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Predicting the Impacts of Climate Change on the Potential Suitable Habitat Distribution of House Crows (*Corvus splendens*) in Tanzania

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Abstract

Global climate change has recently received attention as it affects species distribution at all scales. Many species, including invasive species, have indicated a shift in their ecological ranges in response to climate change. However, little is known about the impacts of climate change on house crows (*Corvus splendens*) habitat distribution in Tanzania. We assessed the impacts of climate change on current and future potential suitable habitat distribution for house crows using Maxent 3.4.1. We estimated the extent of both current and future potential suitable habitats for house crows, the persistence of house crows' suitable habitats through time, and the size of suitable habitat in protected areas of Tanzania. Current suitable habitat distribution tallied with the observed house crow distribution along the coast of the Indian Ocean. We identified new potential suitable areas around Lake Victoria. Future climate change will likely cause extreme expansion of house crows throughout this century; interestingly, contemporary house crow suitable niche will likely persist towards the end of this century, as we predicted overlap between potential current and future suitable niche. We predicted 51,000 km^2 as the currently suitable area, which was more than 20 times less than predicted future potential ranges in Tanzania. Future climate change impacts are estimated to expand suitable habitat for house crows into protected areas of Tanzania. These findings suggest that the biodiversity would continue to experience threats from house crow invasions. Mitigation measures against house crow are inevitable, to alleviate socio-economic impacts likely from house crow invasions in Tanzania.

Subject Areas

Ecology

Keywords

House Crows, Climate Change Impacts, Species Distribution Modeling, Tanzania

1. Introduction

Climate change predictions indicate an upward trend in temperature for at least the next nine decades [1], even though there is uncertainty with different climate models predicting different magnitudes of warming [2]. On average, global temperatures are expected to rise by 0.8˚C - 2.6˚C and by 1.5˚C - 3˚C in Africa by the year 2050 [3]. These changes in climate would likely cause species habitat modification including range expansion of biodiversity such as house crow and other bird species or contraction in addition to altering their relationships with the biophysical environment [2]. The influence of climate change on species distribution has been demonstrated in fossil records and the observed trends from the twentieth to twenty-first centuries on species range shifts [2]. This scientific evidence suggests a need to investigate the impacts of climate change on different species to provide necessary baseline information for conservation planning and management [4] and how to design and set control strategies in case of invasive species.

Globally, the genus crow (*Corvus*) is found in all continents, including Asia, North America, Europe, Australia, and Africa. Europe accommodates raven, carrion, hooded, rook and jackdaw while in Africa there are pied crow *Corvus albus*, Somali Crow *Corvus edithae*, cape crow *Corvus capens*, white-necked raven *Corvus albicollis*, Fan-tailed Raven *Corvus rhipidurus* and Piapiac *Ptilostomus afer* and the invasive species house crow *Corvus splendens* [5] [6] [7]. Apart from the mentioned crow species, house crow is one of the most successful exotic crows in Africa being introduced to Tanzania since the 1890s on the island of Zanzibar as garbage scavengers from the Indian Subcontinent [8]-[13].

Since then, the house crow population has continued to expand in the coastal regions including Morogoro as recorded in 1999 [13] [14] [15] and progressing inland [16] [17], now in Dodoma, Singida, Tabora (Nzega), Kilimanjaro, Manyara and Arusha [5] [6]. In Dar es Salaam, direct impacts from house crows have been studied and demonstrated that numbers are tremendously increasing [13]. [15] reported the numbers of house crow as about 20,000 individuals, likely to date this number has continued to increase since then.

An increase in the number of house crows in Tanzania will possibly ruin the population of biodiversity including bird species. Reports show negative effects of house crows on native biodiversity [11] [18] as it increases competition with local birds, they feed on eggs, fledglings, and similar food species [18] [19] [20]. The house crow predates small animals, including amphibians, reptiles, birds, and mammals. It poses a special risk to species of small birds breeding in its vicinity. Examples from eastern Africa, show that house crows are known to pillage passerine nests (eg: ploceids) and heronries [18], mob and harass adult birds, and probably displaced many native birds from their natural habitats [11] [18] [21]. [22] studies in Mombasa, observed that it eliminates small native birds in their native environment and affected species including weavers (*Ploceidae*) and sunbirds (*Nectariniidae*). Locally, pied crow were displaced from their native habitats [22]. Therefore, interactions with local bird species are therefore in jeopardy as house crow population increases.

House crows are known to predate chicks and eggs inhibiting free-ranging poultry farming, sometimes house crows feed on crops such as maize (*Zea mays*) and sorghum (*Sorghum vulgare*) [18] [21]. Wide range of feeding behaviour of house crow has also resulted in high losses to crops and orchards [22]. The house crow was also reported to damage young maize cobs, as well as soft fruits like mangoes, pawpaw and bananas, thus rendering them useless for selling [11] [22]. Other impacts of house crow include nuisance to people, diseases spread and presents a real threat to the tourist amenities and industry in some regions of Tanzania when their numbers increase. Loud cawing calls, and human settlements contamination with droppings appear to be a very common phenomenon toward humans and wildlife located near their nesting sites and possibly affects human welfare [11]. Study by [11] observed flocks of adult crows actively attacking other bird species, human or otherwise, the situation becoming of concern especially when children are involved.

We use ecological niche models (ENMs) to predict a species' potential distribution under different environmental change scenarios [23], the ENM have been shown to provide critical information for conservation planning [4] [23]. ENMs integrate the relationships between species presence and its environmental conditions to identify a species' potential distribution at un-sampled locations [24] [25] [26] [27]. In this study, we used the maximum entropy modeling approach [25] to estimate the extent and distribution of potentially suitable habitat for House Crows in Tanzania under current and future climate scenarios; to provide important baseline information for monitoring programs against this species in Tanzania.

