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MODELING THE DISTRIBUTION OF FOUR-BIRD SPECIES UNDER CLIMATE CHANGE IN ETHIOPIA

Lumbani Benedicto Banda[1,2]* and Nega Tassie[3]

ABSTRACT: Climate change is one of the major threats to bird populations. Its effects on birds include range shifts, changes in population sizes, earlier breeding and changes in breeding performance. Under climate change, conservation of birds will require an understanding of the present status and responses of birds to future climates. However, our knowledge of the future distribution of bird species is limited especially in developing countries like Ethiopia where avian research is still in its infancy. Here, we used the MaxEnt model to predict the current and future distribution of four-bird species (*Bostrychia carunculata*, *Columba albirtoques*, *Corvus crassirostris*, and *Lybius undatus*) in Ethiopia under different climate scenarios. The results indicated that maximum temperature, annual precipitation, and human population density were the main factors that determined the distribution of these species. Further, suitable areas for these species were projected to decline under future climate scenarios with the greatest declines being experienced in 2070 under RCP 8.5. However, highland areas experienced low geographic range losses for the four-bird species under climate change. These findings suggest that conservation measures that protect and maintain important highland habitats can ensure the persistence of these bird species under future climates.

Key words/phrases: Bird species, Climate change, Ethiopia, MaxEnt, Species distribution.

INTRODUCTION

Climate change is one of the major threats to biodiversity and its adverse effects have already started manifesting in different taxa (Chen *et al*., 2011; Hetem *et al*., 2014). An increasing body of research suggests that species will shift their geographic distributions under climate change as they track favourable climates (Thomas *et al.*, 2004; Hickling *et al*., 2006; Chen *et al*., 2011). Generally, these shifts could threaten their persistence through range reductions which may decrease population sizes (Gaston, 1994),

[1] Africa Centre of Excellence for Climate Smart Agriculture and Biodiversity Conservation, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia. E-mail: lumbabanda@gmail.com
[2] Department of Environmental Sciences and Management, Lilongwe University of Agriculture and Natural Resources (LUANAR), Bunda College Campus, P.O. Box 219, Lilongwe, Malawi.
[3] Department of Biology, Bahir Dar University, P.O. Box 1817, Bahir Dar, Ethiopia. E-mail: nega7719@gmail.com
*Author to whom all correspondence should be addressed

consequently aggravating the risk of population and species extinction (Thomas *et al*., 2004). In tropical regions, species are expected to shrink their distributions with a warming climate by shifting to higher elevations (Chen *et al*., 2011). Nevertheless, the survival of species in newly suitable areas created by climate change may not be guaranteed because these new regions may not be protected (Araujo *et al*., 2004; Thuiller *et al*., 2006; Araujo *et al*., 2011). One possible option available for species is adaptation, however, this is plausible when the rate of climate change is slow, but the current rate of change is very fast making adaptation difficult for some taxa (Hetem *et al*., 2014).

Birds are among the most vulnerable species to climate change due to their high sensitivity to climate and weather (Sparks *et al*., 2002). Effects of climate change on birds include; range shifts, changes in population sizes, earlier breeding and changes in breeding performance (Crick, 2004). These effects are severe on endemic bird species, which have specialized ecological niches, thus making them more vulnerable to extinction than other species (Isik, 2011). Conservation of species under climate change will need knowledge of the species that will be most vulnerable to future changes and the factors that might influence their vulnerability or resilience (Case *et al*., 2015). Furthermore, conservationists now acknowledge the value of preparing for short and long-term extreme weather events in the management of species under climate change (Lawler *et al*., 2015).

Ethiopia is rich in avifauna diversity and endemism with 73 Important Bird Areas (IBAs) (Shimelis Aynalem and Afework Bekele, 2008). It possesses over 860 bird species, of which 16 are endemic and 14 species are endemic to both Ethiopia and Eritrea (Seyoum Kiros *et al*., 2018; Lepage, 2018), Unfortunately, bird diversity in this country is threatened by anthropogenic activities, which have led to habitat destruction and fragmentation (Zerihun Girma *et al*., 2017b). In addition, birds have also been threatened by climate change (Sala *et al*., 2000). Understanding how birds will respond to these threats will form a basis for designing sustainable and effective conservation strategies.

