

**MODELLING THE CURRENT AND FUTURE POTENTIAL
DISTRIBUTION AREAS OF *COLUMBA ALBITORQUES* IN
ETHIOPIA**

Aynyirad Tewodros

Department of Biodiversity and Ecosystem Management, Haramaya University, Ethiopia

Corresponding Author Email: aynyiradtewodros@gmail.com

ABSTRACT

Understanding species' responses to climate change is essential for predicting future biodiversity patterns and informing conservation strategies. However, in Ethiopia, the impacts of climate change on bird distributions remain poorly documented. This study utilized the MaxEnt model to predict the current and future distribution of the White-collared Pigeon (*Columba albitorques*) under different climate scenarios. Species occurrence records were obtained from the Global Biodiversity Information Facility (GBIF), and bioclimatic variables from WorldClim, along with land cover and human population density data, were used as environmental predictors. Multicollinearity among predictors was assessed to ensure that only biologically relevant and non-redundant variables were retained. Habitat suitability was then projected for 2050 and 2070 under two greenhouse gas emission scenarios (RCP 6.0 and RCP 8.5). The MaxEnt model performed well (AUC = 0.854), identifying maximum temperature, annual precipitation, land cover, and human population density as the most influential predictors of *Columba albitorques* distribution. Future projections indicate substantial declines in suitable habitat across all scenarios, with losses of 44.5–54% by 2050 and 54.9–75.5% by 2070, the largest reductions occurring under RCP 8.5 in 2070. These findings suggest that *Columba albitorques* is highly sensitive to climate warming and habitat alteration. Conservation efforts focused on protecting high-elevation habitats and mitigating human-induced habitat degradation will be essential for maintaining viable populations under future climate conditions.

Keywords: Species distribution modelling, climate change, MaxEnt, Ethiopia, *Columba albitorques*

1. INTRODUCTION

Climate change has become one of the most significant drivers of biodiversity loss worldwide. It affects species through local extinctions, increased disease prevalence, altered phenology, changes in morphology and behavior, shifts in gene frequencies, and broad modifications in geographic ranges (Stephens *et al.*, 2016; Mason *et al.*, 2019). Numerous studies show that many species respond to warming temperatures by shifting their distributions toward higher elevations or latitudes (Bertrand *et al.*, 2011). As climate change intensifies, suitable habitats for many species are expected to shrink (Dyderski *et al.*, 2018), increasing extinction risk, especially for range-restricted or specialized species (Bellard *et al.*, 2012; Urban, 2015; Bladon *et al.*, 2012).

Birds are among the best-studied biological groups and play essential ecological roles as pollinators, seed dispersers, scavengers, and predators of insect pests. Their global diversity exceeds 11,000 species, occupying nearly every habitat and continent (Rajpar and Zakaria, 2011). Because they respond rapidly to environmental change, birds are valuable indicators of ecosystem health. Their wide distribution, diverse habitat use, and sensitivity to climatic and land-use changes make them excellent subjects for assessing ecological impacts at local and global scales.

Ethiopia hosts remarkable avian diversity due to its wide range of ecosystems, including afro-alpine zones, humid forests, wetlands, semi-arid lowlands, and extensive rift-valley systems (Wolff, 1961). The country supports about 867 bird species, including 19 endemics, 38 globally threatened species, and several highland specialists restricted to the Ethiopian and Eritrean highlands. Among these is the White-collared Pigeon (*Columba albitorques*), a highland endemic species commonly found above 1800 m. Although the species is currently listed as “Least Concern,” its restricted range, habitat specificity, and reliance on high-elevation landscapes may expose it to threats from climate change and increasing anthropogenic pressures.

Rapid human population growth in Ethiopia has accelerated habitat degradation, fragmentation, and land-use change, all of which threaten bird species, especially those confined to specific ecological zones. As climate change interacts with human-driven landscape alteration, highland species may experience compounded pressures that reduce their distributions and long-term persistence.

Birds are known to respond strongly to climate variability, showing shifts in migration timing, breeding cycles, and habitat selection (King and Finch, 2013; Li *et al.*, 2022). Evidence suggests that warming is driving many species toward mountain peaks and polar regions (Lehikoinen and Virkkala, 2013). Despite this, little is known about how climate change will affect the distribution of *Columba albitorques* under future conditions. Given the ecological importance and restricted range of this species, understanding its potential response to climate change is crucial for effective conservation planning. However, research on the climate-driven distribution dynamics of the White-collared Pigeon in Ethiopia remains limited. Therefore, this study aims to fill this knowledge gap by predicting the current and future potential distribution of *Columba albitorques* under different climate scenarios, and identifying the key environmental factors influencing its distribution.

2. MATERIALS AND METHODS

2.1 Study Area Description

The study was conducted in Ethiopia, a landlocked country in the Horn of Africa (E 32°58'–48°00', N 3°25'–14°55'). Ethiopia covers about 1,112,000 km² (472,000 square miles) and has an estimated population of 126.5 million as of 2023 (World Bank, 2023). The country lies entirely within tropical latitudes and is relatively compact, with similar north-south and east-west dimensions (FAO, 2003). Ethiopia features diverse climates and landscapes, ranging from equatorial rainforests with high rainfall and humidity in the south and southwest to Afro-alpine zones on the peaks of the Simien and Bale Mountains, and desert-like conditions in the northeast, east, and southeast lowlands (World Bank, 2021). Overall, the country is largely arid but exhibits high variability in precipitation. Its climate is generally divided into three zones: the alpine vegetated cool zones (Dega), which occur above 2,600 m.a.s.l. with temperatures near freezing up to 16°C; the temperate Woina Dega zones, between 1,500 and 2,500 m.a.s.l., and the hot Qola zones, covering tropical and arid regions with temperatures ranging from 27°C to 50°C (FAO, 2003) (Figure 1).