2. Methods and Materials

2.1. Study Area

The study was conducted in different regions of Tanzania, as presented in **Figure 1**. Tanzania is an East African country lying south of the Equator between latitudes 1˚ and 12˚S, and longitudes 29˚ and 41˚E (**Figure 1**). The country comprises the Tanzania mainland and the island (Zanzibar). It covers a total area of approximately 945,087 km^2 consisting of a land area of 883,087 km^2 (881,087 km^2

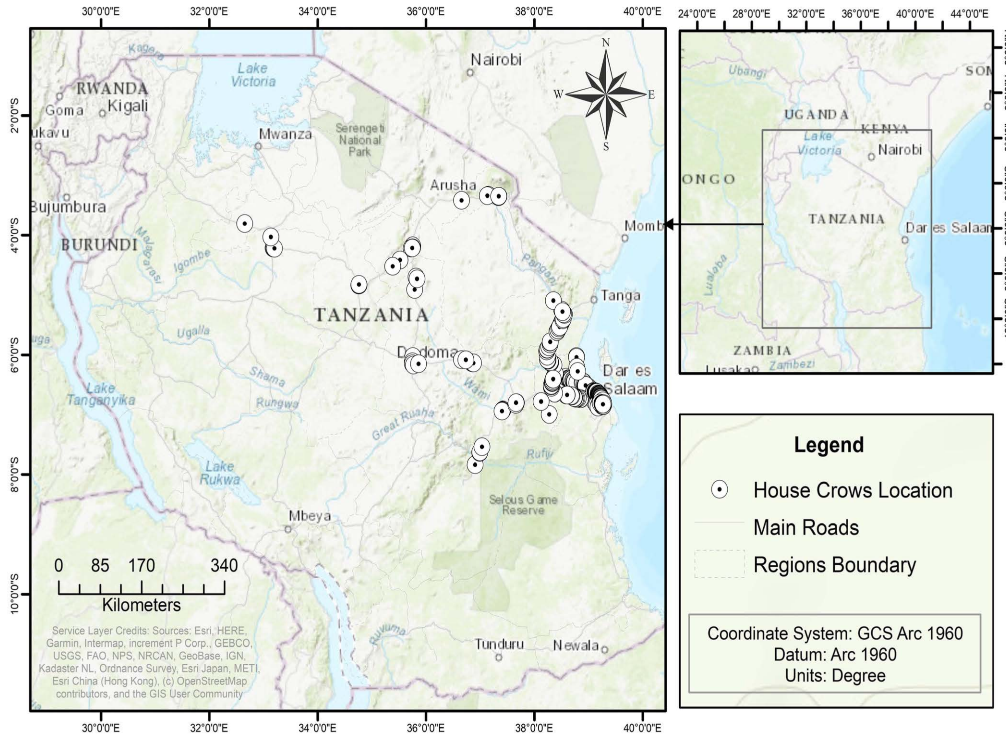

Figure 1. Study area location.

mainland and 2000 km² Zanzibar, and 62,000 km² of inland water bodies and part of the Indian Ocean. The country borders Kenya and Uganda to the north; Rwanda, Burundi, and Democratic Republic of Congo to the west; Zambia and Malawi to the south-west; Mozambique to the South and the Indian Ocean to the East (**Figure 1**).

A more significant proportion of Tanzania is covered by plateaus, with a tropical climate and moderate temperature. However, the thin coastal stretch along the Indian Ocean is hot and humid throughout the year, especially from November to April. As a result, the rain patterns of the country vary across regions. Lake Victoria, coastal areas and other areas in the north and east receive two rainy seasons, one less intense, known as short rains season, between October and December, and the other more intense, known as long rains season, from March to May, with the peak in April. The western, southern, and central area of Tanzania and the southern slopes of Mount Kilimanjaro, receives rains from November to April [28].

2.2. House Crow Data

BirdLasser smartphone application was used to record all house crows observed along the existing roads in Tanzania. In Forest Reserve and National Park areas walking transects were created of more than 5 km where presence of crows were recorded. House crow sightings relied on both direct sightings aided by the use of binoculars and indirect observations using calls. BirdLasser is an application designed for both Apple and Android phones that facilitates recording of bird observation locations (it is not a bird identification guide) [29]. A distance of 100 m on either side of the road or transect was maintained, although sometimes distance was increased depending on visibility. We used observers' experience in identifying the species, and sometimes field guide books were used to identify crow species [30]. The house crows observations were grouped in a trip card and were created per road transect. Observations of house crow were added by tapping on the LOG button, searching for the appropriate species in the list, and then tapping on it. The software automatically recorded each record's dates, time, and GPS locations. In addition, the application allows users to add a large variety of supplementary information (e.g., number of individuals seen, demography, habitat use, and behavior.

2.3. Current and Future Predictor Variables

We obtained both current (see **Table 1**) and future climate variables from the WorldClim database at 1-km^2 [31]. We ran pairwise Pearson correlation tests using ENMTOOLS [32] to reduce multi-collinearity and overfitting [33]. We retained one variable for pairs with ±0.75 [34]. We obtained land cover data for Tanzania from MODIS land cover product (MCD12Q1) and elevation data from the digital elevation model (DEM) from USGS website. Since House crows are regarded to be associated with humans [10], we considered groups of land cover classes and slopes derived from elevation data.

To project the current potential distribution of house crow to future climatic conditions data from the three downscaled global climate models (GCMs) of the Coupled Model Inter-comparison Project Phase 5 (CMIP5): ACCES1-0(#), CCM4, and HadGM2-AO for the year 2050 and 2070 from WorldClim [27] were used.

Table 1. Percent variable contribution in predicting current potential suitable habitat for house crow (*Corvus splendens*) in Tanzania.

Variable	Definition	Percent contribution	Permutation importance
bio19	Precipitation of Coldest Quarter	25.6	26
dem_new1	Elevation	21.9	7.5
landcover1	Land cover classes	20.5	10.6
bio18	Precipitation of Warmest Quarter	6.6	5.5
bio13	Precipitation of Wettest Month	5.9	2
bio03	Isothermality	5.7	7.4
bio01	Annual Mean Temperature	4.3	13.5
bio15	Precipitation Seasonality	3	8.7
bio04	Temperature Seasonality	2.5	6.2
bio12	Annual Precipitation	2	9.6
bio14	Precipitation of Driest Month	1	1.7
slope_new1	Inclination	0.9	1.4

For each of these GCMs, the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) has defined four Representative Concentration Pathways (RCP2.6, RCP4.5, RCP4.5, RCP6, and RCP 8.5) corresponding to radiative forcings of 2.6 W/m^2, 4.5 W/m^2, 6 W/m^2 and RCP 8.5 W/m^2 respectively [35]. These pathways represent different future climatic conditions based on projected increases in greenhouse gas concentrations (and implied emissions) [36]. Therefore, we selected RCP 4.5 and RCP 8.5 for each of the two future projections.

2.4. Modelling Approach

We applied machine learning tool Maxent 3.4.1 [37] to estimate current and future suitable habitats for house crows in Tanzania. Maxent outperforms most among other species distribution modeling methods utilizing presence only data such as GARP, as well as presence/absence data [24] [25]. It builds inference from incomplete species information by estimating species distribution using the probability of distribution of the maximum entropy [25] [38]. The following settings were used in Maxent: None auto features, convergence threshold of 0.00001, maximum number of background = 10,000, regularization multiplier = 1, iteration = 1000. This helped to maintain comparability with previous studies. We used a low number of predictors to address potential issues with overfitting and transferability [39] [40]. We split the occurrence data into 75% for training and 25% for testing and applied a 10-percentile threshold bootstrap approach to convert raw model outputs to actual distributional estimates [41] [42].