Recently, there has been an increasing number of studies that have enhanced our understanding of the ecology and response of birds to various threats in Ethiopia. However, most of these studies have focused on species diversity, composition, abundance and distribution in different habitats (Shimelis Aynalem and Afework Bekele, 2008; Nega Tassie and Afework Bekele, 2008; Addisu Asefa *et al*., 2017; Zerihun Girma *et al*., 2017a; Zerihun

Girma *et al*., 2017b). Studies on the effects of climate change on the distribution of various avifauna species are rare, especially in Ethiopia. Nevertheless, the conservation of birds in the presence of a rapidly changing climate requires knowledge of the present status and future response of the species to changes in climate (Siegel *et al*., 2014). However, such knowledge is inadequate, especially in developing countries like Ethiopia, where avian research is still in its infancy.

Here we predicted the effects of climate change on the distribution of four bird species – Wattled Ibis (*Bostrychia carunculata*), White-collared Pigeon (*Columba albirtoques*), Thick-billed Raven (*Corvus crassirostris*) and Banded Barbet (*Lybius undatus*). These species are under the Least Concern (LC) conservation category of the International Union for Conservation of Nature (IUCN). *B. carunculata*, *C. albirtoques*, and *L*. *undatus* are endemic to Ethiopia and Eritrea while *C*. *crassirostris* is endemic to Ethiopia, Eritrea, and Somalia. *B. carunculata* mainly inhabits grasslands and heathlands and it is often observed near water but roosting and breeding are mainly on cliffs (Sinclair and Ryan, 2010). *C. albirtoques* inhabits rocky cliffs and gorges, while *C. crassirostris* prefers mountainous areas and *L. undatus* prefers woodlands and forests (Sinclair and Ryan, 2010). We selected these species because of their endemism and wide distribution. Thus, their response to changes in climate may provide an indication of how endemic and widely distributed species will be affected by climate change. Our objectives were two-fold: i) identifying the most relevant variables that influence the distribution of the four bird species and ii) predicting the distribution of the four bird species under future climate scenarios.

MATERIALS AND METHODS

The study area

The study was conducted in Ethiopia which covers an area of about 1.13 million km² and has a human population of over 100 million. The country is found between 03°N and 15°N latitude and 33°E and 48°E longitude (Fig. 1). It has a wide range of altitudinal differences with the highest peak at Ras Dashen (4620 m above sea level) and the minimum 126 below sea level in the Afar depression (Weldemariam Tesfahunegny, 2016). Climatic conditions in Ethiopia vary depending on elevation and range from hot and arid climates in lowlands to cool climates in highlands. Wide elevation gradient allows for the occurrence of different species with different attitudinal preferences including our study species. For instance, *B. carunculata* occurs from 1500–4100 m, *L. undatus* from 300–2400 m, *C.*

crassirostris from 1200–4100 m while *C. albitorques* is dominant above 2400 m (Weldemariam Tesfahunegny, 2016).