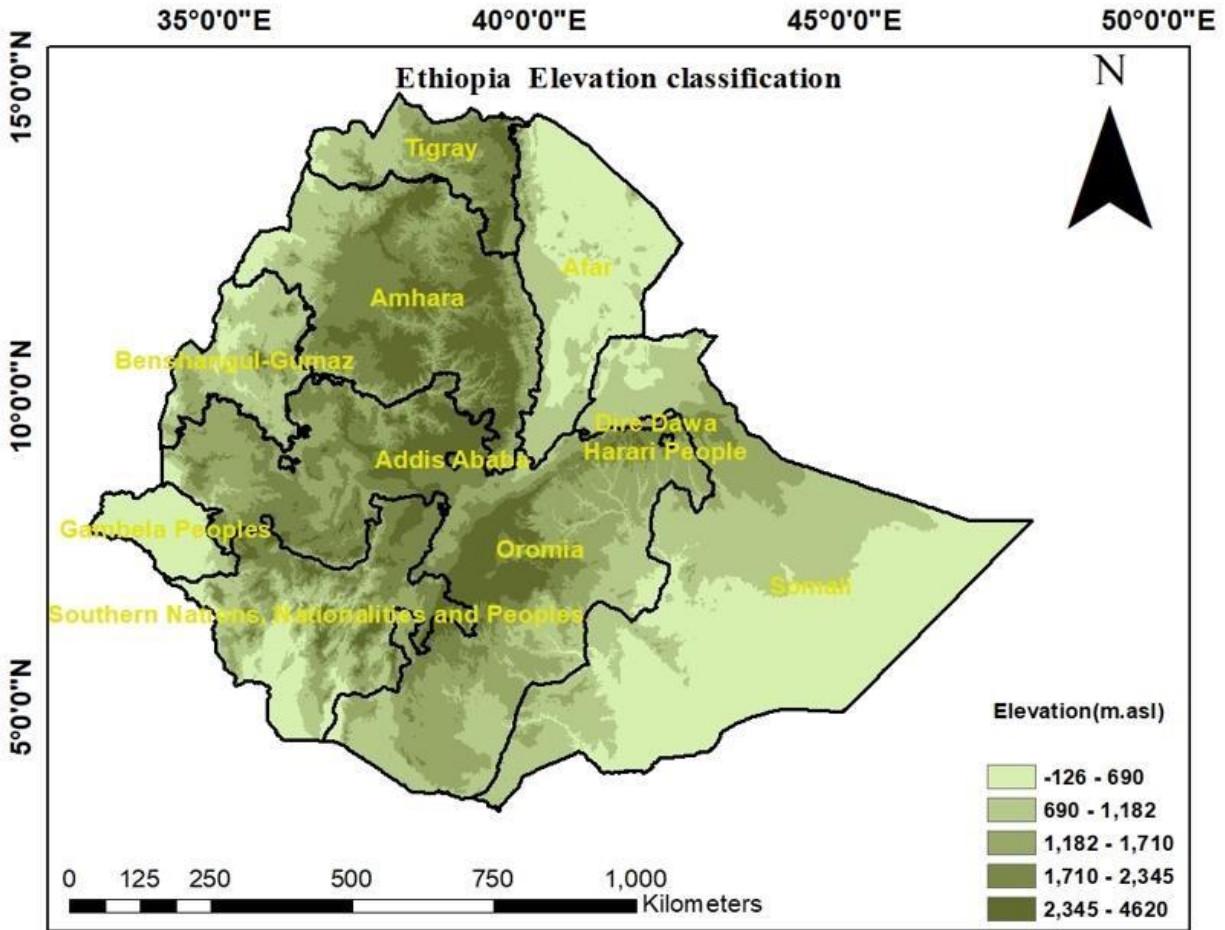


Figure 1. Elevation map of the study area, Ethiopia

2.2 Species Description

Pigeons are among the most successful bird groups, occupying a variety of habitats, especially in tropical and temperate zones, including some of the harshest environments on Earth (Baptista *et al.*, 1997). Among these, White-collared pigeons are very common in areas above 1800 m. a. s. l. in Ethiopia and Eritrea (1800-4100 meters). They appear alone, in pairs, or in flocks during feeding, resting, and roosting. Occasionally, they form large mixed flocks with speckled pigeons (*Columba guinea*). These pigeons inhabit rugged areas such as cliffs, escarpments, plateaus, villages, and large buildings. In Ethiopia, they are found in Addis Ababa, Sululta, Ankober, Debre Zeit, Lalibela, Shashemene, Gosh Meda, Bale Mountain National Park, Simien Mountain National Park, Choke Mountain, Entoto Natural Park, Jimma, Lake Ashenge, Debre Birhan, North Omo,

and Guassa Community Conservation Area (Fasil, 2021). *Columba albitorques* has a uniform slaty-gray coloration with a sharply defined white collar patch and white on the wings with irregular dark spots. Adults measure between 28–31 cm; males weigh about 292 g, and females approximately 262 g. These pigeons regularly move from roosting sites to feeding areas, such as agricultural lands and moorlands at lower elevations of cliffs (Weldemariam Tesfahunegny, 2016). Breeding behavior is solitary and monogamous.

2.3 Species Occurrence Data

Occurrence records for *Columba albitorques* were obtained from the Global Biodiversity Information Facility (GBIF, www.gbif.org). Duplicate records and those with missing coordinates were removed before analysis. The cleaned dataset was then used for species distribution modeling.

