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

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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 applied MaxEnt modeling to predict the current and future distribution of the White-collared Pigeon (*Columba albitorques*) under two greenhouse gas emission scenarios (RCP 6.0 and RCP 8.5) for 2050 and 2070. Species occurrence records were obtained from the Global Biodiversity Information Facility (GBIF), and bioclimatic variables from WorldClim. Environmental predictors included land cover and human population density. The model performed well (AUC = 0.854), identifying maximum temperature, land cover, and human population density as the most influential predictors of *Columba albitorques* distribution. Future projections indicate substantial declines in suitable habitat, ranging from 44.5 to 54% by 2050 and 54.9 to 75.5% by 2070, with the largest reductions occurring under RCP 8.5 by 2070. These findings suggest that *Columba albitorques* may experience habitat contraction and increased elevational compression under warming scenarios. Conservation strategies that protect high-elevation habitats and reduce human-induced habitat degradation will be essential for maintaining viable populations under future climate conditions.

Keywords: Climate change, MaxEnt, *Columba albitorques*, Ethiopia, habitat suitability

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 & 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 & 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 (World Bank, 2023) and exhibits steep elevational gradients and heterogeneous climates, ranging from lowland arid regions to afro-alpine zones in the Simien and Bale Mountains (World Bank, 2021). 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).