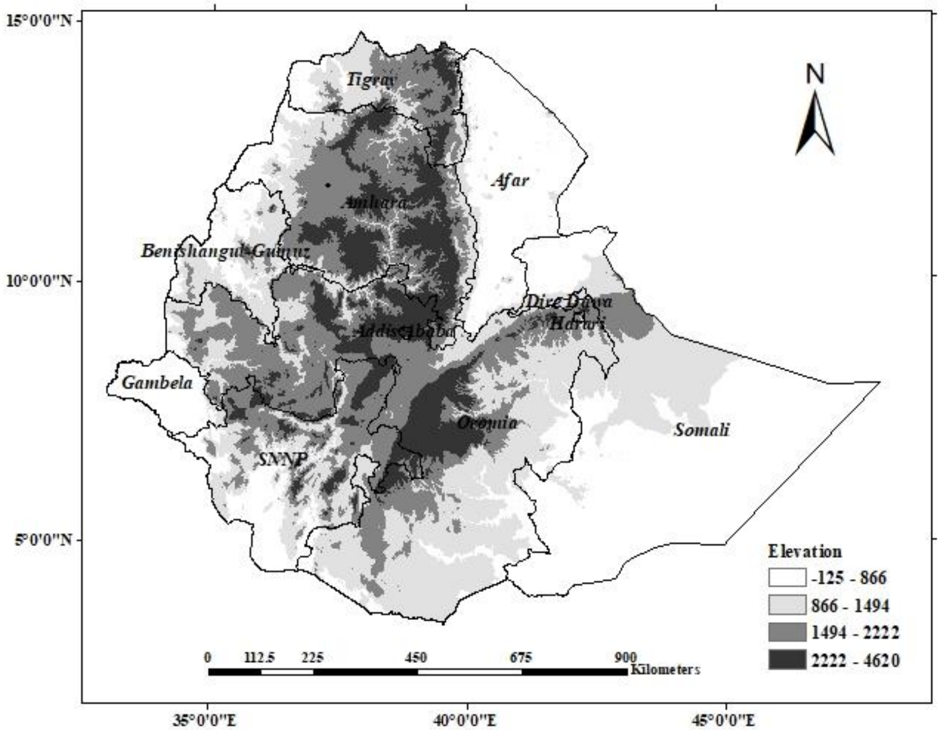

Fig. 1. Elevation map of Ethiopia; elevation ranges from 125 m to 4620 m above sea level.

Species occurrence data

We used species occurrence records obtained from various sources including; eBird (www.ebird.org), Atlas of Birds of Ethiopia (Ash and Atkins, 2009), Natural History Museum of Addis Ababa University and from others (Nega Tassie, 2007; Nega Tassie and Afework Bekele, 2008). Duplicate records were removed and finally, we used 206 occurrence records for *B. carunculata*, 131 for *C. albitorques*, 229 for *C. crassirostris* and 178 records for *L. undatus*.

Environmental data layers

Maximum temperature and nineteen bioclimatic environmental layers that represent different aspects of precipitation, temperature and seasonality were obtained from Worldclim 1.4 (www.worldclim.org) at a resolution of

30 arc seconds (Hijmans *et al*., 2005). Under Worldclim 1.4 the current climate scenario represents averages from 1960 to 1990. To extract future climate scenarios the Hadley Global Environmental Model 2-Atmospheric Ocean (HadGEM2-AO) from Worldclim was used as it provides good coverage for Africa (Jaramillo *et al*., 2011; Davis *et al*., 2012). From this model, four Representative Concentration Pathways (RCPs) 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).

To account for the effect of anthropogenic activities on the distribution of birds (Pulliam, 2000; Soberón, 2007), we included variables that are associated with human influences on ecosystems or landscapes. In this regard, we incorporated human population density figures from the World Population database (https://www.worldpop.org/) and land-use classes for Ethiopia (http://due.esrin.esa.int/page_globcover.php). Unlike bioclimatic variables that were dynamic (changing under different climate scenarios), human population density and land cover variables were considered static because we did not find reliable future projections for these variables. Thus, an implicit assumption that human population density and land cover will not change for the future was made. Even though such an assumption is unlikely, including static variables that affect species distribution is better even if it means making the assumption that their values will not change in the future (Stanton *et al*., 2012). Besides models that combine static and dynamic variables were found to perform better or no worse than models that only included dynamic variables (Stanton *et al*., 2012).

Environmental variables are usually spatially correlated, however fitting models with correlated variables can affect model transferability especially when correlations change over space and time (Dormann *et al*., 2012). Hence before fitting environmental variables to the MaxEnt model, we performed a multicollinearity analysis using Environmental Niche Modeling tools (ENM tools 1.44). For pairs of variables that were highly correlated (≥ 0.75) (Stiels *et al*., 2015), only one of the variables was retained (Guisan and Thuiller, 2005) based on its biological significance to the bird species. From an initial set of twenty one variables (Table 1), we retained the following ten variables after correlation analysis; mean diurnal range (Bio2), isothermality (Bio3), temperature annual range (Bio7), annual precipitation (Bio12), precipitation of driest month (Bio14), precipitation seasonality (Bio15), precipitation of warmest quarter (Bio18), maximum temperature (tmax), human population density (pop) and land cover (Table 1).

Table 1. Full set of environmental variables selected as potential predictors.