2.4 Environmental Data Layers

Bioclimatic variables used to project the current and future distribution of *Columba albitorques* were obtained from WorldClim 2.1 (www.worldclim.org) at a spatial resolution of 30 arc-seconds (Hijmans *et al.*, 2005). These variables include temperature and precipitation-related layers that describe different aspects of climate. Future projections were modeled using two greenhouse gas emission scenarios: moderate (RCP 6.0) and high (RCP 8.5), for two time periods: the 2050s (averaged over 2041–2060) and the 2070s (averaged over 2061–2080) (Huang *et al.*, 2020). Human population density and land cover variables were included to represent anthropogenic influences on the distribution of *Columba albitorques*. Human population density data were obtained from WorldPop (www.worldpop.org), and land cover data were obtained from GlobCover (http://due.esrin.esa.int/page_globcover.php). While bioclimatic variables were dynamic, human population density and land cover were considered static due to the lack of reliable future projections. Before modeling, multicollinearity among predictor variables was assessed using a Pearson correlation matrix in R software. Pairs of highly correlated variables ($r \geq 0.75$) were identified, and only one variable from each correlated pair was retained based on its biological relevance to the species. After this screening, ten variables were selected as predictors for MaxEnt modeling (Table 1).

Table 1. Environmental variables used as potential predictors for *Columba albitorques* distribution modeling

Environmental Variable	Description
Bio1	Annual mean temperature
Bio2	Mean diurnal range
Bio3	Isothermality
Bio7	Temperature annual range
Bio12	Annual precipitation
Bio14	Precipitation of the driest month
Bio15	Precipitation seasonality
Bio18	Precipitation of the warmest quarter
Tmax	Maximum temperature
Landcover	Land cover type
Pop	Human population density

All selected predictor variables were applied across both future climate scenarios (RCP 6.0 and RCP 8.5) for the 2050 and 2070 projection years

2.5 Model Setting

The current and future distribution of *Columba albitorques* was predicted using MaxEnt (Maximum Entropy Modeling), a widely used species distribution modeling (SDM) tool suitable for presence-only data (Fourcade *et al.*, 2014; Phillips, 2006). MaxEnt estimates the probability of species occurrence in unsampled areas based on environmental variables and has been shown to perform well even with small sample sizes while providing species response curves (Khanum *et al.*, 2013; Wei *et al.*, 2017). For this study, the MaxEnt settings included a maximum of 5000 iterations, 30% of occurrence records used as test data, a 10% training presence threshold, and five replicates using the subsample method. The subsample method randomly partitions the occurrence data into training and test sets, with 75% of records used for training and 25% for testing model performance (Phillips *et al.*, 2017). Logistic output was chosen to represent the probability of species presence, ranging from 0 (very low suitability) to 1 (very high suitability) (Phillips, 2008). The Jackknife test was applied to evaluate the relative contribution of each environmental variable to the model, and response curves were generated to examine species–environment relationships. All other settings were kept at default values.

2.6 Model Performance Evaluation

Model accuracy was evaluated using the area under the curve (AUC) of the receiver operating characteristic (ROC) value. AUC values range from 0 to 1, with higher values indicating better model performance. Model performance was classified as poor (0.5–0.7), moderate (0.7–0.9), and good to excellent (0.9–1) (Schatz *et al.*, 2017; Fernández and Morales, 2019). MaxEnt's internal jackknife tests identified the most influential environmental variables. A 10-percentile training presence logistic threshold was used to classify suitable vs. unsuitable habitat.

2.7 Classification and Mapping of Suitable and Unsuitable Areas

ArcGIS 10.8 was used to process MaxEnt outputs (ASC files) and to generate maps of suitable and unsuitable habitats. The vector-to-raster and reclassification tools were applied to create binary suitability maps based on the 10th percentile training presence logistic threshold, where pixels above the threshold were classified as suitable and those below as unsuitable (Hao *et al.*, 2012; Liu, 2005; Liu and Mai, 2022; Yan *et al.*, 2021). The total area of suitable habitat was then calculated using ArcGIS spatial analysis tools.

3. RESULTS

3.1 Model Performance and Variable Importance

The MaxEnt model performed well in predicting suitable habitat for *Columba albitorques*, with a mean AUC of 0.854. This high value indicates very good discriminatory power, demonstrating that the model reliably distinguished areas of suitable habitat from unsuitable environments (Figure 2).

