to fill this gap by predicting the impact of global climate change on the spatial distribution of suitable habitats for Ethiopian wolves using the MaxEnt model for influencing the decision for species and their ecosystem conservation in the face of changing climate [2, 15].

The MaxEnt is commonly used for modelling the species distribution from occurrence data using the principle of maximum entropy subjected to environmental constraints of the occurrence location [18, 19, 20]. In connection with this, we hypothesized that the Ethiopian wolf will have too narrow or no suitable habitat range for survival as the global climate change in the forthcoming couple of decades. It is also assumed climate change will lead to the total extinction of the Ethiopian wolf at the end of the 21st century. To test the hypothesis, four Representative Concentration Pathway scenarios of IPCC for 2050 and 2070 were used. The findings of this study will provide a vital contribution to on-going

Table 1. Bioclimatic Variables used in species distribution modeling.

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

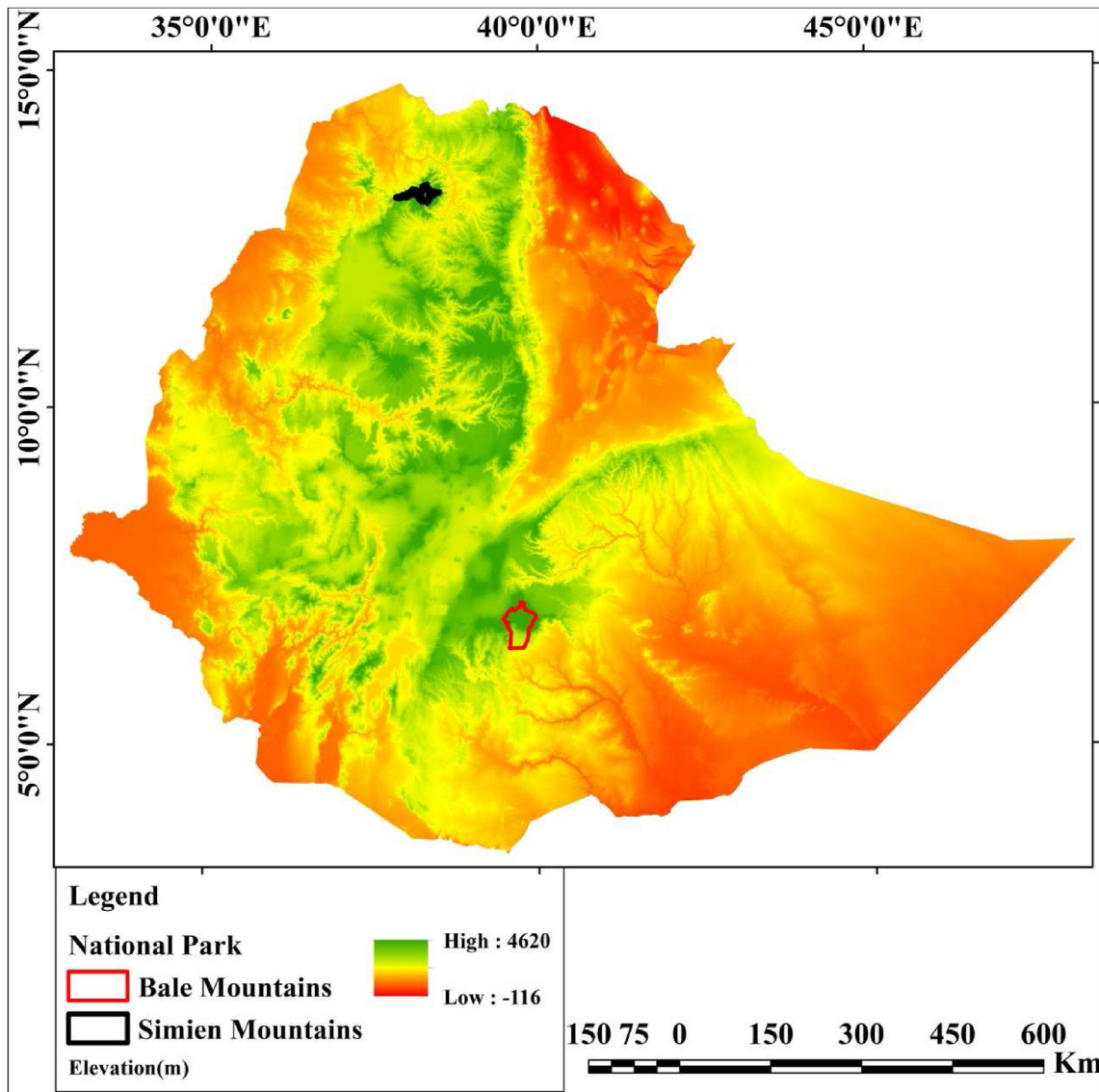


Figure 1. Location of the study area.

scientific debates on the impact of climate change on endemic species and urge the urgency of species conservation in the contemporary world.