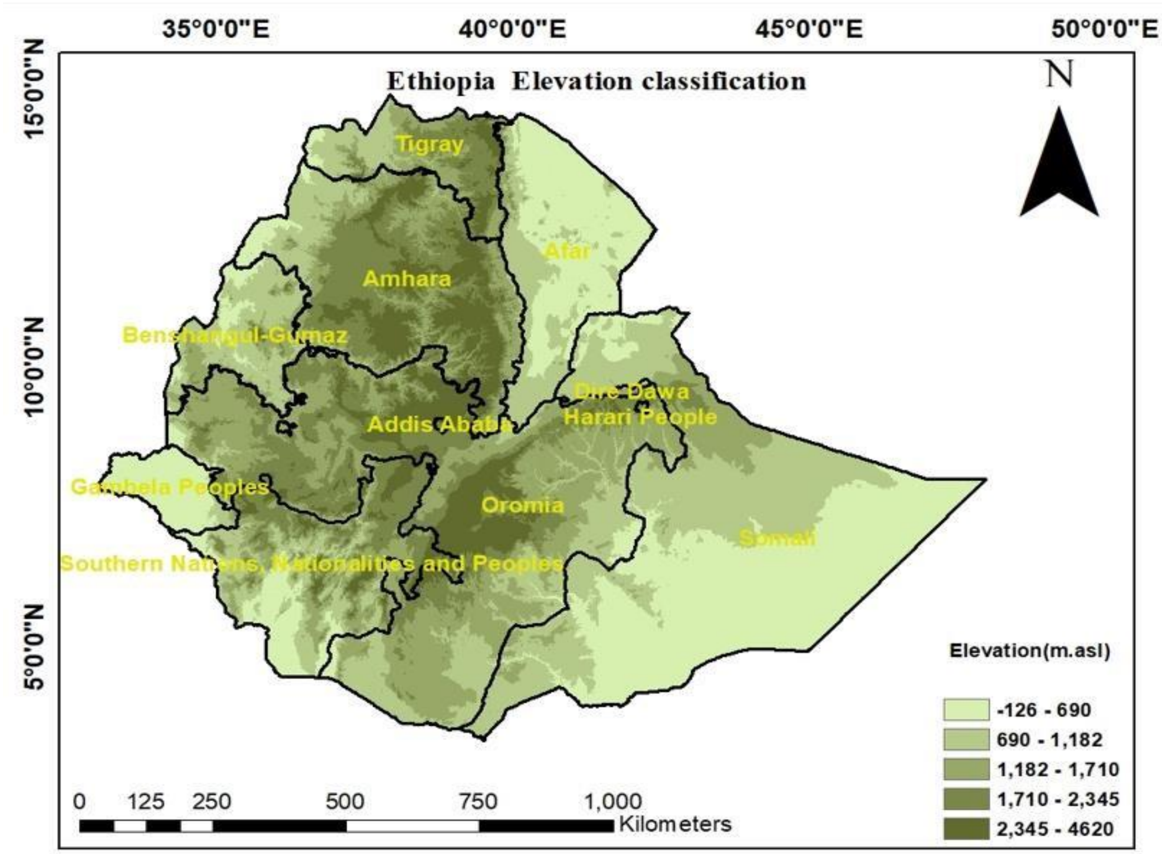

Figure 1. Elevation map of the study area, Ethiopia

2.2 Species Description

Columba albitorques (White-collared pigeons) is a medium-sized pigeon species, recognized as one of the most successful bird groups in tropical and temperate zones, including some of the harshest environments on Earth (Baptista *et al.*, 1997). In Ethiopia and Eritrea, these pigeons are commonly found at elevations of 1800 - 4100 m.a.s.l. inhabiting rugged areas such as cliffs, escarpments, plateaus, villages, large buildings, and agricultural landscapes. Individuals regularly move between roosting sites and feeding areas, such as agricultural lands and moorlands at lower elevations (Weldemariam, 2016).

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

For this study the Bioclimatic variables were obtained from WorldClim 2.1 (30 arc-seconds resolution; www.worldclim.org) (Hijmans *et al.*, 2005). 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 data were obtained from (WorldPop) (www.worldpop.org), and land cover data were obtained from GlobCover (http://due.esrin.esa.int/page_globcover.php), both included to represent anthropogenic influences on the distribution of *Columba albitorques*. While bioclimatic variables were treated as dynamic, human population density and land cover were considered static due to the lack of reliable future projections. Multicollinearity among predictor variables was assessed using a Pearson correlation matrix in R software. Pairs of variables with high correlation ($r \geq 0.75$) 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
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

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 subsample method in MaxEnt was applied, which randomly partitions occurrence records into 75% for training and 25% for testing model performance in each of five replicates (Phillips *et al.,* 2017). A maximum of 5000 iterations was set, and a 10^{th} percentile training presence logistic threshold was used to distinguish suitable from unsuitable habitats. Logistic output format was selected 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).

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 & 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, suggesting very good discriminatory power between suitable and unsuitable areas (Figure 2).