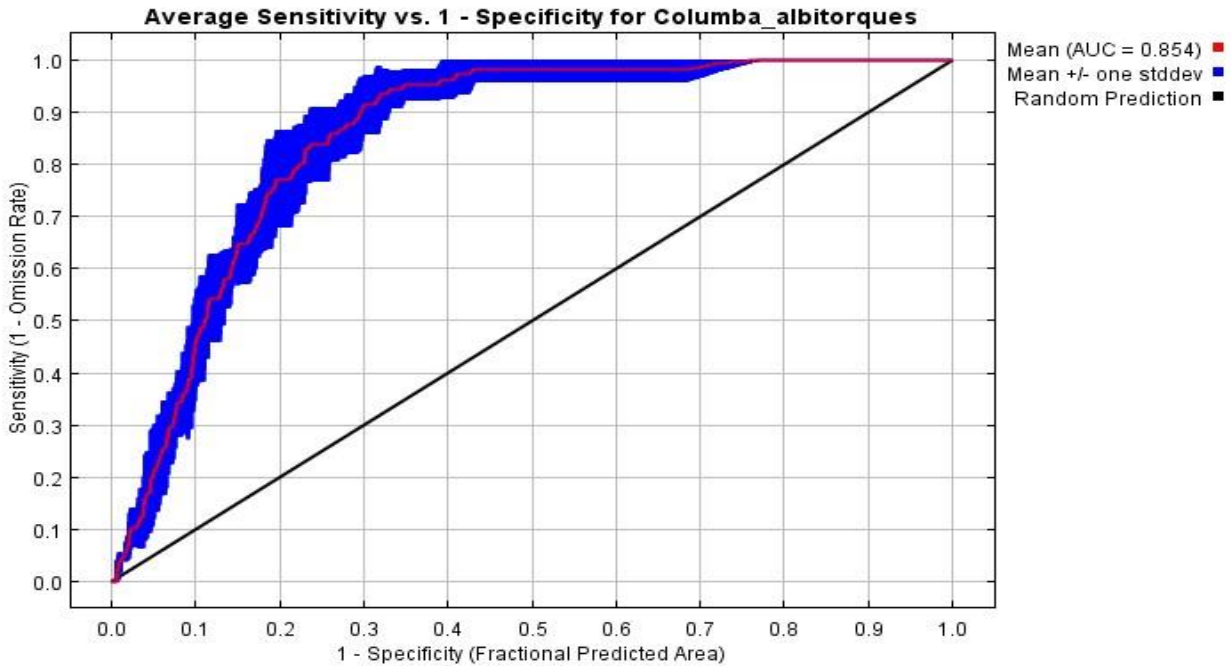


Figure 2. The AUC of the training and test data for the 5 replicate runs of *Columba albitorques*.

The jackknife test of variable importance showed that human population density (pop) was the most influential predictor of the species distribution, followed by mean monthly maximum temperature (tmax) and land cover (Figure 3).

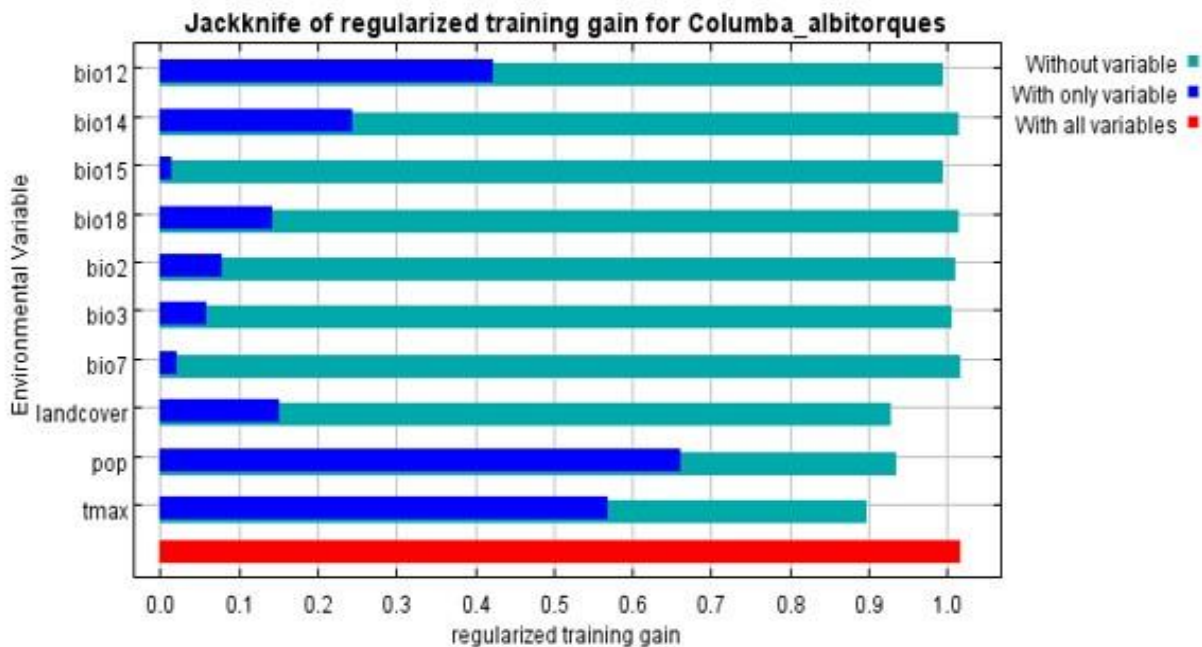


Figure 3. Jackknife test of variable importance in the MaxEnt model predicting *Columba albitorques* distribution.

These findings were further supported by the percent contribution of each variable to the MaxEnt model. Human population density was the most influential, contributing 62.4%, followed by maximum temperature (tmax) and land cover at 11.5% and 10.6%, respectively. In contrast, mean diurnal range (bio2) and precipitation of the warmest quarter (bio18) had minimal influence, contributing only 1.2% and 0.2% toward explaining the current distribution of *Columba albitorques*. (Table 2).