2. Materials and methods

2.1. Study area description

The study was conducted in Ethiopia. Ethiopia is a country located in the horn of Africa having a wide range of altitudinal variation that ranges from -116 m below sea level at Dallol depressions to 4620 masl at Ras-dashen (Figure 1). The estimated total land surface of the country is 1,104 km². Ethiopia is the second-most populous country in Africa. The country is rich in species with significant global importance [21]. Ethiopia encompasses diverse ecological zones and many rare, endemic and endangered species [22].

The Ethiopian wolf, an endemic to Ethiopia, is confined in the isolated mountains of Bale and Simen Mountains National Parks [12]. Furthermore, currently, the distribution of wolves is limited to high altitudes within the elevation range between 3000 and 4500 masl [5].

2.2. Species occurrence data and environmental variables

A total of 497 species occurrence (presence) data were recorded, out of which 437 occurrence points were collected from a field survey during 2018–2021 using the GPS. The rest 60 species occurrence records were collected from GBIF databases (GBIF.org) accessed on 18 December 2020 (<https://doi.org/10.15468/dl.c3y2yq>). The 19 bioclimatic variables (Table 1) having a spatial resolution of 1km² (30s) were downloaded from the Worldclim database (www.worldclim.org). Worldclim version 2.1 climate data was used by averaging for the years 1970–2000.

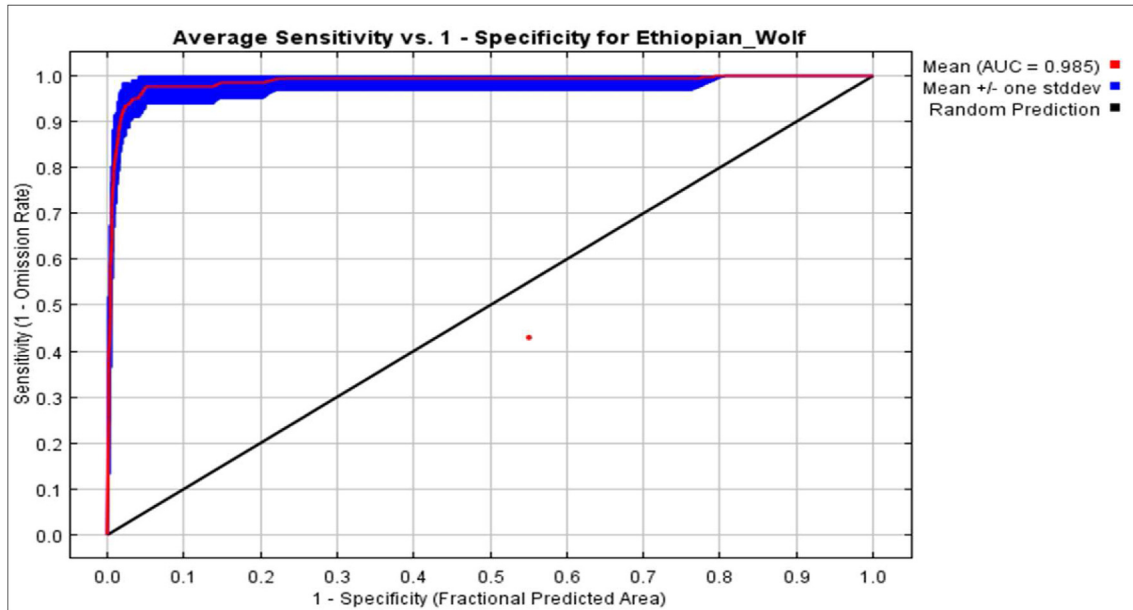


Figure 2. The mean AUC value for the current period (1970–2000).