For future times, we used three selected Climate Models and their respective Representative Concentration Pathways (RCP 4.5 and 8.5) for GCMs: ACCES1-0(#), CCM4, and HadGM2-AO) to predict future potential suitable habitat distribution of house crows for the year 2050 and 2070 respectively. We excluded land cover data when modeling future conditions. We maintained elevation and slope as static variables in the future modelling as these variables are not likely to vary significantly over the next century [43].

We assessed model accuracy by the area under the receiver operating curve-AUC statistics. This measure is suitable because it is threshold independent in nature [25]. In models utilizing presence only data, the AUC is used to discern that the model correctly identifies a presence site rather than a background site [44].

Rather than averaging pixel values from all model replicates, we applied the *Model majority rule*, each pixel is classified as suitable if two-third of the model replicates predicted presence for that site [45] in our case seven out of ten replicates. This is because Maxent replicates generate different estimates [46]. We combined the resulting binary outputs of each GCMs to obtain future suitable areas for 2050 and 2070 using the same approach classifying as suitable any pixel with at least two of the three GCMs as suitable using ArcGIS 10.4.

It is widely recognized that animal distribution may decide to remain in their original niche by adjusting to changing environmental conditions through ecological flexibility and house crows are known as flexible species tolerating wider environmental conditions [8]. To estimate such potential, we overlapped current and future predicted suitable areas following [33]. We estimated areas suitable under current and future periods in all categories through 2050 and 2070 respectively. Finally, we estimated the size of predicted potential suitable habitat in all categories of protected areas in Tanzania by clipping each: Wildlife Management Areas (WMA), game reserves, national parks, and Ngorongoro Conservation Area in Tanzania, information relevant for demonstrating needs for incorporating control strategies for house crows under climate change.

3. Results

3.1. Model Accuracy

Under current conditions, the model had AUC = 0.977 ± 0.002, indicating that there is a higher than random chance that pixel identifying presences are suitable for the species (**Figure 2**). All future models had AUC ranging from 0.941 - 9.48, corroborating current predictions in power to delineate suitable against unsuitable conditions. According to [47], the range of AUC values have been graded as AUC = 0.5 as "no discrimination", 0.7 < AUC < 0.8 as acceptable range, 0.8 < AUC < 0.9 is excellent range and AUC > 0.9 is outstanding.

3.2. Variable Importance

The most important variables in determining potentially suitable habitat for house crows were precipitation of Coldest Quarter (25.6%), elevation (21.9%), and Landcover (20.5%), respectively (**Table 1**). Suggesting that under current

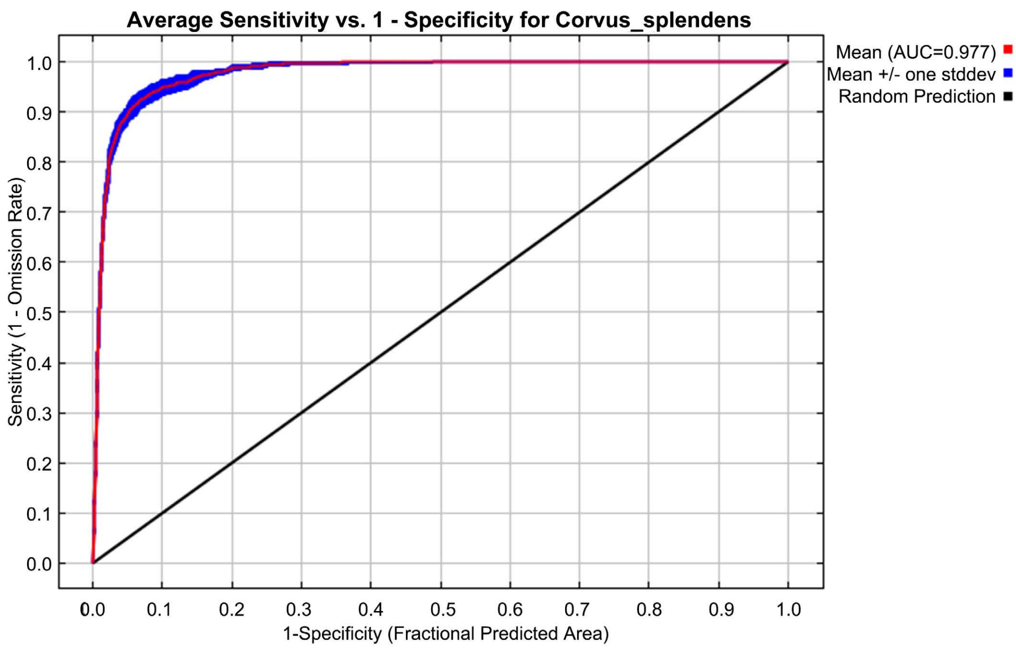

Figure 2. Maxent output showing model accuracy for current conditions.

conditions, *Corvus splendens* prefers areas that receive about 100 mm of rainfall during the coldest quarter, lower elevations above sea level, and mostly in cultivated land and highly populated areas respectively (Figure 3).

Permutation importance (Table 1) refers to the contribution for each variable determined by randomly permuting the values of that particular variable among training points both presence and background, and measure the resulting decreese in the training AUC [25]. Large decrease implies that the model depends greatly on that variable [25]. The values are then normalized to provide percentages (Table 1). This measure depends only on the final Maxent model, not the path used to obtain it [25]. In our case, the model used slope the most (Table 1).

3.3. Current Predicted Potential Suitable Habitat Distribution

The most suitable habitats for house crows in Tanzania are the coastal regions: Dar es Salaam, Tanga, Morogoro, and Coastal region (Figure 4). These regions were previously reported as centres for the species introduction in 1980s [13], While reports only show that recently this species now occurs in Dar es Salaam, Morogoro, and Dodoma [13]. In this study, we report new potential areas around