Table 2. Percent contribution and permutation importance of environmental variables in the MaxEnt model for predicting the distribution of *Columba albitorques*

Variable	Percent contribution (%)	Permutation importance
pop	62.4	26.1
tmax	11.5	28.6
landcover	10.6	11.3
bio12	5.3	17.7
bio14	2.9	0.5
bio7	2.8	0.2
bio3	1.9	5.7
bio15	1.2	0.7
bio2	1.2	8.7
bio18	0.2	0.6

The response curves showed how each environmental variable affected the predicted probability of *Columba albitorques* presence. Suitable conditions were associated with precipitation in the driest month of 1–58 mm, annual precipitation between 600 and 900 mm, and areas where the annual temperature range fell between 190 and 280. Habitat suitability declined sharply when maximum temperature increased beyond approximately 37.8°C, indicating strong sensitivity to heat stress. Suitable precipitation seasonality values were around 36 mm, and declines in this variable reduced the likelihood of species occurrence. Increased precipitation of the warmest quarter (190–610 mm) favored occurrence, while decreases in isothermality (78–92) and increases in mean diurnal range (63.8–85°C) influenced suitability patterns. Human population density also affected species distribution but showed a constant influence on occurrence, indicating tolerance or adaptation to human-modified landscapes. Land cover was another important variable,

influencing habitat suitability differently across cover types, with some land uses associated with higher suitability and others with lower suitability (Figure 4).

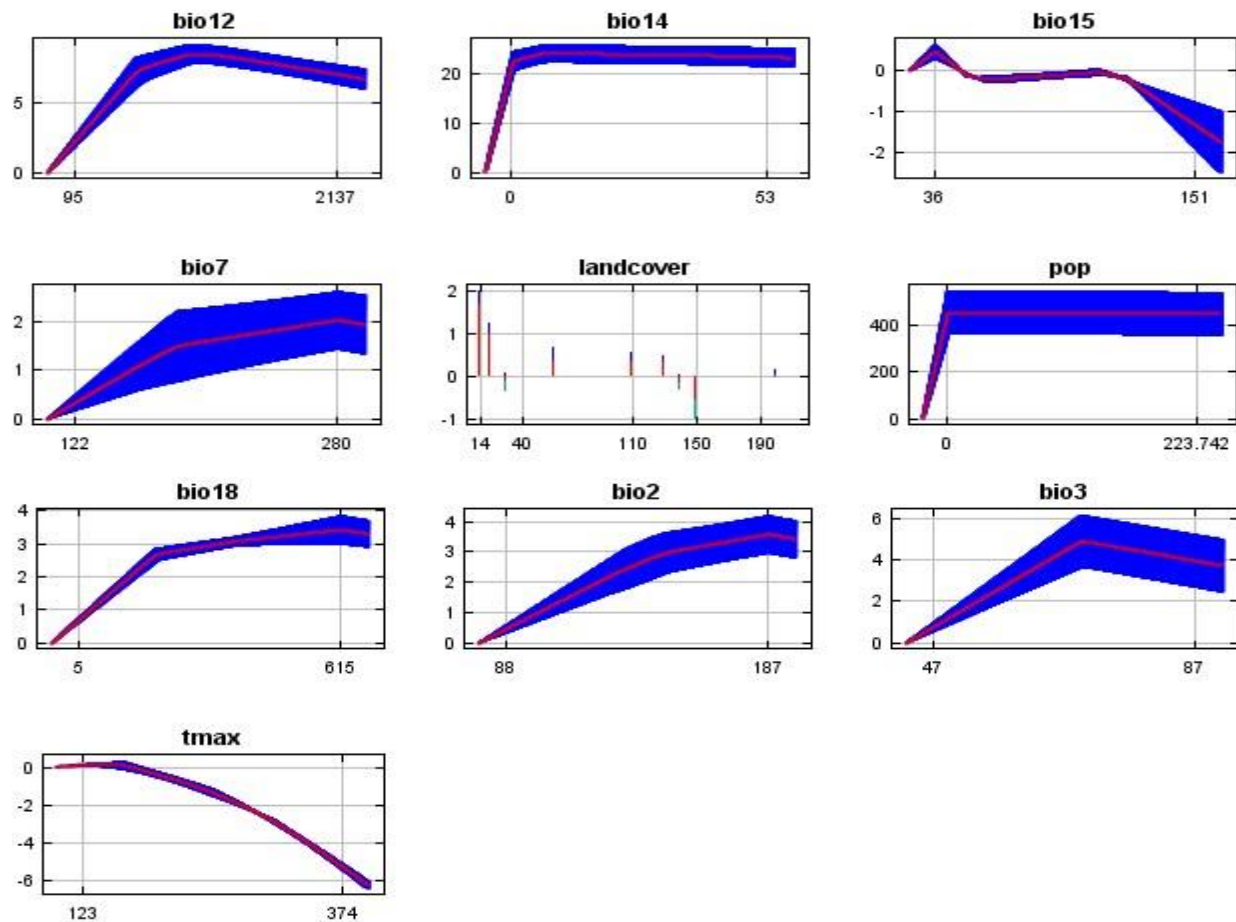


Figure 4. Response curves of the most relevant environmental factors affecting the distribution of *Columba albitorques*

3.2 Potential Distribution of *Columba albitorques* Under Current and Future Climate Conditions

The MaxEnt model predicted a total of 253,361 km² of suitable habitat for *Columba albitorques* under current climate conditions in Ethiopia. Species distribution maps indicated a narrow distribution range, primarily concentrated in highland regions (Figure 5).