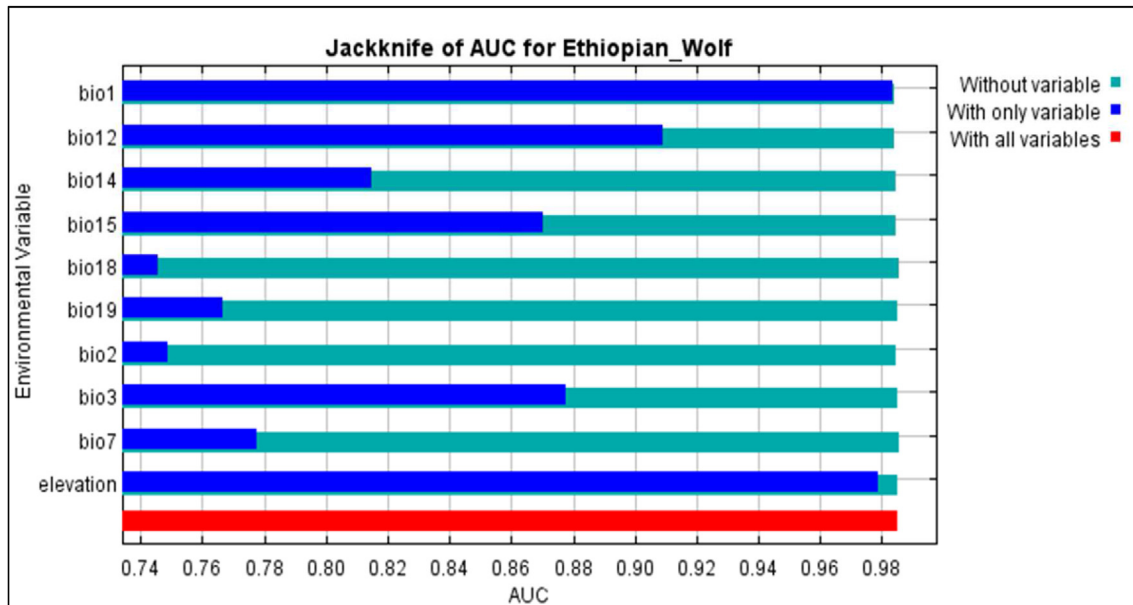


Figure 3. Jackknife test results of variable importance.

Table 2. Contribution of predictor variables in the model.

| Variable | Relative contribution (%) | Permutation importance (%) |
|-----------|---------------------------|----------------------------|
| Bio1 | 82.55 | 93.49 |
| Bio2 | 0.64 | 0.31 |
| Bio3 | 0.01 | 0.07 |
| Bio7 | 0.21 | 0.29 |
| Bio12 | 3.09 | 1.30 |
| Bio14 | 1.24 | 3.22 |
| Bio15 | 0.26 | 0.85 |
| Bio18 | 0.32 | 0.19 |
| Bio19 | 1.39 | 0.27 |
| Elevation | 10.31 | 0.00 |

The General Circulation Model (GCM) HadGEM2-AO was used to estimate the impact of future climate on Ethiopia's wolf. The HadGEM2-AO is one of the most powerful global climate projections to predict the effect of climate change on species distribution [23]. The four Representative Concentration Pathways (RCPs) such as RCPs 2.6, RCPs 4.5, RCPs 6, and RCPs 8.5 for the 2050s (2041–2060) and 2070s (2061–2080) were used. The RCPs 2.6 represent the lowest greenhouse gasses emission (GHG) scenario, RCPs 4.5 and RCPs 6 represent the intermediate GHG emission scenario, and RCPs 8.5 highest GHG emission scenario [24]. The scenario-based data were downscaled to the extent of the study area using GIS software. The correlation among 19 bioclimatic variables was determined by using the Pearson correlation coefficient. The correlation coefficient value of 0.8 was used as a cut point to include bioclimatic variables and 9 variables having a threshold value below the cutoff point were used for simulation analysis (Table S1). These variables