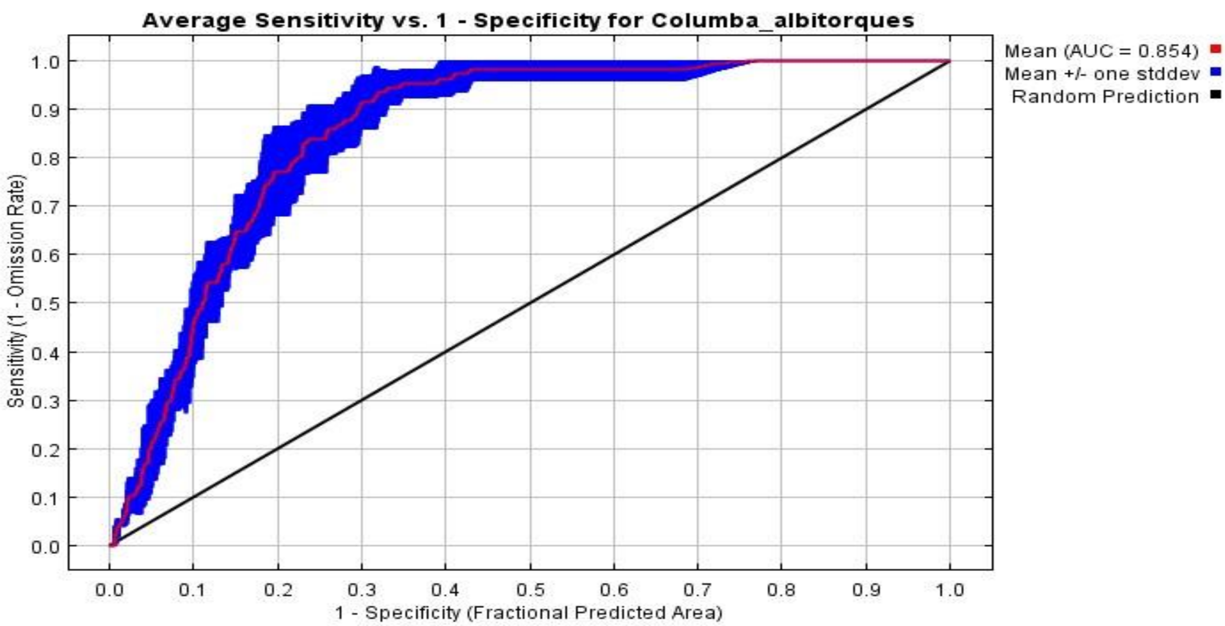

Figure 2. The AUC of the training and test data for the 5 replicate runs of *Columba albitorques.*

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. Other variables including, mean diurnal range (Bio2), Isothermality (Bio3), Temperature annual range (Bio7), and Precipitation seasonality (Bio15) showed a lower contribution to the predicted model's prediction of *Columba albitorques'* habitat suitability (Figure 3).

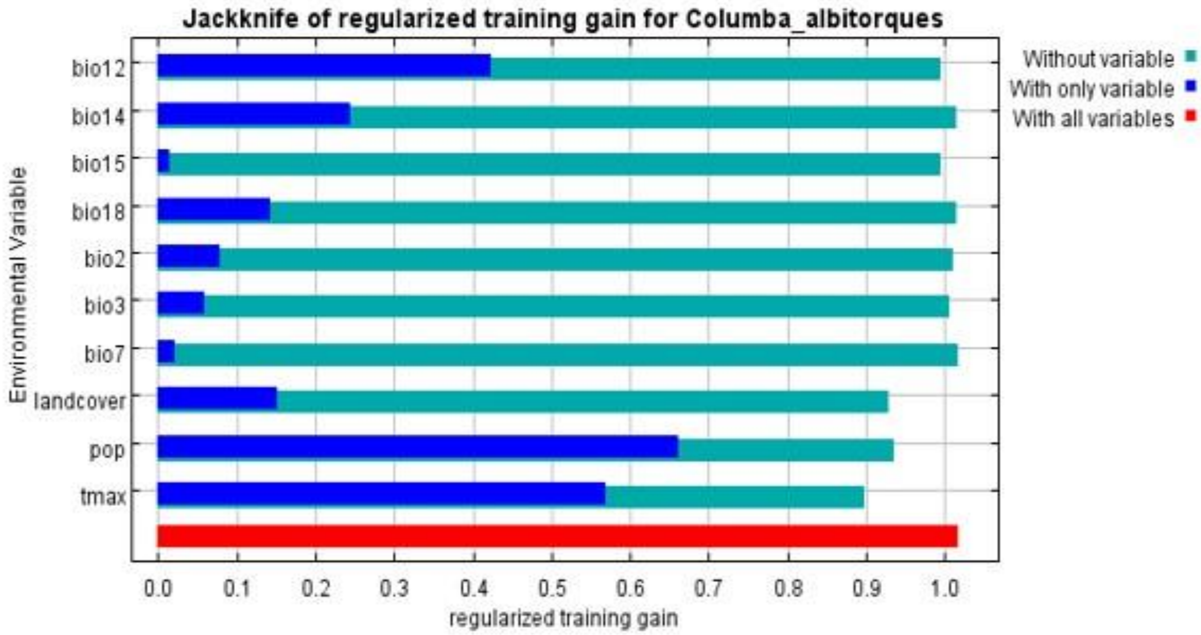

Figure 3. Jackknife test of variable importance in the MaxEnt model predicting *Columba albitorques* distribution.