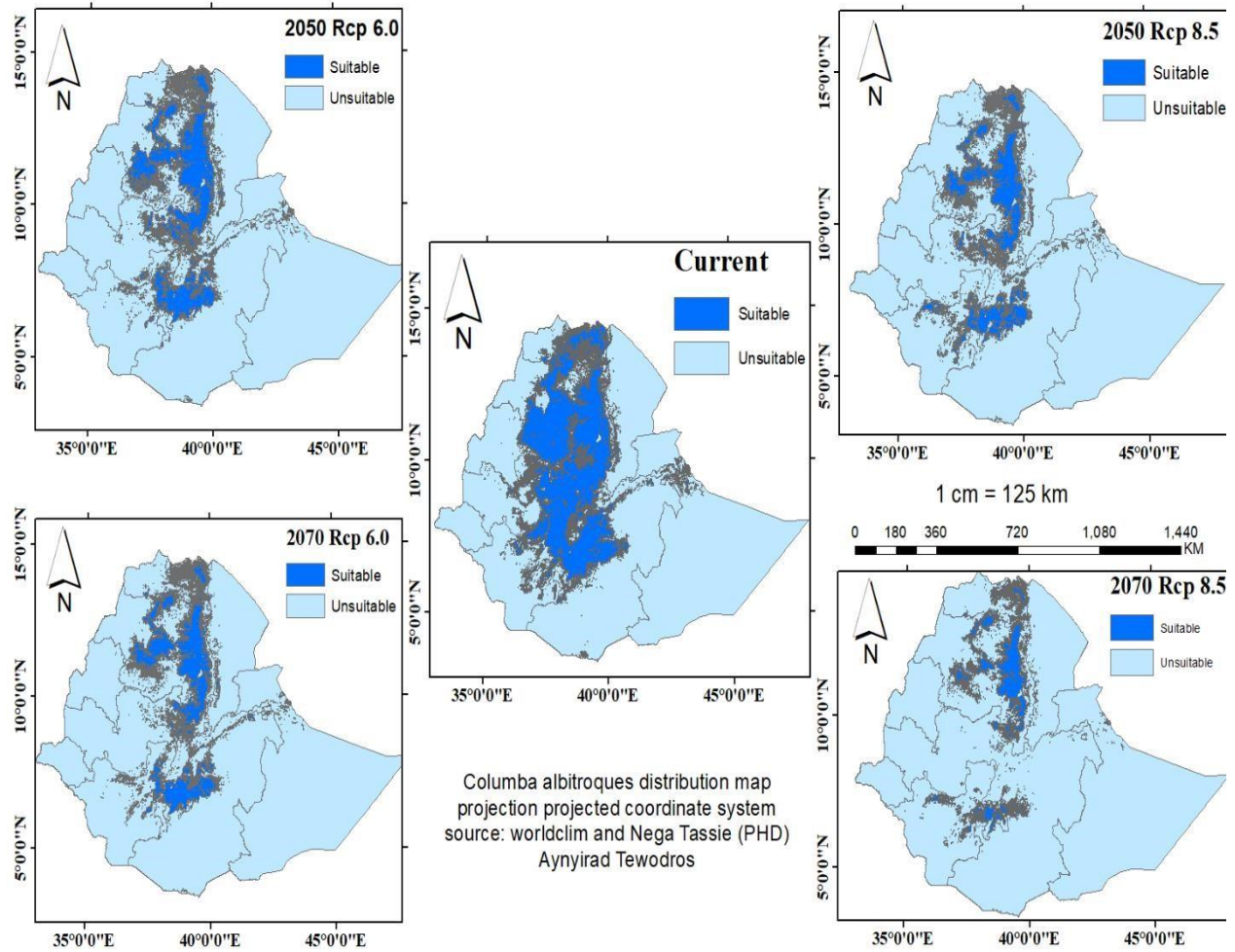


Figure 5. Distribution of *Columba albitorques* under different climate scenarios

Future projections under two greenhouse gas emission scenarios (RCP 6.0 and RCP 8.5) indicated substantial reductions in the total area of suitable habitat by 2050 and 2070. By 2050, suitable areas were projected to decrease to 140,693 km² (a decline of 44.5%) under RCP 6.0 and to 116,546 km² (a decline of 54.0%) under RCP 8.5. By 2070, projected losses increased further, with suitable areas reduced to 114,249 km² (a 54.9% reduction) and 62,034 km² (a 75.5% reduction) under RCP 6.0 and RCP 8.5, respectively (Table 3).

Table 3. Current and projected suitable areas (km²) for *Columba albitorques* under different climate scenarios.

Species	Time slices	Distribution in Km ²	Percent
<i>Columba albitorques</i>	Current	253,360.9	0
	2050 RCP 6.0	140,670.9	44.5
	2050 RCP 8.5	116,446.6	54.03
	2070 RCP 6.0	114,337.3	54.9
	2070 RCP 8.5	62,017.7	75.5

Overall, the MaxEnt model predicted substantial reductions in suitable habitat for *Columba albitorques* under future climate scenarios. Suitable areas were projected to decrease considerably by 2050 and 2070, with the greatest losses occurring under the 2070 RCP 8.5 scenario and the smallest reductions under the 2050 RCP 6.0 scenario. Spatial patterns indicated that lower-elevation and peripheral areas experienced the most pronounced contraction of suitable habitat.

4. DISCUSSION

The MaxEnt model predicted the current and future habitat suitability of *Columba albitorques* in Ethiopia with good performance, as indicated by a high mean AUC value of 0.854, suggesting reliable discrimination between suitable and unsuitable environments. Analysis of variable importance using the jackknife test and percent contribution revealed that human population density was the most influential factor, contributing 62.4% to the model. Despite its strong contribution, increasing human population density did not reduce the probability of species occurrence according to the response curves. This pattern likely reflects the species' ecological adaptability. Previous studies indicate that *Columba albitorques* roosts and breeds primarily in highland areas but moves to lowlands to forage, regularly visiting grain fields, villages, and towns for food (Weldemariam, 2016). The species is known to use anthropogenic structures such as churches, large buildings, roads, and bridges on plateaus (Weldemariam, 2016; Nega and Banda, 2020). These behaviors suggest that climatic factors, particularly temperature and precipitation, influence breeding site selection, while opportunistic foraging allows the species to exploit human-modified habitats. Such adaptability may explain why areas with higher human population density contribute strongly to the model without corresponding reductions in habitat suitability, highlighting the species' resilience to certain anthropogenic pressures. Although *Columba*

albitorques appears tolerant of areas with higher human population density, ongoing increases in human activity may still pose a threat. Expansion of agriculture, settlement, and infrastructure can result in the loss or degradation of nesting and roosting habitats, particularly in highland areas, potentially reducing long-term habitat suitability despite the species' current adaptability. These observations underscore the importance of maintaining and protecting critical highland habitats to ensure the species can continue to exploit both natural and human-modified environments under changing climatic conditions.