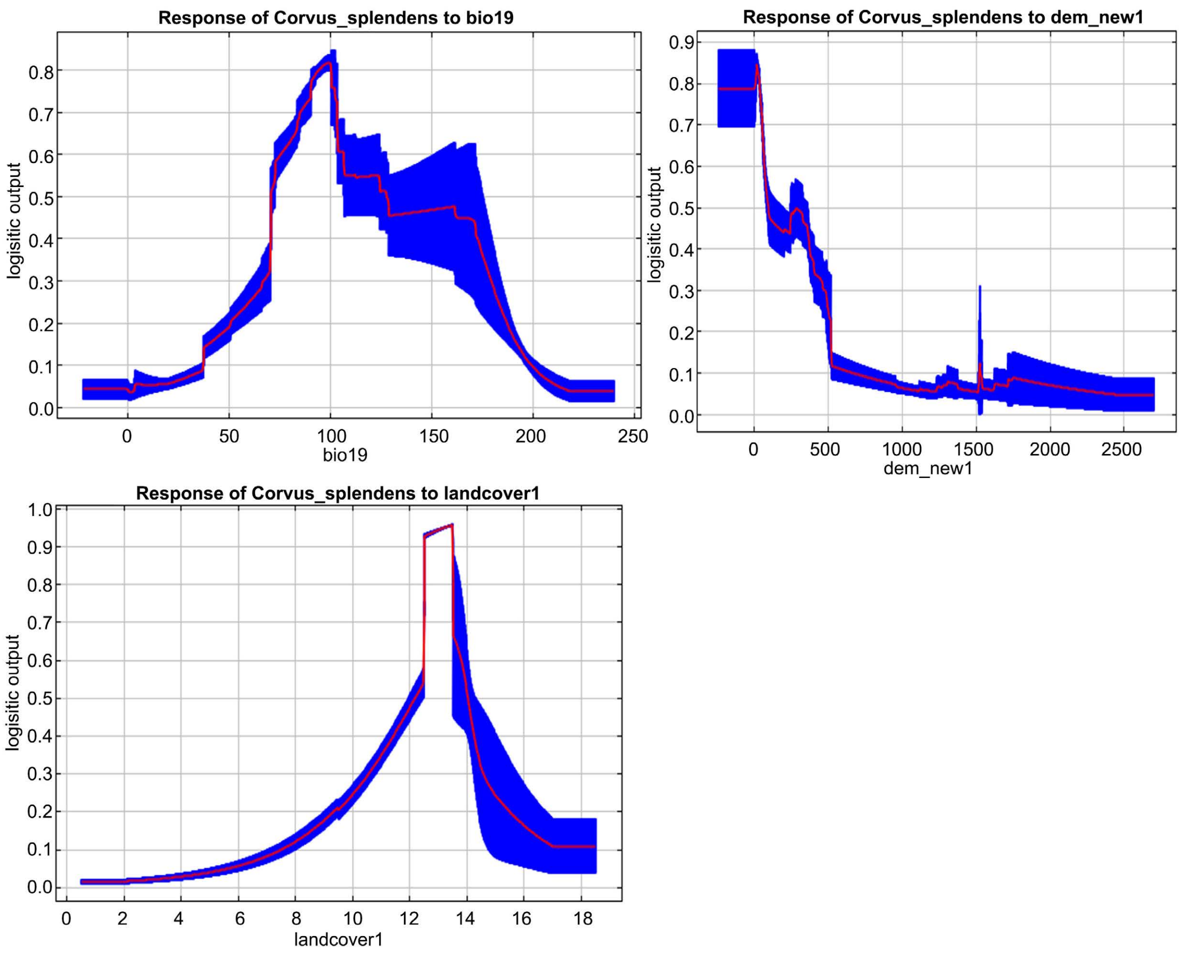

Figure 3. Maxent outputs of most important variables in predicting current potential suitable habitat distribution for *Corvus splendens* in Tanzania.

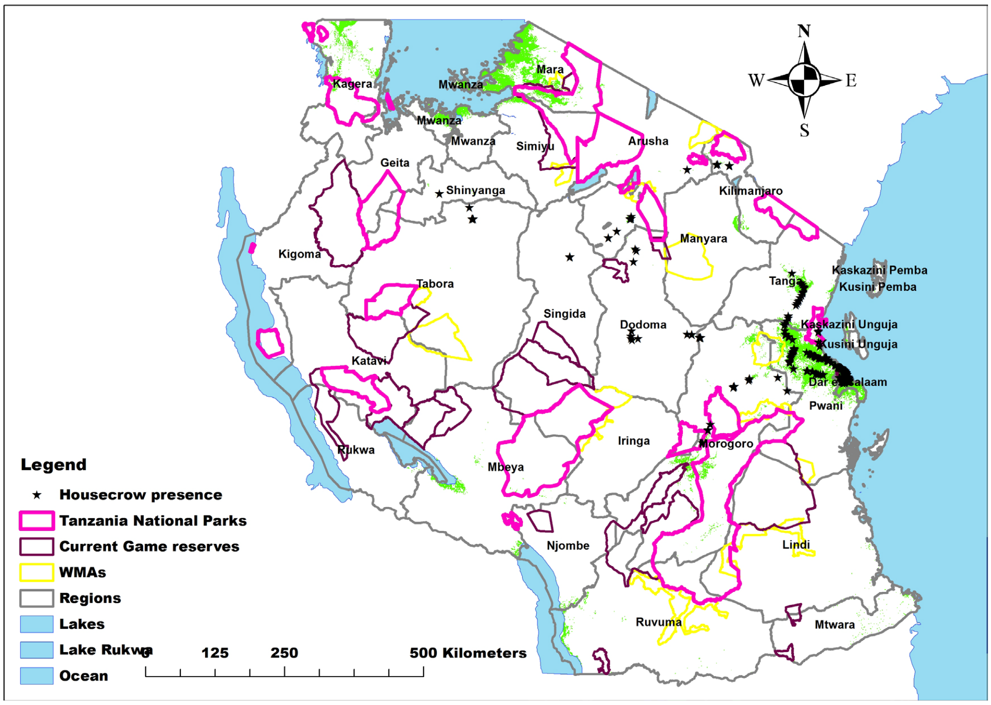

Figure 4. Current predicted potential suitable areas for house crows (green= suitable, star crow sighting, white = unsuitable).

Lake Victoria in Mara, Mwanza, Shinyanga, and Kagera regions. Likewise, some parts of Mbeya and along Lake Nyasa and Kilimanjaro (Figure 4).

3.4. Projected Potential Suitable Habitat Distribution in 2050

Under RCP 4.5, future potential suitable niche for house crows in Tanzania will enormously expand: along the coast of Indian Ocean, Zanzibar, and inland region (Figure 5). Fewer regions will remain unsuitable for this species (Figure 5). Under RCP 8.5, the trend will mirror RCP 4.5 but with more areas and fewer patches estimated free of invasion (Figure 6).

3.5. Projected Potential Suitable Habitat Distribution in 2070

Under RCP 4.5, enormous expansion of suitable habitat is predicted to occur with some parts free of such (Figure 7). Important to note is that Kilimanjaro and Iringa are the colder regions with suitable habitats to expand than RCP 4.5 by 2050 (Figure 5). Interestingly under RCP 8.5 by 2070, much reduction in suitable habitat is observed in Tanzania (Figure 8). Coastal regions, Lake Victoria areas, Zanzibar and Mbeya will be likely the most affected areas (Figure 8) unlike the extensively suitable habitats observed in RCP 8.5 by 2050 (Figure 6).