The percent contribution analysis identified human population density as the most influential predictor, contributing 62.4% to the MaxEnt model's prediction of the distribution of *Columba albitorques*, followed by maximum temperature (tmax) and land cover, which contributed 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%, respectively (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'* occurrence (Figure 4). Habitat suitability was highest where precipitation of the driest month ranged from 1–58 mm and annual precipitation ranged from 600 - 900 mm. Areas with an annual temperature range of 12 - 28°C were also favorable. Suitability declined sharply when the maximum temperature exceeded 37.8°C. optimal precipitation seasonality was around 36 mm, while increased precipitation of the warmest quarter (190–610 mm) favored occurrence. Decreases in isothermality (47–87) and increases in mean diurnal range (8.8–18.7°C) influenced suitability patterns. Human population density also affected species distribution but showed a constant influence on occurrence, while Land cover influenced suitability differently depending on cover type (Figure 4).

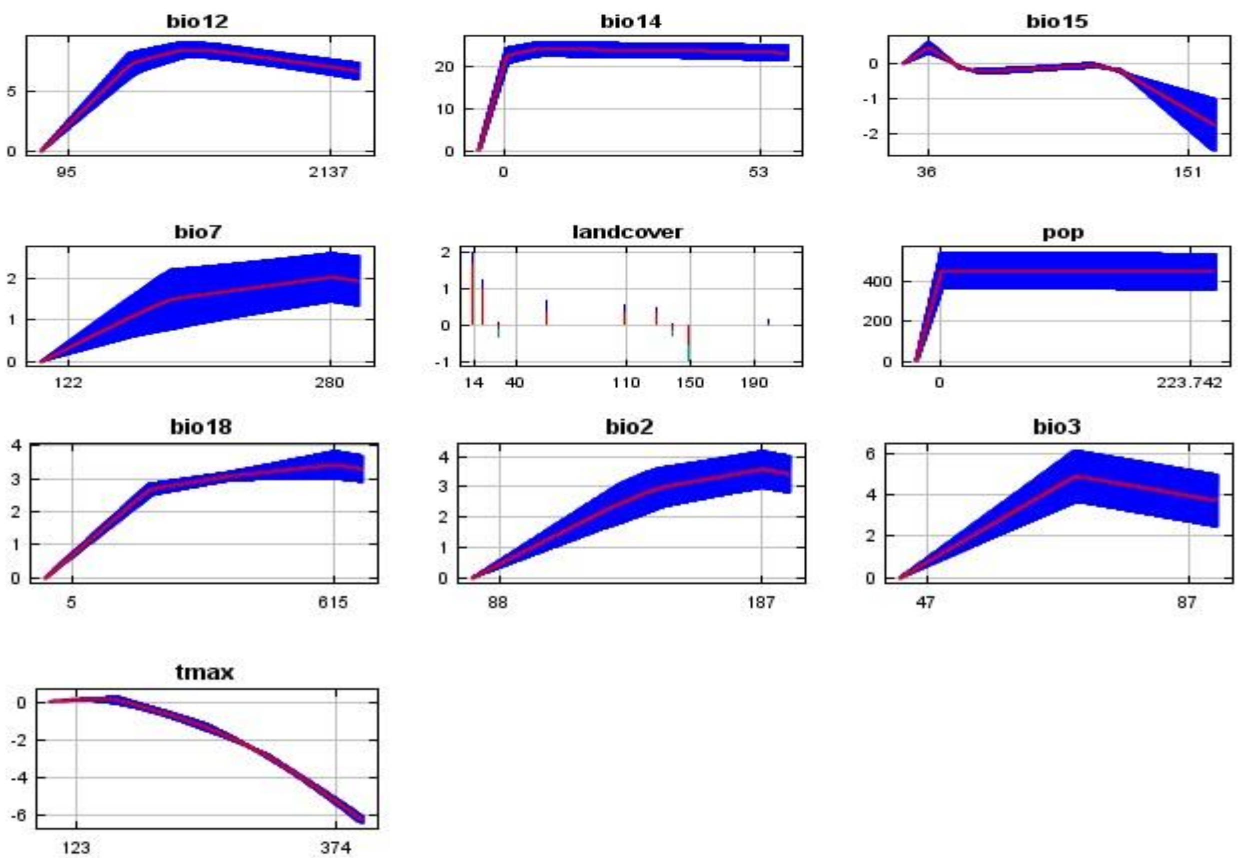

Figure 4. Response curves of the most relevant environmental factors affecting the distribution of *Columba albitorques*

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).