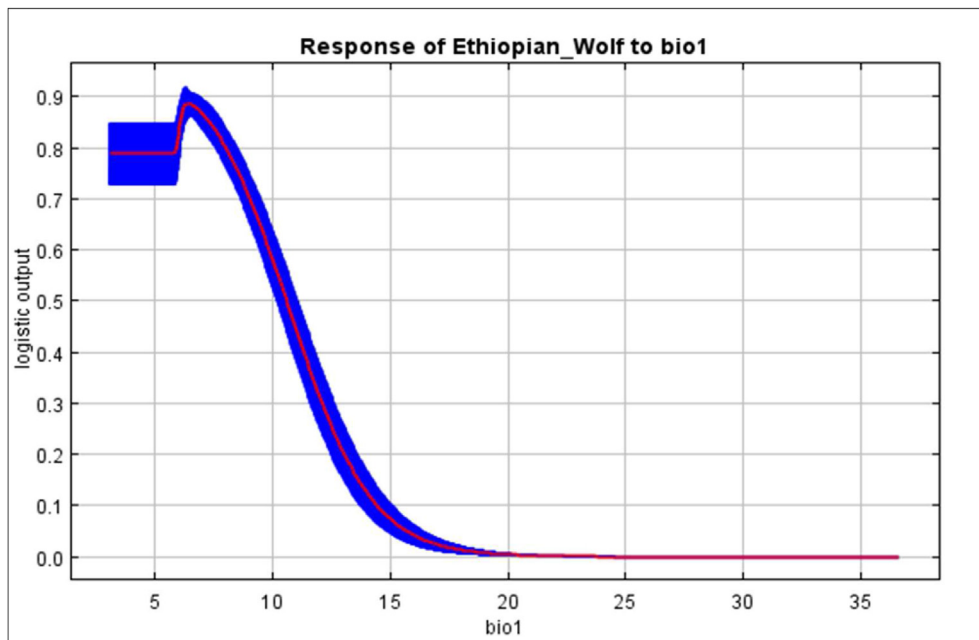


Figure 4. The response of *C. simensis* to mean annual temperature.

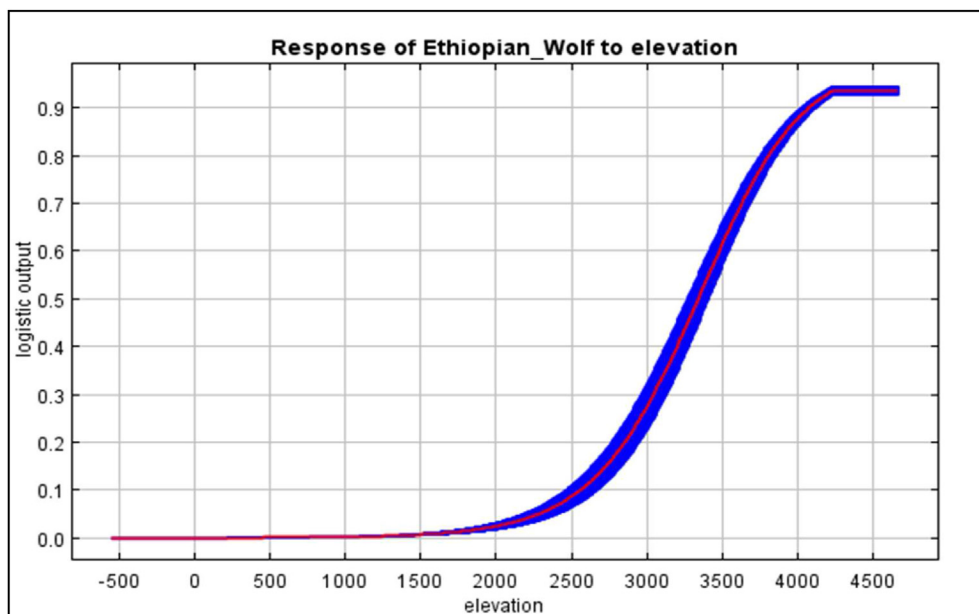


Figure 5. The response of Ethiopian wolf to elevation.

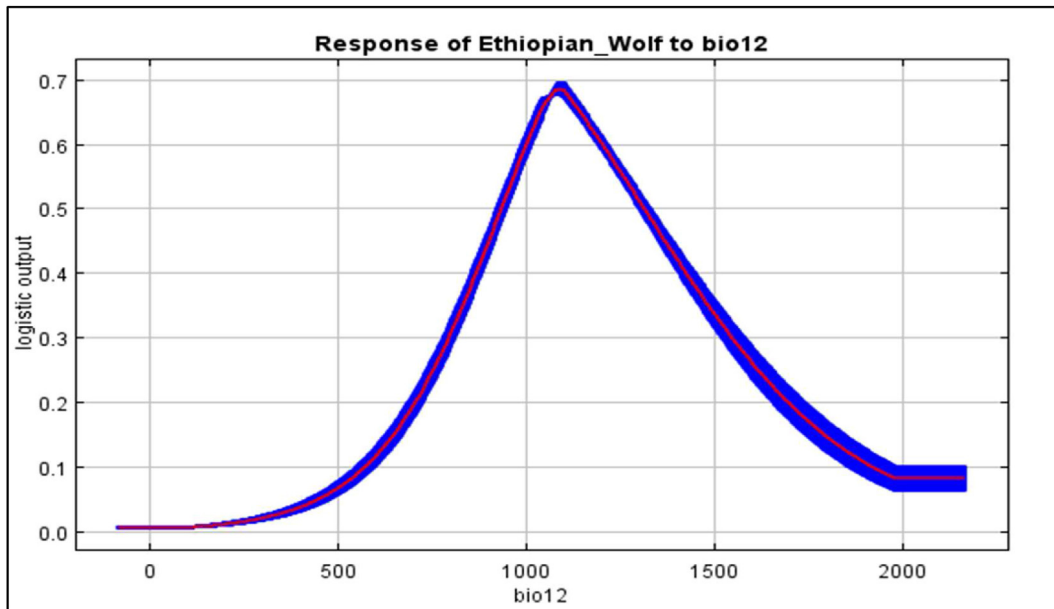


Figure 6. The response of Ethiopian wolf to mean annual precipitation.