3.6. Estimates of the Persistence of Suitable Habitat in Tanzania

Overlap areas between current and future predicted areas, however, show two exciting patterns: first, the reduction of about 10,000 km^2 (Table 2 and Table 3) through time (see Figure 9). Secondly, we noted the persistence of potentially suitable niches through the end of the 21st Century (Figure 9) and (Table 3), suggesting for prolonged persistence of house crows niches.

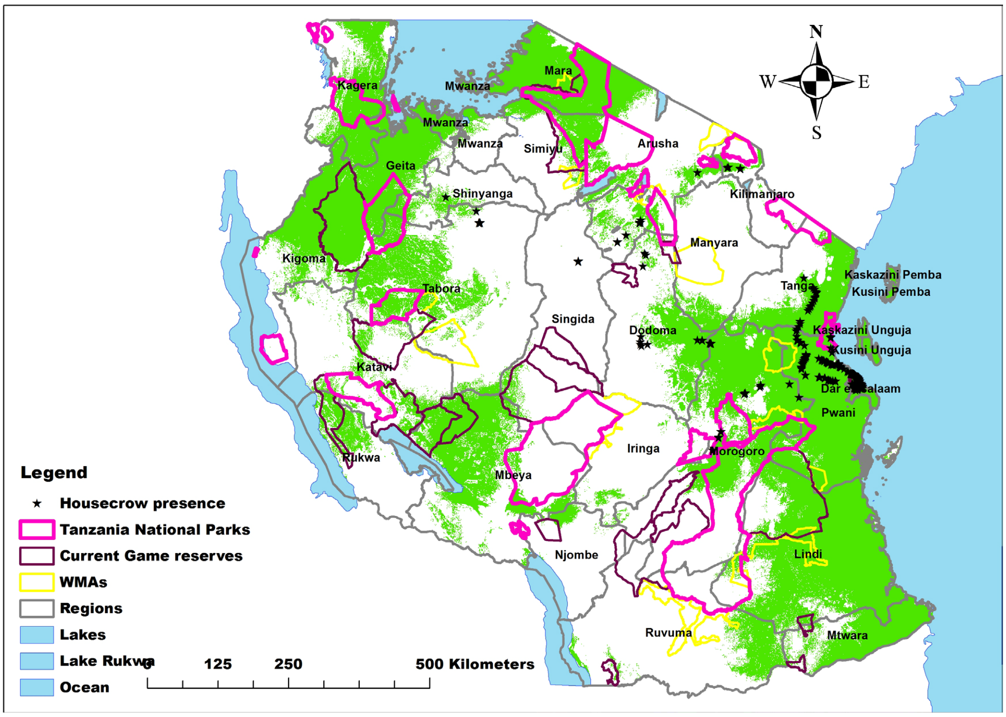

Figure 5. Future predicted potential suitable habitat areas for house crows under GCM 4.5 2050 (green = suitable, white = unsuitable).

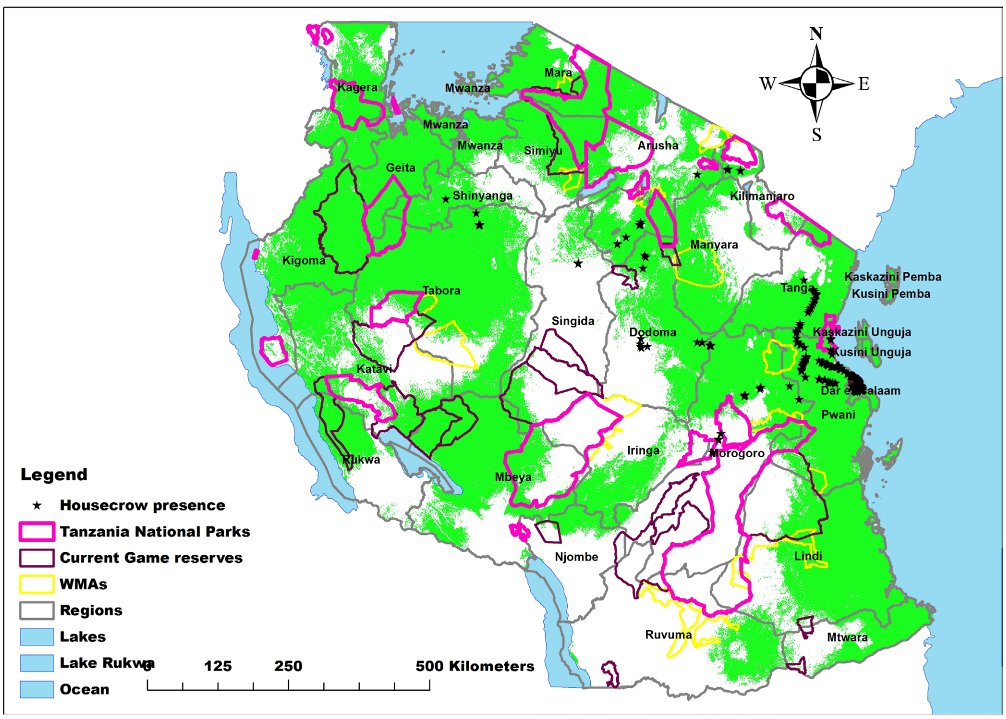

Figure 6. Future predicted potential suitable habitat areas for house crows under GCM 8.5 2050 (green = suitable, white = unsuitable).