Following human population density, maximum temperature (t_{max}) and land cover were the next most influential factors, contributing 11.5% and 10.6% to the model, respectively. The response curves revealed that *Columba albitorques* is highly sensitive to heat, with habitat suitability declining sharply when maximum temperatures exceed approximately 37.8°C. This thermal sensitivity suggests that the species' distribution is closely tied to the cooler conditions of highland areas, an observation supported by Fasil (2021), who reported that the species is most common above 1800 m a.s.l. in Ethiopia and Eritrea, and by Lumbani and Nega (2018), who noted that high temperatures reduce suitable habitat availability. These cooler highlands likely provide microclimatic conditions within the species' tolerable range, underscoring the role of thermal constraints in determining habitat suitability. Land cover also influenced habitat suitability, indicating that *Columba albitorques* relies on specific habitat structures. These may include highland farmlands, urban edges, or mixed landscapes that provide suitable foraging and roosting opportunities. Taken together, these findings highlight that the species' distribution is shaped not only by climatic conditions but also by the availability of structural habitats, emphasizing the need to consider both natural and human-modified landscapes when assessing current and future habitat suitability.

In addition to temperature and land cover, *Columba albitorques* showed distinct climatic preferences related to precipitation. Suitable conditions were associated with annual precipitation between 600 and 900 mm, precipitation in the driest month of 1–58 mm, and higher precipitation during the warmest quarter (190–610 mm). Declines in isothermality and increases in mean diurnal range also influenced suitability. These patterns indicate that precipitation not only shapes habitat structure but also affects the availability of food and other resources critical for survival and reproduction. Even if some precipitation variables contributed minimally to the model, they still

help define the species' climatic niche and refine spatial patterns of suitability, emphasizing that both temperature and precipitation interact to determine the distribution of *Columba albitorques*.

Under current climatic conditions, *Columba albitorques* occupies a relatively narrow range of suitable habitat, yet it is considered Least Concern due to its local abundance. Future projections under RCP 6.0 and RCP 8.5 scenarios suggest substantial reductions in suitable areas by 2050 and 2070, with the greatest loss occurring under the 2070 RCP 8.5 scenario. These reductions are likely driven by the species' thermal sensitivity, reflecting its adaptation to cooler highland environments. Rising temperatures may not only reduce suitable habitat but also alter elevational distributions and affect reproductive success. These findings underscore the importance of conserving high-elevation habitats and incorporating climate-driven range shifts into long-term conservation planning.

In summary, *Columba albitorques* is projected to experience substantial reductions in suitable habitat under future climate scenarios. To mitigate these impacts, conservation efforts should prioritize high-elevation refugia, monitor population trends, and integrate land-use planning, addressing both climate change and habitat alteration to ensure the species' long-term persistence.

5. CONCLUSION

This study examined the key environmental variables influencing the current and future distribution of *Columba albitorques* in Ethiopia using the MaxEnt modeling approach. The model identified human population density (62.4%), maximum temperature (11.5%), and land cover (10.6%) as the most influential predictors shaping the species' distribution, while precipitation of the warmest quarter (0.2%), mean diurnal range (1.2%), precipitation seasonality (1.2%), and isothermality (1.9%) contributed minimally. Under current conditions, the species occupies a relatively narrow but abundant range, consistent with its Least Concern status. Model projections revealed substantial declines in suitable habitat by 2050 and 2070 under both RCP 6.0 and RCP 8.5 scenarios, with the most severe reduction (75.5%) under RCP 8.5 in 2070, indicating strong sensitivity to rising maximum temperatures. These findings underscore the need for studies documenting the spatial extent and intensity of anthropogenic pressures, investigating the drivers of habitat suitability decline, and supporting the development of targeted conservation strategies to ensure the long-term persistence of *Columba albitorques* in Ethiopia.

Acknowledgments

I sincerely thank Dr. Nega Tassie (Department of Biology, Bahir Dar University) for his guidance and support throughout the preparation of this manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable. This study used publicly available species occurrence and environmental data and did not involve experiments with human or animal subjects.

Data Availability Statement

Species occurrence records for *Columba albitorques* were obtained from the Global Biodiversity Information Facility (GBIF: <https://www.gbif.org>). Bioclimatic variables were obtained from WorldClim 2.1 (<https://www.worldclim.org>), land cover data from ESA GlobCover (http://due.esrin.esa.int/page_globcover.php), and human population density data from WorldPop (<https://www.worldpop.org>). All input data are publicly accessible via these sources.

Conflicts of Interest

The author declares no conflict of interest.

AI Assistance Statement

Portions of this manuscript were revised for clarity and grammar using ChatGPT (OpenAI). The author reviewed and verified all content.