Environmental variables	Source	Type	Used/Not used
Bio1 - Annual mean temperature	WorldClim (Hijmans *et al*., 2005)	Dynamic	NS
Bio2 - Mean diurnal range	“	Dynamic	**U**
Bio3 - Isorthemality	“	Dynamic	**U**
Bio4 - Temperature seasonality	“	Dynamic	NS
Bio5 - Maximum temperature of the warmest month	“	Dynamic	NS
Bio6 - Minimum temperature of the coldest month	“	Dynamic	**U**
Bio7 - Temperature annual range	“	Dynamic	NS
Bio8 - Mean temperature of wettest quarter	“	Dynamic	NS
Bio9 - Mean temperature of driest quarter	“	Dynamic	NS
Bio10 - Mean temperature of warmest quarter	“	Dynamic	NS
Bio11 - Mean temperature of coldest quarter	“	Dynamic	NS
Bio12 - Annual precipitation	“	Dynamic	**U**
Bio13 - Precipitation of wettest month	“	Dynamic	NS
Bio14 - Precipitation of driest month	“	Dynamic	**U**
Bio15 - Precipitation seasonality	“	Dynamic	**U**
Bio16 - Precipitation of wettest quarter	“	Dynamic	NS
Bio17 - Precipitation of driest quarter	“	Dynamic	NS
Bio18 - Precipitation of warmest quarter	“	Dynamic	NS
Bio19 - Precipitation of coldest quarter	“	Dynamic	NS
tmax - Maximum temperature	“	Dynamic	**U**
pop - Human population density	https://www.worldpop.org/	Static	**U**
landcover- Land cover	http://due.esrin.esa.int/page_globcover.php	Static	**U**

Hint: “U” and “NS” indicate if the variable was used or not used in the final MaxEnt model, respectively

Modelling the distribution of bird species using MaxEnt

Predictions of potential current and future distribution of the birds were made using MaxEnt version 3.3.3k; a software based on the maximum entropy method (Phillips *et al*., 2006). MaxEnt uses presence-only data to estimate potentially suitable habitats as a function of environmental variables. MaxEnt was chosen for this study because it performs better among species distribution models that use presence-only data (Wei *et al*., 2017).

Models for the four bird species were calibrated using similar settings. The logistic output was selected to allow MaxEnt to generate a continuous map with an estimated probability of presence between 0 and 1. The maximum number of iterations was set to 5000. We allowed MaxEnt to generate response curves which indicate the relationship between the environmental variables and the predicted probability of presence for a given species. Fifteen subsample replicates were run for each species and averaged into a single model. During the model runs, 75% of the species occurrence records were used for training the model and the remaining 25% for validation. The remaining settings for the MaxEnt model were left as default.

The performance of the MaxEnt models was evaluated using the area under the curve (AUC) of the receiver operating characteristic (ROC) value. The AUC values range from 0 to 1, where high AUC values imply a good model fit. 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). A jackknife test (a statistical measure of the influence of environmental variables in distinguishing occurrence localities from the total study area) was used to determine which variables were most important for the distribution of the species (Cooper-Bohannon *et al*., 2016; Rebelo and Jones, 2010).

Classification of suitable and unsuitable areas for the bird species

MaxEnt output generated continuous maps with an estimated probability of occurrence in each pixel that ranged from 0 to 1. The maps were reclassified into binary maps of suitable and unsuitable areas using a 10^{th} percentile training-presence logistic-threshold value obtained from MaxEnt model results (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 were classified as unsuitable (Hao *et al*., 2012). From the binary suitability maps, the sizes of suitable areas for each species under different climate scenarios were calculated. These analyses were conducted using ArcGIS 10.3.

RESULTS

Model performance and variable importance for species distribution

The prediction accuracies of the MaxEnt models for all the four bird species were good, as the mean AUC values were greater than 0.75 (Table 2). The high AUC values observed here indicate that the model performed well in predicting potentially suitable habitats for the four bird species. Of all the four bird species, the MaxEnt model for *L. undatus* had the lowest mean AUC value while the MaxEnt model for *C. albitorques* had the highest mean AUC value (Table 2).

Table 2. Mean AUC values and percent contribution to the MaxEnt model for the most important variables influencing the distribution of the bird species.

Species	**Mean AUC**	**Variable**	**Contribution to the MaxEnt model (%)**
Bostrychia carunculata	0.804	Maximum temperature	23.6
		Annual precipitation	28.7
		Human population density	36.0
Columba albitorques	0.874	Annual precipitation	5.5
		Maximum temperature	12.3
		Human population density	60.6
Corvus crassirostris	0.770	Human population density	18.2
		Annual precipitation	19.1
		Maximum temperature	47.7
Lybius undatus	0.762	Maximum temperature	13.3
		Human population density	21.8
		Annual precipitation	35.6

The MaxEnt models for all species showed that the variables that were most important in predicting the distribution of all the four species were annual precipitation (Bio12), maximum temperature (tmax) and human population density (Pop). However, the contribution of each variable to the MaxEnt model varied depending on the species (Table 2).