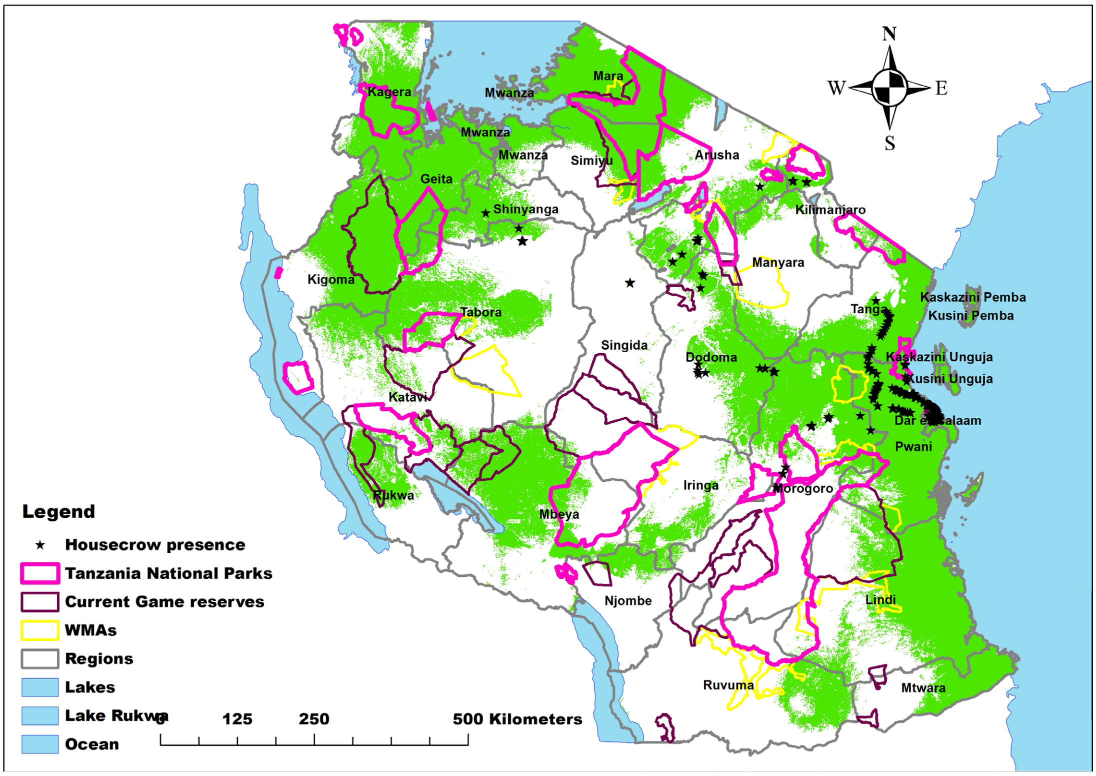

Figure 7. Future predicted potential suitable habitat areas for house crows under GCM 4.5 2070 (green = suitable, white = unsuitable).

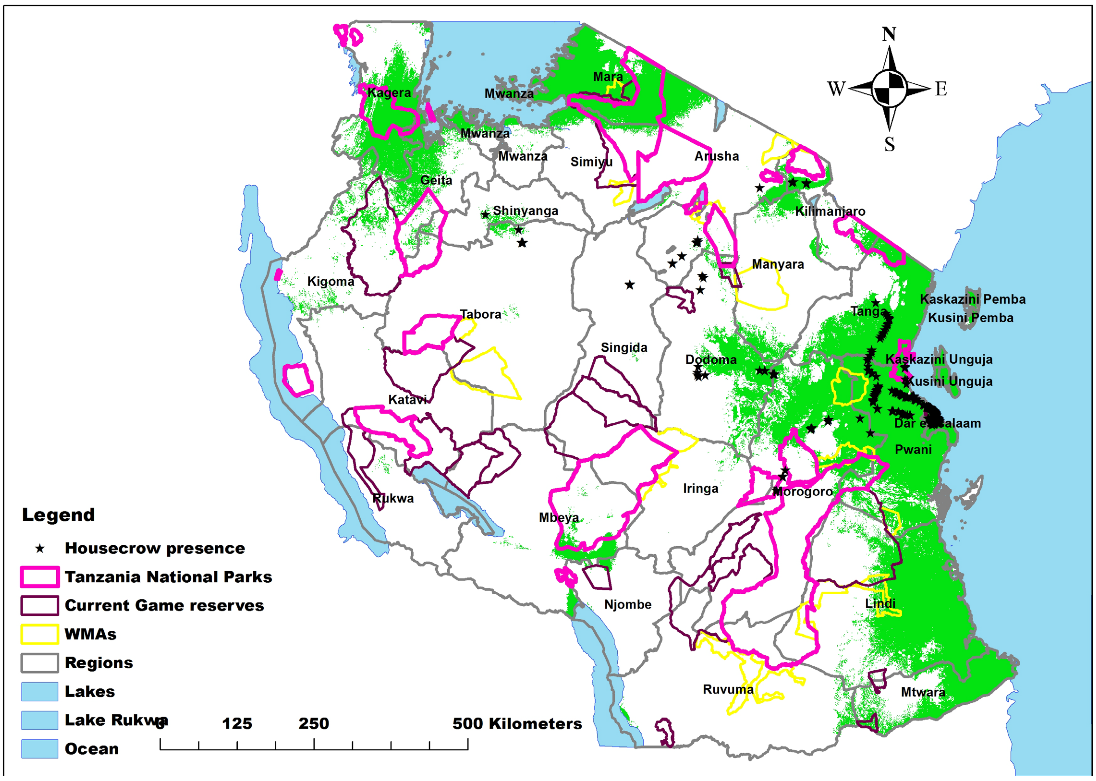

Figure 8. Future predicted suitable habitat areas for house crows under GCM 8.5 2070 (green = suitable, white = unsuitable).