are Bio1, Bio2, Bio3, Bio7, Bio12, Bio14, Bio15, Bio18, and Bio19. Moreover, considering the altitudinal range limitation of Ethiopian wolves [12], elevation was included in the analysis as a conservative variable. The importance of individual variables was assessed using the contribution percentage and permutation importance. All included predictor variables (bioclimatic and environmental factors) were resampled to the pixel size of 30-meter resolution.

2.3. MaxEnt model and data analysis

The MaxEnt model is one of the most popular for predicting species geographical distribution by using the presence-only data and environmental conditions of the locations [20]. MaxEnt has several advantages over other species distribution models [18]. It uses only presence data, uses both continuous and categorical variables, efficient, concise, and

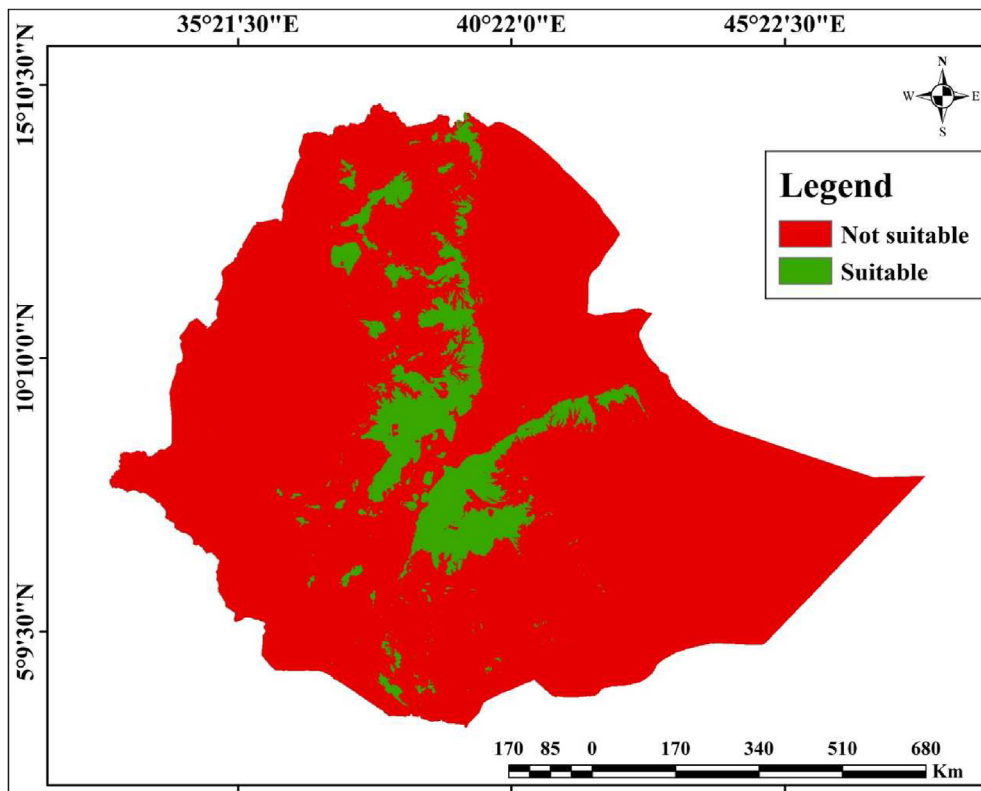


Figure 7. The current suitable habitat distribution for Ethiopian wolf.

easy to analyze [19]. For this study, we run the model using the MaxEnt algorithm version 3.4.1. The data sets were divided into two comprising 70% for training and 30% for testing or model validation. In the modeling process, the model feature was checked for Linear, quadratic, and product functions. The robustness of the model result was checked, the regularization multiplier was adjusted to 3 and the maximum number of background points was also adjusted to 10000. The replication was attuned to 10 with subsample run type. The maximum iteration was fixed to 5000 and a 10 percentile training presence logistic threshold was applied. The model performance was evaluated using Area under Receiver operating characteristic curve (AUC) plot. Based on AUC value, the model can be categorized as failing ($AUC < 0.6$), bad ($0.6 < AUC < 0.7$), reasonable ($0.7 < AUC < 0.8$), good ($0.8 < AUC < 0.9$) and excellent ($AUC > 0.9$) [25,26]. Moreover, dominantly contributing variables were assessed by the jackknife test.