In addition, the sensitivity of each species to the variables that greatly influenced the distribution varied depending on the species. For example, the probability of occurrence for *B. carunculata* increased with an increase in annual precipitation from 550 mm to 1900 mm, while an increase in maximum temperature above 25°C, rapidly decreased the probability of occurrence of this species. For *C. albitorques*, an increase in maximum temperature above 17°C led to a sharp decline in the probability of occurrence. While an increase in annual precipitation up to 1400 mm led to an increase in the probability of occurrence for *C. albitorques*, but precipitation increase above this level led to a decrease in the probability of occurrence. *C. crassirostris* and *L. undatus* were less sensitive to annual precipitation changes above 550 mm. Precipitation amounts that favoured the occurrence of these two species ranged from 550 mm to 2500 mm. Besides, increases in maximum temperature above 30°C led to a rapid decline in the probability of occurrence for both *C. crassirostris* and *L. undatus*.

Even though human population density was found to play an important role in determining the distribution of all the four bird species, its effect on the probability of occurrence of the species was constant. Thus, an increase in human population density did not change the probability of occurrence of the bird species. This finding is counter-intuitive because it is generally expected that an increase in human population density should lead to a change in the probability of occurrence.

Current and future distribution of *Bostrychia carunculata*, *Columba albitorques*, *Corvus crassirostris*, and *Lybius undatus*

MaxEnt model predictions for the current distribution of suitable areas for the four bird species indicated that *B. carunculata*, *C. crassirostris*, and *L. undatus* had a wide range of suitable areas across Ethiopia (Fig. 2, 4, 5) while *C. albitorques* had a narrow distribution (Fig. 3). Although, *C. albitorques* had a relatively narrow distribution of suitable areas, the distribution coverage of suitable areas was still large enough to justify its categorization under least concern species by IUCN.

Despite the bird species having a wide range of suitable areas, future projections revealed that the amount of suitable areas will decline. The highest range losses were observed in 2070 under RCP 8.5 for all the four species (Fig. 2, 3, 4, 5). Largely, our findings also revealed that areas with high elevation were least affected by range losses of the four bird species.

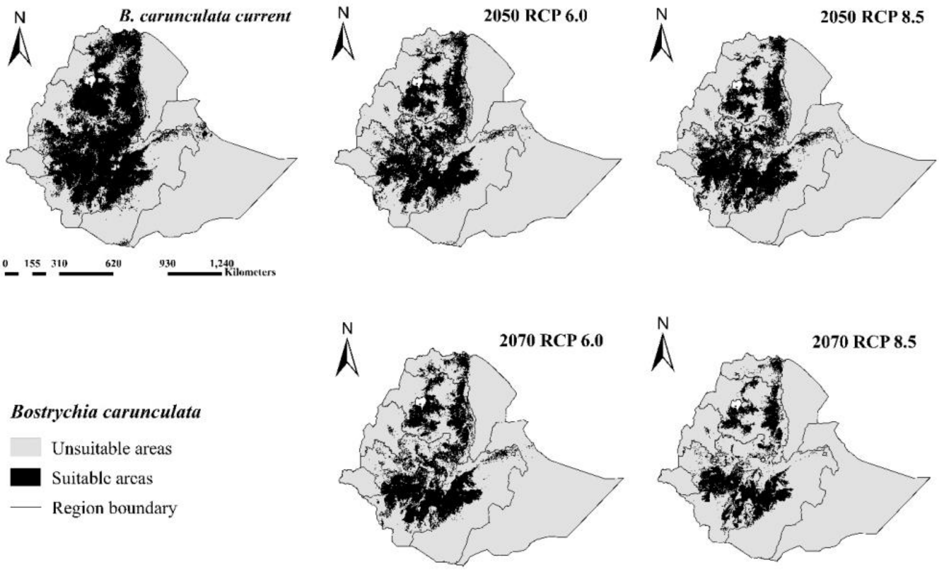

Fig. 2. Distribution of *Bostrychia carunculata* under different climate scenarios. Potentially suitable areas for this species are declining with an increase in years and with changes in climate scenarios. The lowest size of the suitable range is observed in 2070 under RCP 8.5 climate scenario.