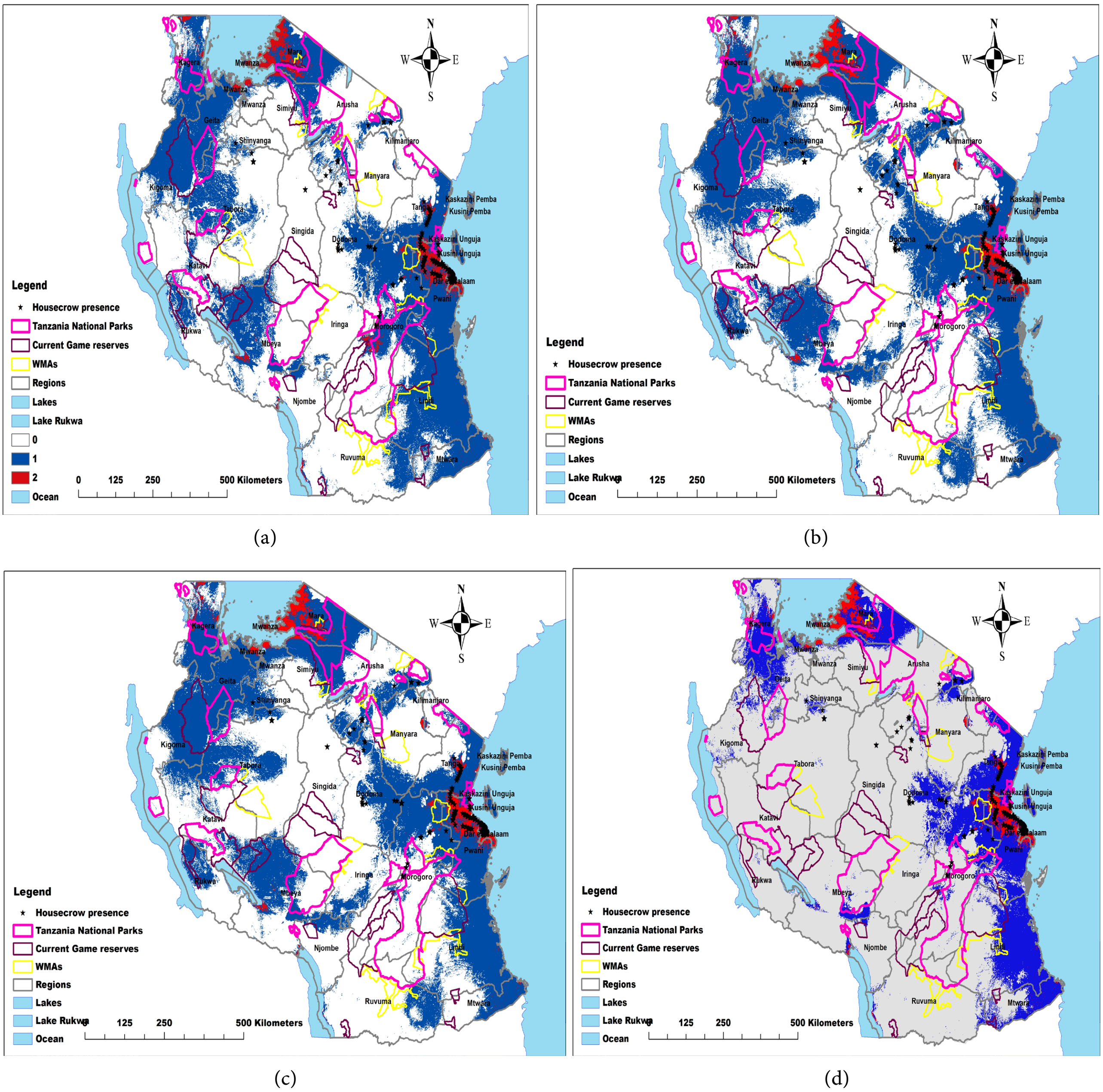

Figure 9. Overlap of current and future predicted suitable habitat areas for house crows (blue = no overlap, red = overlap, grey = not suitable). (a) Overlap with GCM 4.5 2050; (b) Overlap with GCM 8.5 2050; (c) Overlap with GCM 4.5 2070; (d) Overlap with GCM 8.5 2070.

Table 2. The extent of current and future suitable habitat size for *Corvus splendens* in Tanzania.

Model category	Estimated suitable area (km^2)
Current conditions	51,537
GCMs_4.5_2050	431,986
GCMs _8.5_2050	618, 561
GCMs_4.5_2070	462,117

Continued

GCMs 8.5_2070	249,964
Overlap: current and GCM 4.5_2050	46,206
Overlap: current and GCM 8.5_2050	45,281
Overlap: current and GCM 4.5_2070	44,986
Overlap: current and GCM 8.5_2070	41,420

Table 3. Size of predicted suitable habitat for *Corvus splendens* under current and future climate change in protected areas of Tanzania (in km^2).

Prediction category	WMA (Wildlife Management Areas)	Current Game Reserves	Current National Parks and Ngorongoro Conservation Area
Current conditions	574	250	2057
GCM 4.5_2050	17,200	44,584	49,779
GCM 8.5_2050	17,443	48,923	54,351
GCM 4.5_2070	9007	37,964	46,105
GCM 8.5_2070	7098	8067	24,663
Overlap: Current and GCM 4.5_2050	574	228	1893
Overlap: Current and GCM 8.5_2050	574	200	1489
Overlap: Current and GCM 4.5_2070	571	200	1493
Overlap: Current and GCM 8.5_2070	574	201	1485

3.7. Extent of Predicted Suitable Habitat Distribution under Different Scenarios (in km^2)

Current predicted area is about 51,537 km^2 (Table 2). Future projections through 2050 indicate that house crows will expand profusely in Tanzania under both RCPs 4.5 and 8.5, respectively (Figures 4-8). Under RCP 8.5 in the year 2050, the size is huge, representing the business as usual scenario (Table 2). An interesting scenario observed under RCP 8.5 by 2070 where expansion will be less compared to the same scenario by 2050 (Table 2). Of concern is that the estimated area that will remain suitable through time is extensive (Table 2). When compared with the current predicted area, these overlapping potential areas, only a little reduction will likely exist in present time, much of the niche will likely remain important for the house crows in Tanzania as refugia (Table 2)

3.8. Estimated Suitable Habitat Size for *Corvus splendens* in Protected Areas of Tanzania

We estimated that different protected areas are at risk of house crows (Table 3). Though current conditions, estimated a smaller size of suitable areas in all forms of protected areas in Tanzania, National Parks and Game reserves show more risks than WMAs (Table 3).

There are potential future risks associated with climate change among protected areas, as we estimated significantly larger areas suitable for house crows (**Table 3**). National parks and game reserves are potentially the most areas at risk of invasion by house crows in Tanzania (**Table 3**). WMAs are not safe too, though estimates indicate less area suitable (**Table 3**). Overlapping suitable areas in these protected areas by category suggests that the trend will remain over 2050 and 2070 under both RCPs 4.5 and 8.5, respectively (**Table 3**).

4. Discussion

Ecological niche modeling using MaxEnt algorithm has been widely applied in invasive studies, using regional and global occurrence data to predict local potential distribution before and after the invasion [10] [15] [48]. To the best of our knowledge, the present study is the first to use MaxEnt to predict the impacts of climate change on the contemporary and future potential suitable habitat distribution of house crows in Tanzania. We demonstrate that use of the MaxEnt algorithm and the reported locations of the house crow in Tanzania predicted the range expansion of house crows, current distribution is centrally along the Indian Ocean coastal regions (**Figure 4**), these suitable areas are likely to remain so across time (**Figure 9**) although little contraction will likely happen within the current niche (**Figure 9**). Interestingly, predictions showed that future climatic conditions will extremely cause large expansion across Tanzania with only few regions likely to remain free of house crows (**Figures 5-8**). The rapid cause of house crows range expansion may relate to higher success of establishment and spread in novel areas if the climate match is similar to that of the native range like in the coastal areas of the Indian Ocean. House crows also have shown tolerance to climatic conditions, whereby house crows were observed to inhabit Arusha and Kilimanjaro the regions of low temperature range between 1.3˚C - 6.0˚C [49]. Study by [8] reported that house crows exhibited a wide temperature tolerance, where it has been observed as surviving winter temperatures as low as −8˚C. Our study echoes the findings by [8] in New Zealand where house crows were predicted to have expanding niche under climate change. Likewise, the study by [10] at a global scale suggested that house crows will expand in most equatorial Africa based on native range. In both [10] and [8], they reported an association with humans as implied by cultivated and settlement areas probably this linkage helps them secure food.