3. Results

3.1. Model performance evaluation and variables contribution

The mean AUC value for the current period (1970–2000) was presented (Figure 2). The result showed that the mean AUC value was 0.985. The model performance was found excellent for predicting the distribution of Ethiopian wolves.

The Jackknife test result (Figure 3) showed that the habitat for Ethiopian wolf is largely governed by mean annual temperature, elevation, annual precipitation, isothermality, precipitation seasonality, and precipitation of the driest month.

Table 2 showed the relative contribution and permutation importance of the predictors (bioclimatic and environmental variables) in the model for predicting the habitat distribution for Ethiopian wolves.

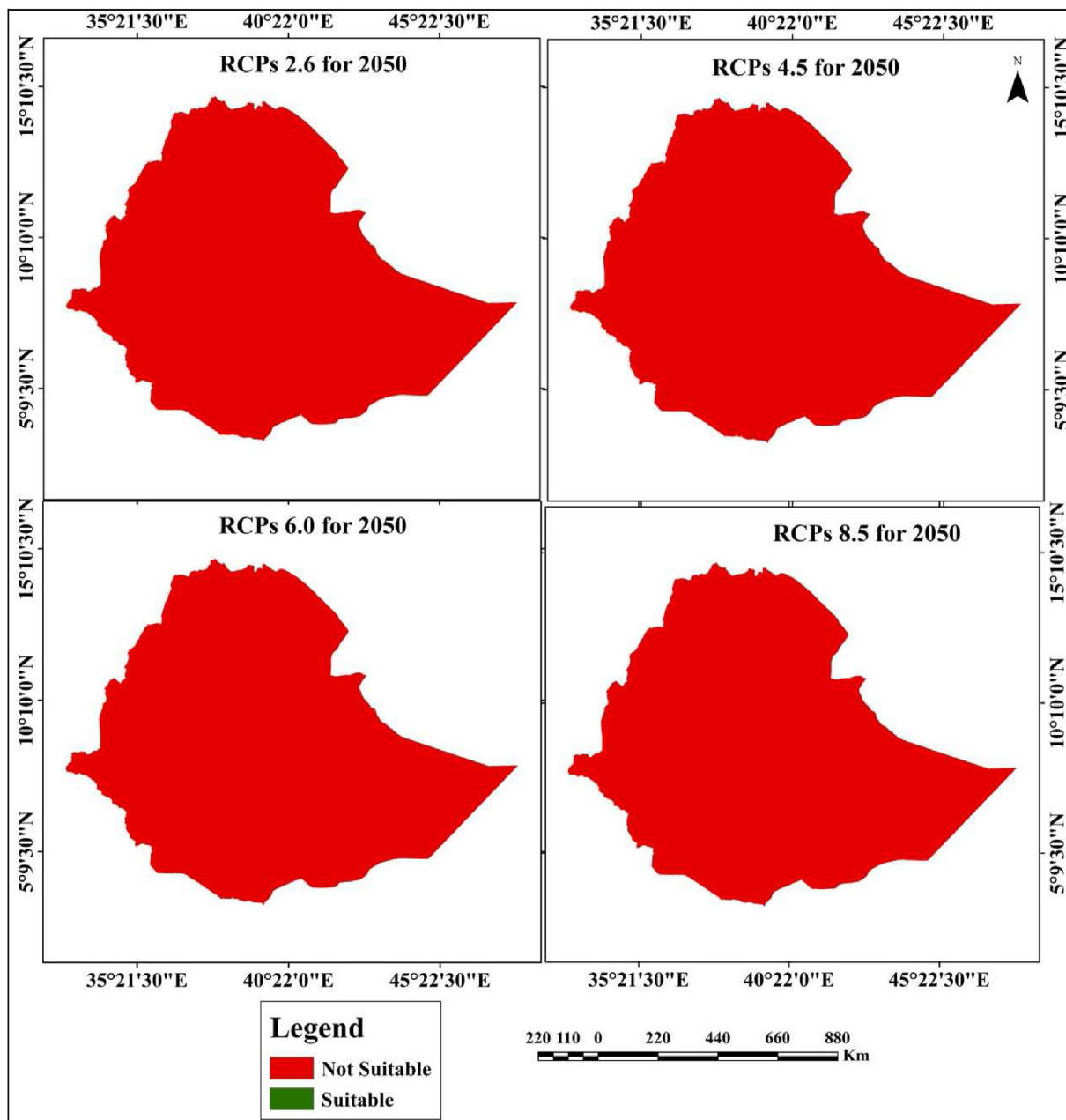


Figure 8. Distribution of suitable habitats for *C. simensis* for 2050 by RCPs.