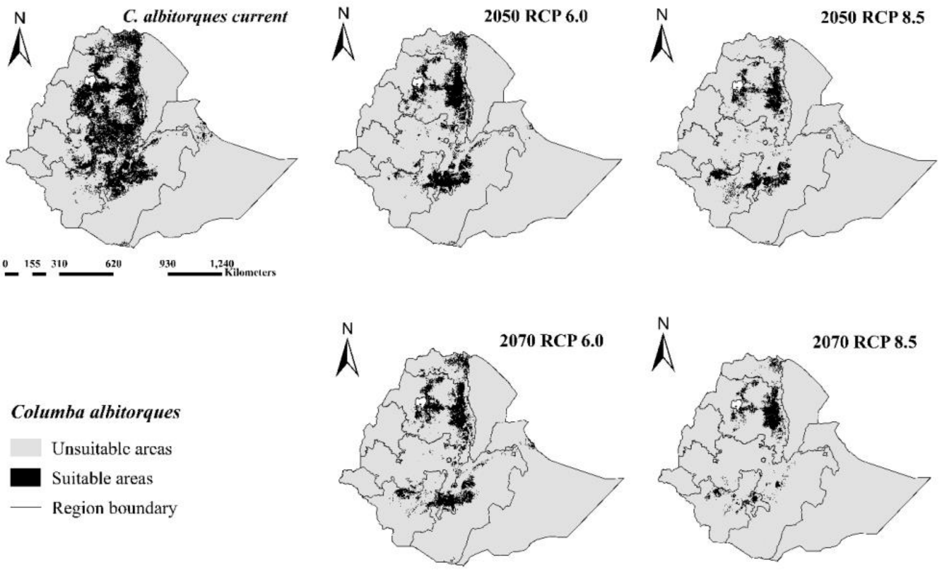

Fig. 3. Distribution of *Columba albitorques* under different climate scenarios. Potentially suitable areas for this species are declining with an increase in years and with changes in climate scenarios. The lowest size of the suitable range is observed in 2070 under RCP 8.5 climate scenario.

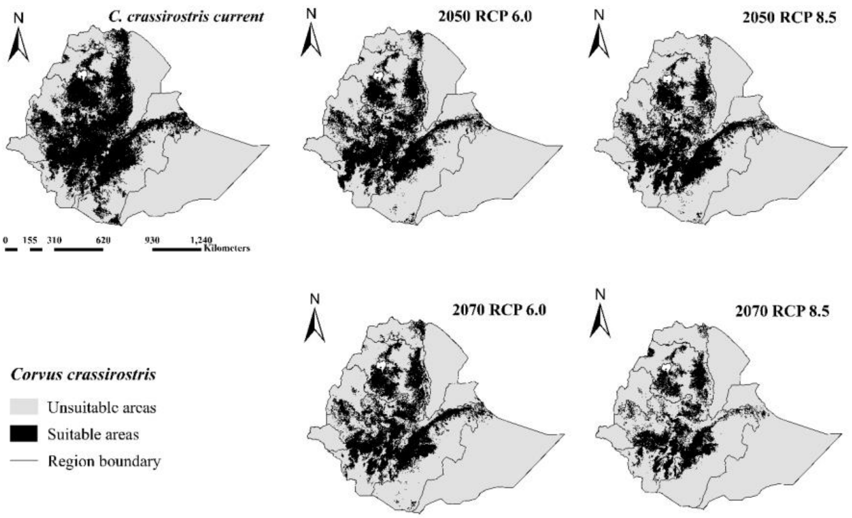

Fig. 4. Distribution of *Corvus crassirostris* under different climate scenarios. Potentially suitable areas for this species are declining with an increase in years and with changes in climate scenarios. The lowest size of the suitable range is observed in 2070 under RCP 8.5 climate scenario.