These findings are important for initiating monitoring programs against house crows spread in Tanzania because this species causes negative impacts to biodiversity [5] [12] [50] [51], crops [51] [52] [53] human health and the economy [13] [15]. In addition, biodiversity conservation programs should focus on timely assessing the ecology of house crows in relation to other avian species in Tanzania. Lastly, control programs are inevitable to limit the spread of house crows from eastern part (**Figure 4**) to western part of the country as shown in future scenarios (**Figures 5-8**). With little resources, best time would be now than in future times, when suitable niches may become unmanageable in size.

The most important predictor variables of house crows were precipitation of coldest quarter, elevation, and land cover classes (**Figure 3**). Precipitation of coldest quarter of about 100 mm had high prediction probability of house crow suitable habitat (**Figure 3**). House crows were predicted in elevation range of 0 - 250 m.a.s.l., suggesting that in the coastal lowland provides conducive conditions to be inhabited by invasive crows. However, house crows adapt a wide range of elevation and temperature tolerance as they were sited in cool areas such as Kondoa (1769 m.a.s.l.) and Kateshi (1735 m.a.s.l.), where temperatures are low echoing [8].

Land cover classes 13 and 14 which stand for agricultural and built areas, predicted suitable habitats for house crows (**Figure 3**), corroborating a study by [10]. House crows prefer to leave in association with humans [10] [15]. Ongoing land cover changes over Tanzania would result in negative impacts by allowing house crow invasions.

The observed results suggest that the spread of house crow in Tanzania would continue beyond 21st century as there are indications that the current niche will persistently be suitable beyond this period over all climate scenarios (**Figure 9**). It was predicted that house crows would continue to spread due to the presence of environmental variables like elevation, temperature, and population increase that favor their distribution. At present time, small numbers of this species have been reported in new areas of Korogwe, Mikumi, and Ifakara towns, as well as Dodoma town [5]. New observation of some individuals in Nzega District (Tabora Region) was confirmed (see **Figure 4**), indicating that the species has extended its range to nearly the western part of Tanzania compared to previous range [13] [16]. Also, a small number of house crows were observed in Arusha town, Babati Endasaki, and Kateshi (**Figure 1**). It seems reasonable to suggest that the impacts of house crows would continue to spread in Tanzania and be comparable to those impacts experienced in New Zealand and Australia [8]. Establishing a focus on the impacts of house crows on biodiversity, crops damage and spread of disease in Tanzania are worthwhile investing.

The presence and expansion of house crows have implications to; biodiversity, agriculture, and health already noted elsewhere. Favorable conditions for house crow survival in cultivated land and highly human populated areas (**Table 1**) suggest that this species will expand as cities are expanding and more agricultural areas openings. In this study, we note that land cover types: inhabited and cultivated area had higher contributions to model prediction (**Figure 3**). These findings are similar to ones found by [10] who reported that house crows tend to live in association with human settlements [8] and they feed on garbage [10]. This will increase the ecological potential for the distribution of house crows into new areas and prevent other species of animals such as birds, reptiles, and small mammals to inhabit [10] [11] [13]. House crow species were observed to extend from coastal to nearby areas, for breeding and sometimes for roosting, frequently scavenging in farmlands nearby cities and towns [8]. Models show that occupied areas are large towns or semi-towns, whereby house crow species take advantage of litter and food wastes' collects [5] [54] [55]. Such quick occupancy of house crow will decrease indigenous bird species by destroying nests, reduce reptile and amphibians distribution in areas where house crows have occupied in large numbers, because of predation, eating eggs and chicks, and competition for food [10] [13].

Increased house crows in farmland areas will continue influencing agricultural productivity. It is possible that continuous spread of crows in farmlands of Tanzania will likely impact livelihood income as reported to feed on fruit crops including orchards, mango, guava, dates, fig, tomato, cucumber and strawberry elsewhere [10] [51]. House crows also have been observed to destroy grain crops and most frequently eat chicks of domestic poultry [13]. Expanding potential suitable habitat distribution may intensify such in Tanzania, calling for urgent control or eradication program.

Likewise, expanding the range of house crow population in Tanzania will possibly increase the chance of diseases spread in turn affecting human health [8]. House Crows have been reported as carriers and transmit diseases: cholera, dysentery, and West Nile Virus [10] [51] [56]. In addition, house crows host Campylobacter, Salmonella, and mycoplasmas affecting human health [57] [58]. House Crow populations are also reported to be a potential host in transmitting avian influenza [10] and Newcastle disease virus [59].

House crows in Tanzania will continue to spread beyond regions of their introduction posing challenges on how to conserve biodiversity and possibly how to control diseases associated with house crow presence. Practically, it has been observed to be impossible to monitor their spread and eradicate them from the region due to the reason that there is no reliable data available on the number of crows in and around United Republic of Tanzania. As recommended, there is need for more research into the house crows to clearly understand their numbers in the country and the extent of dispersal. Generally, this study provides highlights and a detailed record of how house crows are currently distributed in Tanzania and the results predicted on how this invasive species will potentially continue spreading to new areas in Tanzania. Information on recent observations in Saadan National Park, Saadan village Center and other regions previously uninhabited by house crows, suggest that the species is likely to expand its range further in Tanzania similar to other parts of the world [8]. Presence of house crows in protected areas may affect tourist industry by disturbing tourists and local citizens with their loud calls, heavy defecation and aggressive attacks when attempting to steal food from lodges, campsites, and other biodiversity suggesting for active conservation planning against this species.

5. Conclusion and Recommendations

This study in Tanzania is the first of a kind, illustrating the potential spread of house crows across Tanzania as time goes on using maxent platform. While our results suggest alarming rates of niche expansion over Tanzania across times, it is important to address niche conservatism indicated by larger persistent size of suitable habitat in the current suitable niche. These findings are important as the persistence of suitable niche suggests that there would be a potential for re-invasion beyond the 21st century. Equivocally, our results suggest that "time is now" to act against house crows in Tanzania. Focused control programs are likely to produce best results in the future, as the area would be beyond control. We have identified potential regions that would help in areas of focus for resource allocation in control programs. Finally, these results form a baseline for establishing monitoring programs on how house crows expand and utilize new areas as climate shifts through time. However, it is important to note issues common in modelling using the probability of likelihoods. This is because climate data used are projected layers. To reduce uncertainty in our models we applied three GCMs, unlike in [10] and [48] who used a single GCM, likewise the pixel size of 1 km^2 is huge, future work using smaller pixel size could increase predictability. However, many studies of similar approaches have been used to guide surveys, conservation action planning and management decisions elsewhere with success. We believe that our findings are robust and can help in the establishment of management strategies against house crows in Tanzania.

Conflicts of Interest

The authors declare no conflicts of interest.

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