Though all predictor variables contributed to model prediction, the relative contribution of mean annual temperature (82.55%) was highest followed by elevation (10.31%) and annual precipitation (3.09%).

The model result indicated that the suitable habitat tends to decline as temperature increased beyond 6 °C and cannot exist above 20 °C (Figure 4).

The model result showed that the altitude gradient above 2500 masl was suitable for the species (Figure 5).

The model prediction result revealed that mean annual precipitation of 500–2000 mm is optimal for the species' survival (Figure 6). However, as the two extreme conditions of annual precipitation (below 500mm and above 2000) happen, the suitable habitat for species tends to decline (Figure 6).

3.2. Current and future suitable habitat for Ethiopian wolf

The model prediction results revealed that 9.4% of the total landmass of Ethiopia is currently suitable for Ethiopian wolves (Figure 7). The current potentially suitable habitat is distributed in the highlands of the country south to north (Figure 7).

The future model projection for all scenarios of climate change showed the total loss of potentially suitable habitat to the endangered

and endemic Ethiopian wolves in the mid of 21st century (Figure 8). Similarly, the model result showed the complete loss of potentially suitable habitat for Ethiopian wolves at the end of 2070 (Figure 9).

4. Discussion

Climate change affects the current and future potentially suitable habitat distribution for biodiversity [27]. Some species might get advantages of climate change by getting additional suitable areas for their reproduction and growth [28]. On the other hand, others are adversely affected by climate change [29]. The findings of this study revealed that climate change has harmed the current and future distribution of suitable habitats for Ethiopian wolves. For all scenarios of climate change, our model prediction result revealed the complete loss of potentially suitable habitat for Ethiopian wolves in the forthcoming couple of decades. For the current climate condition, the model prediction of suitable habitat for Ethiopian wolves is consistent with the species' current distribution.

The model result showed that mean annual temperature, precipitation, and elevation highly governed the distribution of the Ethiopian wolf. The Ethiopian wolf requires 500–2000 mm of mean annual