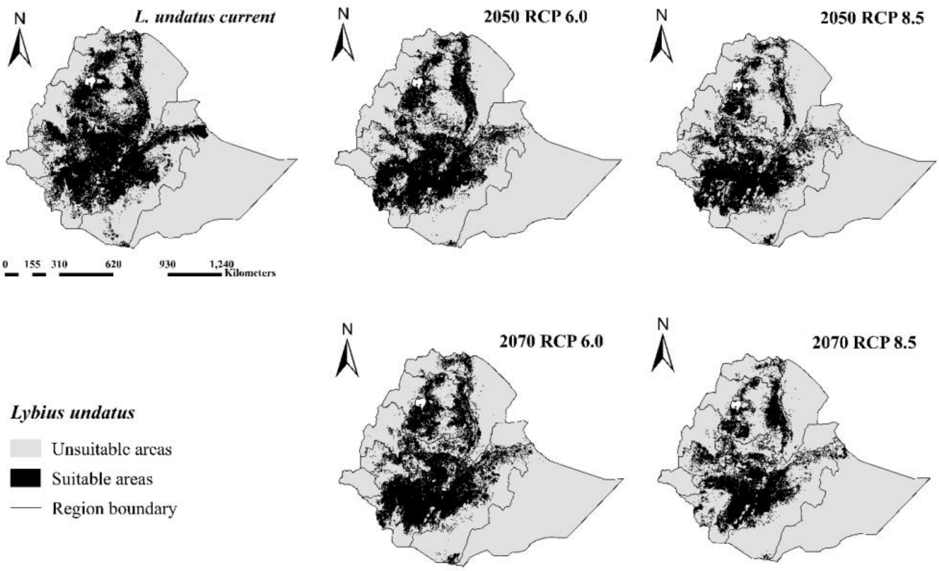

Fig. 5. Distribution of *Lybius undatus* under different climate scenarios. Potentially suitable areas for this species are declining with an increase in years and with changes in climate scenarios. The lowest size of the suitable range is observed in 2070 under RCP 8.5 climate scenario.

Generally, the maximum range loss for the bird species was huge under future climate scenarios and it ranged from 30.7 to 77% (Table 3). The highest percentage of range loss was observed for *C. albitorques* while the least range loss was observed for *L. undatus*. These results indicate that among the four species *C. albitorques* was highly sensitive to climate change followed by *B. carunculata* and *C. crassirostris* while *L. undatus* was the least sensitive species to climate change.

Table 3. Current and projected suitable areas (km^2) for four endemic bird species under different climate scenarios.

	Current and future climate scenarios				
Species	**Current**	**2050 RCP 6.0**	**2050 RCP 8.5**	**2070 RCP 6.0**	**2070 RCP 8.5**
Bostrychia carunculata	341,874.9 (0)	242,406.3 (29.10)	251,393.6 (26.47)	218,580.5 (36.06)	157,806.1 (53.84)
Columba albitorques	182,128.1 (0)	86664.50 (52.4)	62919.00 (65.5)	78,332.50 (57.0)	41,862.30 (77.0)
Corvus crassirostris	376,566.8 (0)	278,106.1 (26.1)	264,224.3 (29.8)	256,941.9 (31.8)	182,346.0 (51.6)
Lybius undatus	343,972.5 (0)	302,267.4 (12.1)	270,059.7 (21.5)	310,710.1 (9.7)	238,203.9 (30.7)

Note: Figures in parentheses indicate the percentage of geographic range losses

DISCUSSION

MaxEnt predictions for the distribution of *Bostrychia carunculata*, *Columba albitorques*, *Corvus crassirostris*, and *Lybius undatus* revealed that overall these species occur in areas with high elevations, these results are consistent with previous findings (Weldemariam Tesfahunegny, 2016), thus, suggesting that the MaxEnt models correctly predicted the current distribution of these species. Besides, these results also explain why all the species had a very low potential occurrence in the Somali Region of Ethiopia. This is because about 95% of the areas in the Region are lowlands with an average altitude of 900 m, which has an impact on the occurrence of the species.

Additionally, the rare occurrence of the bird species in the Somali Region can also be explained with respect to temperature and precipitation conditions. For all bird species of this study, the probability of occurrence in an area declined when maximum temperatures exceeded 25°C and increased when annual precipitation was above 550 mm. In the Somali Region, temperatures range from 32°C to 40°C, and the annual precipitations range from 300–500 mm. These climate climatic conditions impacted habitat availability for the four bird species in the Region.