6. REFERENCES

- Baptista, L. F., Trail, P. W., & Horblit, H. M. (1997). Columbidae. In J. del Hoyo, A. Elliott, & J. Sargatal (Eds.), *Handbook of the Birds of the World* (Vol. 4, pp. 60–231). Lynx Edicions.
- Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters*, 15, 365–377.
- Bertrand, R., Lenoir, J., Piedallu, C., Riofrio-Dillon, G., Ruffray, P., Vidal, C., Pierrat, J., & Gégout, J. (2011). Changes in plant community composition lag warming in lowland forests. *Nature*, 479, 517–520.
- Dyderski, M. K., Paż-Dyderska, S., Frelich, L. E., & Jagodziński, A. M. (2018). How much does climate change threaten European forest tree species distributions? *Global Change Biology*, 24, 1150–1163.
- Embassy of Ethiopia. (2023). *Overview of Ethiopia*. Embassy of Ethiopia, Washington.
- Fasi, A. (2021). Diurnal activity patterns and foraging habits of White-collared Pigeon (*Columba albitorques*) in Menz-Guassa Community Conservation Area.
- Fernández, I. C., & Morales, N. S. (2019). One-class land-cover classification using MaxEnt: Effects of parameterization on accuracy. *PeerJ*, 7, e7016. <https://doi.org/10.7717/peerj.7016>
- Food and Agriculture Organization. (2003). *Ethiopia: Country pasture/forage resource profiles*. FAO. <https://www.fao.org/4/J1552E/J1552E00.pdf>
- Fourcade, Y., Engler, J. O., Rödder, D., & Secondi, J. (2014). Mapping species distributions with MaxEnt using geographically biased presence data. *PLoS ONE*, 9, e97122.
- Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *Int. J. Climatol.* 25(15): 1965–1978.
- Huang Z., Bai, Y., Alatalo, J. M., & Yang, Z. (2020). Mapping biodiversity conservation priorities for protected areas: A case study in Xishuangbanna Tropical Area, China. *Biological Conservation*, 249, 108741.

- Khanum, R., Mumtaz, A., & Kumar, S. (2013). Predicting impacts of climate change on medicinal asclepiads in Pakistan using MaxEnt. *Acta Oecologica*, 49, 23–31.
- King, D., & Finch, D. M. (2013). *The effects of climate change on terrestrial birds of North America*. U.S. Forest Service, Climate Change Resource Center.
- Lehikoinen, A., & Virkkala, R. (2015). Climate change and directions of density shifts in birds. *Global Change Biology*, 22, 1121–1129.
- Li, X., et al. (2022). The effects of climate change on birds and approaches to response. *IOP Conference Series: Earth and Environmental Science*, 1011, 012054.
- Liu, C., Berry, P.M., Dawson, T.P. and Pearson, R.G. (2005). Selecting thresholds of occurrence in the prediction of species distributions. *Ecography* 28: 385–393.
- Liu, G., & Mai, J. (2022). Habitat shifts of *Jatropha curcas* under climate scenarios in the Asia-Pacific Region. *Energy*, 251, 123885.
- Mason, L. R., Green, R. E., Howard, C., Stephens, P. A., Willis, S. G., Aunins, A., et al. (2019). Population responses of birds to climate change vary with ecological traits. *Climatic Change*, 157, 337–354.
- Nega, T., & Banda, L. B. (2020). Modeling the distribution of four bird species under climate change in Ethiopia. ResearchGate.
- Phillips, S. J., & Dudík, M. (2008). Modeling species distributions with MaxEnt: New extensions and evaluation. *Ecography*, 31(2), 161–175.
- Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species distributions. *Ecological Modelling*, 190, 231–259.
- Phillips, S. J., Anderson, R. P., Dudík, M., Schapire, R. E., & Blair, M. E. (2017). Opening the black box: MaxEnt open-source release. *Ecography*, 40(7), 887–893.

Rajpar, M. N., & Zakaria, M. (2011). Bird species abundance and microclimate relationships in a Malaysian wetland. *International Journal of Zoology*, 758573. <https://doi.org/10.1155/2011/758573>

Schatz, A. M., Kramer, A. M., & Drake, J. M. (2017). Accuracy of climate-based forecasts of pathogen spread. *Royal Society Open Science*, 4, 160975. <https://doi.org/10.1098/rsos.160975>

Stephens, P. A., Mason, L. R., Green, R. E., Gregory, R. D., Sauer, J. R., & Alison, J. (2016). Consistent responses of bird populations to climate change on two continents. *Science*, 352(6281), 84.

Urban, M. C. (2015). Accelerating extinction risk from climate change. *Science*, 348, 571–573.

Wei, J., Zhang, H., Zhao, W., & Zhao, Q. (2017). Niche shifts and potential distribution of *Phenacoccus solenopsis* under climate change. *PLoS ONE*, 12(7), e0180913.

Weldemariam, T. (2016). *A catalogue for endemic birds of Ethiopia*. Ethiopian Biodiversity Institute.

Wolff, J. V. (1961). Wildlife in Ethiopia. *Ethiopian Forestry Review*, 2, 3–13.

World Bank. (2021). *Climate Risk Country Profile: Ethiopia*. World Bank Group. <https://climateknowledgeportal.worldbank.org/>

World Bank. (2023). *Ethiopia country overview*. World Bank.. <https://media.afreximbank.com/afrexim/Ethiopia-Country-Brief-2023-1.pdf>

Yan, H., He, J., Xu, X., et al. (2021). Prediction of suitable distribution of *Codonopsis pilosula* in China using MaxEnt. *Frontiers in Ecology and Evolution*, 9, 773396.

Zhu, G., Bu, W., Gao, Y., & Liu, G. (2012). Potential geographic distribution of *Halyomorpha halys*. *PLoS ONE*, 7(3), e0031246. <https://doi.org/10.1371/journal.pone.0031246>