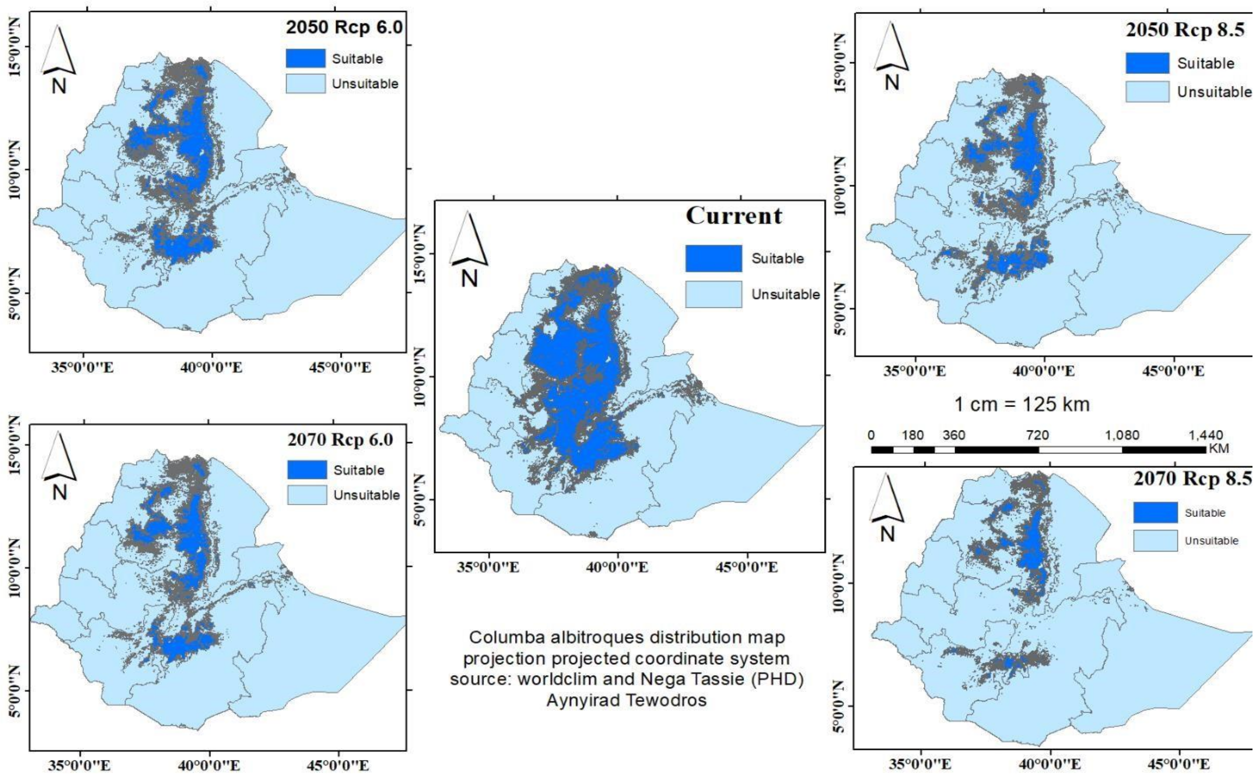

Figure 5**.** Distribution of *Columba albitorques* under different climate scenarios

Future projections under two greenhouse gas emission scenarios (RCP 6.0 and RCP 8.5) suggest 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, losses are expected to intensify, with suitable areas decreasing 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
Columba albitorques	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