Although these birds were predicted to be highly suitable for areas of high elevations, some bird species like *C. albitorques* also move to lowlands to feed. However, roosting sites are predominantly in highlands (Weldemariam Tesfahunegny, 2016). The habit of roosting and breeding only in highlands while feeding at both lower and higher elevations indicate that climatic factors (precipitation and temperature) influence breeding of the species. Our findings also revealed that *L. undatus* had a wide occurrence in northwest Ethiopia, which is contrary to previous observations that this species is uncommon in this region (Weldemariam Tesfahunegny, 2016). This discrepancy in findings suggests that *L. undatus* has not fully colonized its suitable habitats in north-west Ethiopia, hence observations of this species might be uncommon in this region.

Further, the results showed that human population density played an important role in predicting the distribution of all the four species, however, the probability of occurrence of the species did not decrease with an increase in human population density. This finding suggests that the bird 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 the search for food. Indeed, this is consistent with previous studies which reported that species like *B. carunculata* are well adapted to human environments (Weldemariam Tesfahunegny, 2016; Kalkidan Esayas, 2017).

Additionally, *C. albitorques* has been reported to regularly visit grain fields in the search for food and has also been common in towns and villages where they lived in association with churches, large buildings, roads and bridges found in plateaus (Weldemariam Tesfahunegny, 2016). Moreover, *C. crassirostris*, feed on human food and dung of animals including livestock. Such feeding behaviour implies that the presence of humans provides vast opportunities to these species for finding food hence occurrence near human settlement is to be expected. Besides, in some cases, it has been reported that anthropogenic activities can increase avian species diversity and richness (Addisu Asefa *et al*., 2017). Even though increasing human population density did not reveal detrimental effects on habitat suitability for the bird species, increasing human population remains a constant threat because it can lead to increased clearing of bushes and grasslands which form the nesting sites for the bird species (Weldemariam Tesfahunegny, 2016; Kalkidan Esayas, 2017).

The projections of the distribution of four species portrayed huge losses in the size of suitable areas for the species. All species except *L. undatus* had a maximum range loss of greater than 50% in 2070 under RCP 8.5. These reductions in the amount of suitable area under future climate scenarios can be attributed to climate change which is expected to reduce productivity in Ethiopian highlands (Zenebe Gebreegziabher *et al*., 2012). Since all species had a wider tolerance and were less sensitive to changes in annual precipitation than maximum temperatures, it can be assumed that the declines in suitable areas are due to increases in maximum temperatures under future climate scenarios. This claim is evident as *L. undatus*, which had a relatively wider temperature tolerance and experienced the least range loss. Nevertheless, the potential indirect effects of future rainfall changes should not be undermined, as rainfall affects food productivity, consequently affecting food availability for these species. But still, the generalist feeding patterns of these species are likely to act as a refuge for these species. Moreover, the annual precipitation used in this study only reveals mean precipitation values. Hence they do not account for duration and frequencies of precipitation events which can affect breeding or reproductive success consequently limiting distribution of the species (Heuck *et al*., 2013).

Even though the results revealed a general decline in suitable areas for the species, highland areas were least affected by the range losses; suggesting that the bird species ranges may shift towards highland areas. These findings are consistent with the observation that the four bird species in this study were very sensitive to increases in maximum temperature, and since highlands usually experience relatively lower temperatures than lowlands such findings can be expected. Moreover, several studies have reported upslope shifts of bird species geographic ranges in the face of climate change (Flousek *et al*., 2015; Freeman *et al*., 2018). Average temperatures in Ethiopia for 2070 under RCP 8.5 will increase by 4.1°C (Nega Tassie, 2016), as such huge declines in the amount of suitable areas for the four bird species as observed in this study can be expected. Increased temperatures have a negative effect on energy expenditure and egg production (Pendlebury *et al*., 2004), consequently threatening the survival of a given species.

CONCLUSION

In this study, we modelled the current and potential future distribution of *Bostrychia carunculata*, *Columba albitorques*, *Corvus crassirostris*, and *Lybius undatus* under RCP 6.0 and RCP 8.5 scenarios. Our findings indicate that the most important variables that determine the distribution of these species are maximum temperature, human population density, and annual precipitation, respectively. Future projections of the distribution of these species revealed that the amount of suitable geographic areas will decline in both 2050 and 2070 under RCP 6.0 and RCP 8.5 climate scenarios. All the four bird species were found to be very sensitive to changes in maximum temperature hence future temperature increases will cause geographic range declines for these species. Our findings suggest that conservation of highland areas which may form crucial habitat refugia for the bird species under future climates will be vital to ensure the survival of the species as highland areas experienced very low range losses for the bird species.

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