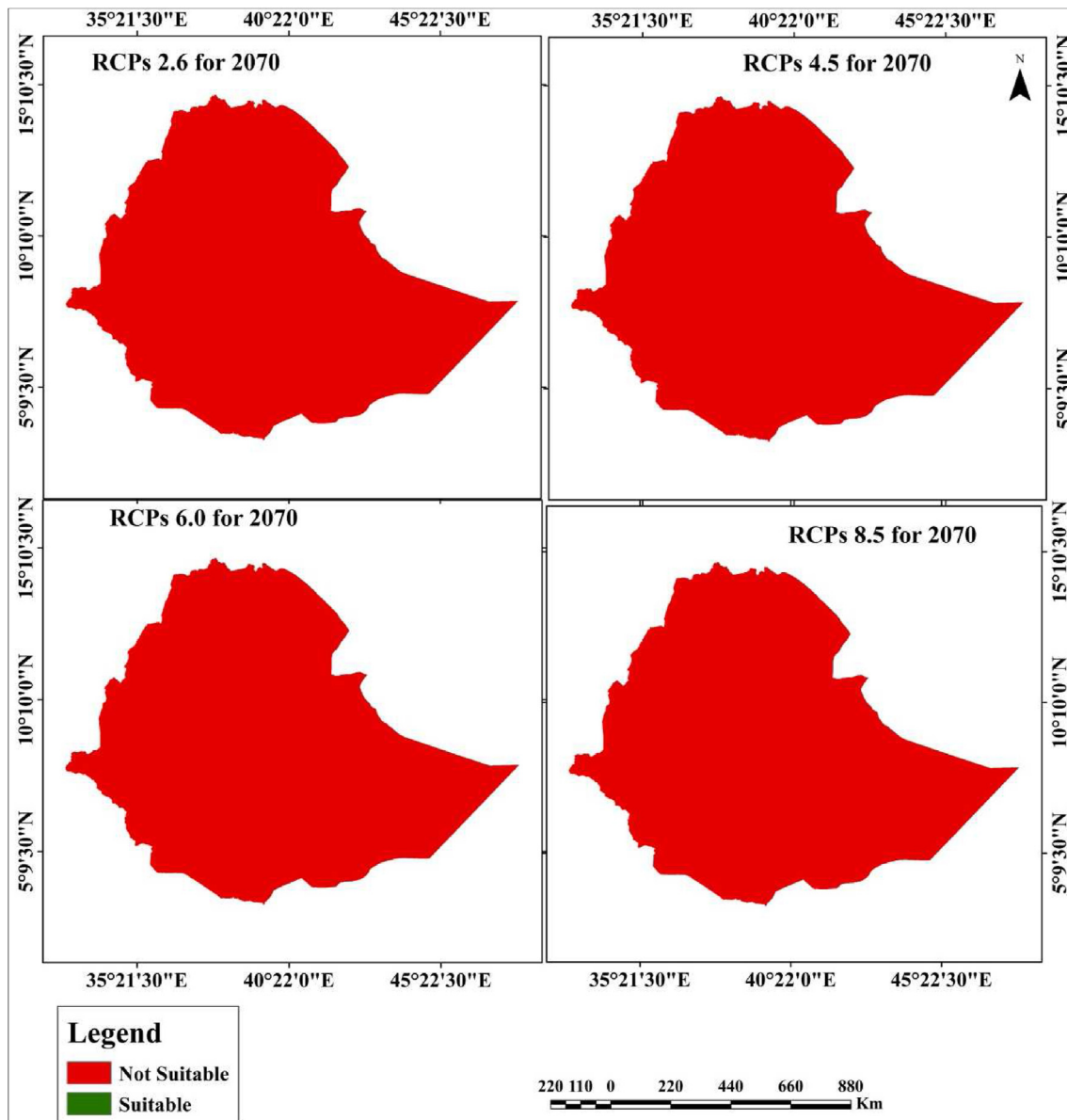


Figure 9. Distribution of suitable habitats for Ethiopian wolf for 2070 RCPs.

precipitation for reproduction, optimum growth, and survival [30]. In line with this, the currently suitable habitats of Ethiopian wolves were characterized by having annual precipitations within the range limits of the model result [5, 28]. However, the climate prediction of the future precipitation indicated an erratic rainfall and a high probability for the occurrence of the two extreme conditions of annual precipitation (below 500mm and above 2000) in Ethiopia. Consequently, the future suitable habitat for the Ethiopian wolf would become lost. The wolves require a cold temperature [31]. The model result confirmed that the mean annual temperature of 5–20 °C found in the elevation gradient between 2500 and 4500 masl is optimum for this species; however, beyond the range the species' survival becomes problematic. The empirical ecological studies confirmed that the habitat range of wolves has been confined to a few mountains of the country with too cold temperatures [6, 9, 12, 18, 27]. However, the temperature of currently suitable habitats for species is consistently predicted to be increased in the forthcoming decades [32]. The rises in temperature beyond the optimum ranges limit the species' reproduction and survival. This, in turn, leads to a significant decline in suitable habitat and species fecundity.

The model prediction revealed that currently 9.4% of the total landmass of Ethiopia is potentially suitable for Ethiopian wolves. These suitable habitats were mainly situated in highlands with peak elevations in the country where climate change is predicted to be changed in the forthcoming decades [24]. Furthermore, currently, suitable areas are characterized by high fragmentation, isolation, and sparsely distributed in the country. The anthropogenic pressures were high in these areas compared to other parts of the country. As a result, beyond climate change, currently, suitable habitats for species are highly subjected to further habitat fragmentation and contraction. Similar to this result, previous studies reported that human-induced habitat fragmentation and growing human population pressure has been hampering the suitable habitat range of the Ethiopian wolf [15].

5. Conclusion

We predict the impact of climate change on the distribution of suitable habitats for globally endangered Ethiopian wolves. The result shows that, currently, 9.4% of the total landmass of Ethiopia is potentially suitable for Ethiopian wolves. However, the entire suitable habitat will be lost in the forthcoming couple of decades for all scenarios of climate change in Ethiopia. This will also lead to total global extinction of the species in the mid of 21st century unless necessary interventions are done in time. Therefore, scaling up the adaptation strategies, genetic resource preservation, and captive breeding are advisable. Further studies to enhance the survival of species with changing environmental conditions are important.

Declarations

Author contribution statement

Yericho Berhanu; Nega Tassie: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed materials, analysis tools, or data; Wrote the paper.

Dejene W. Sintayehu: Performed the experiments; Analyzed and interpreted the data; Contributed materials, analysis tools, or data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in the article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

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