Analysis of variable importance using the MaxEnt model suggested that human population density had the strongest influence on the prediction of *Columba albitorques* distribution. However, response curves showed that habitat suitability did not decline in areas with higher human densities, suggesting that the species is ecologically adaptable to both human-altered habitats and local environmental variability. Previous studies support this pattern, showing that *Columba albitorques* exploits human-modified habitats, regularly foraging in villages, towns, and agricultural fields, and roosting on anthropogenic structures such as churches, bridges, and buildings (Weldemariam, 2016; Nega & Banda, 2020). This ecological flexibility 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. Nevertheless, the ongoing expansion of agriculture, settlement, and infrastructure may still threaten critical nesting and roosting habitats, particularly in highland areas, potentially reducing long-term habitat suitability despite the species' current adaptability. These observations emphasize 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.

Maximum temperature (tmax) was the next most influential factor in determining the distribution of *Columba albitorques*. 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 habitat suitability. 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 appeared to shape distribution patterns, reflecting the species' reliance on specific habitat structures, including highland farmlands, urban edges, or mixed landscapes, that provide suitable foraging and roosting opportunities. In addition, *Columba albitorques* showed preferences for specific precipitation regimes, with suitability influenced by annual rainfall, precipitation in the driest month, and precipitation during the warmest quarter. These patterns may suggest that stable water availability and associated vegetation productivity may be critical for food resources and habitat quality. Sensitivity to variations in isothermality and mean diurnal range also suggests that the species may be constrained by the environment, with high temperature fluctuations, highlighting its adaptation to the relatively stable microclimates of the Ethiopian highlands.

Under current climatic conditions, *Columba albitorques* occupies a relatively narrow range of suitable habitat. However, it is classified as Least Concern because it remains locally abundant, occurs across a broad elevational and habitat spectrum within this restricted range, including urban environments, and does not exhibit population declines rapid enough to meet the IUCN threshold for a threatened category (BirdLife International 2016). Its presence in both natural and anthropogenic habitats suggests a degree of ecological flexibility that may buffer it against some habitat disturbances. However, 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 declines are consistent with the species' sensitivity to rising temperatures and altered precipitation patterns and may lead to elevational range compression, reduced habitat availability, and potential impacts on reproductive success and long-term population viability. Conservation efforts should therefore prioritize the protection of high-elevation refugia, incorporate climate-driven range shifts into land-use planning, and support long-term population monitoring to enhance the species persistence under future climate change.

Study limitations

This study relies on publicly available species occurrence and environmental datasets, which may contain spatial, temporal, or taxonomic biases. Field verification of species presence was not conducted, and fine-scale environmental heterogeneity may not be fully captured by the selected bioclimatic, land cover, and human population layers. Additionally, while future climate projections were based on widely used RCP scenarios, uncertainties inherent to climate models and potential interactions with land-use change could affect predicted habitat suitability. These limitations should be considered when interpreting the results and underscore the need for complementary field studies and long–term monitoring to validate model predictions.

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, maximum temperature, and land cover as the most influential predictors shaping the species' distribution, while other temperature and precipitation-derived variables contributed minimally. Under current conditions, the species occupies a relatively narrow but abundant range. Future 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 occurring under RCP 8.5 in 2070, indicating sensitivity to rising maximum temperatures. These results suggest that ongoing warming may lead to habitat contraction and elevational range compression, emphasizing the need to prioritize high-elevation refugia and integrate climate change considerations into conservation planning for this endemic species.

Declarations

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Author Contributions

A.T. conceived the study, compiled and analyzed the data, and wrote the manuscript.

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Ethical responsibility statement

The author has read, understood, and complied as applicable with the statement on ‘Ethical responsibilities of Authors’ as found in the instructions for Authors.

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.

Informed Consent Statement

Not applicable.

Conflicts of Interest

The author declares no conflict of interest.

Data Availability Statement

The datasets generated and/or analysed during the current study are available from publicly accessible sources: species occurrence records from the Global Biodiversity Information Facility (GBIF: www.gbif.org). Bioclimatic variables 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).

AI Assistance Statement

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

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