Distribution and predictive niche modeling of five endangered raptors species in Kenya

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Abstract

Raptors are apex predators threatened globally by electrocution, collisions, and habitat fragmentation. Most species of raptors are understudied and largely unexplored. Top predators like raptors depend on the sustainability of the ecosystems in which they live and migrate. Knowing how endangered raptors are geographically dispersed, as well as the factors that may influence how they use their habitat, is critical for their protection. This research focuses on Kenya, where there are gaps in knowledge on appropriate habitats and raptor dispersal patterns. With several species of raptors endangered, it is crucial to determine their distribution patterns for management and conservation. To evaluate the size of the realized niches for five Kenyan raptor species at the risk of extinction, we applied species distribution models (SDMs) through an ensembling approach using occurrence data from the Global Biodiversity Information Facility (GBIF) and environmental covariates. These species were: Martial eagle, Secretarybird, Bateleur, Steppe Eagle, and Southern ground hornbill. The five raptors' distribution within and outside protected areas and the role of key environmental predictors in predicting their distribution was estimated. Our findings indicate raptor distribution in several areas in Kenya that is predominantly in the south-western region, extending into the country's central region. Martial eagle had the largest niche range amounting to ca.49,169 km2 while the Southern ground hornbill had the smallest niche range amounting to ca.4,145 km2. Secretarybird had the highest distribution outside protected areas at 77.57% followed by the Martial eagle at 76.89%. Significant predictors of raptor species distribution in Kenya were; precipitation during the warmest quarter, precipitation during the driest month, and precipitation during the coldest quarter. Key areas for raptor conservation listed here could serve as foundation for a number of additional Important Bird Areas (IBAs) in Kenya, according to the A1 Global IBA Criterion for species that are globally threatened.

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Abstract

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Keywords:

Raptors, Species Distribution Modeling, Protected Areas, Raptors-habitat suitability, Raptor conservation

INTRODUCTION

Raptors such as eagles, hawks, falcons, harriers, buzzards, and vultures are predatory birds found throughout the globe except the Antarctica region . Globally, 37% of raptor species are thought to be on the verge of extinction. The countries with the most threatened species are Indonesia, Tanzania, Sudan, and Kenya . 102 different species of raptors can be found in Kenya, with 14% of them threatened globally . Raptors have been chosen with respect to being a potentially useful substitute species on behalf of all biodiversity ; because they are found at the apex of environmental food chains, they serve as custodians of climate change by warning of potential human-induced effects on biodiversity . Along with their highly dynamic habitats, the selection of raptors as an umbrella species for species diversity is because of their variety of prey across the food chain . With the exception of vultures, raptors are generally well-liked by the overall population and extensively studied by scientists due to their appeal and recognition functioning as flagship species for harnessing resources to safeguard and conserve biodiversity in totality

Historical trends and recent assessments of raptor populations in Kenya show a plummet of more than 50% over 40 years . Fourteen of Kenya's 102 raptor species are listed as Critically Endangered, Endangered, or Vulnerable on the IUCN Red List . These species are highlighted in table 1.

Fig. 1 . Examples of raptors species in Kenya. There are declines in some of these species that have not caught the attention of IUCN as a result of worrying national declines. 1st image top row, Wahlberg's eagle (Hieraaetus wahlbergi), image credit by copper (licensed under http://creativecommons.org/licenses/by-nc/4.0/). 2nd image top row Lappet faced vulture (Torgos tracheliotos) by tjeerd (licensed under http://creativecommons.org/licenses/by-nc/4.0/). 3rd image top row Augur buzzard (Buteo augur) by David Bygott (licensed under http://creativecommons.org/licenses/by-nc/4.0/). 4th image top row, Montagu's harrier (Circus pygargus), by Nik Borrow (licensed under http://creativecommons.org/licenses/by-nc/4.0/). 1st image bottom row, Long-crested eagle (Lophaetus occipitalis) by Bram ter Keurs (licensed under http://creativecommons.org/licenses/by/4.0/). 2nd image bottom row Bateleur (Terathopius ecaudatus), image credit by thelandlover (licensed under http://creativecommons.org/licenses/by-nc/4.0/) . 3rd image bottom row; Hooded vulture (Necrosyrtes monachus), image credit by Nik Borrow (licensed under http://creativecommons.org/licenses/by-nc/4.0/)

Table 1: List of raptor species of raptors in Kenya and their IUCN status. Eight of the species have recorded a worrying decline which have not been captured by global estimates.

Common name	Scientific name	IUCN status
Steppe eagle	*Aquila nipalensis*	Endangered
Long crested eagle	*Lophaetus occipitalis*	Least concern
Augur buzzard	*Buteo augur*	Least concern
Hooded vulture	*Necrosyrtes monachus*	Critically endangered
White backed vulture	*Gyps africanus*	Critically endangered
Common kestrel	*Falco tinnunculus*	Least concern
Lappet faced vulture	*Torgos tracheliotos*	Endangered
Montagu's harrier	*Circus pygargus*	Least conern
Bateleur	*Terathopius ecaudatus*	Endangered
Black Kite	*Milvus migrans*	Least concern
Wahlberg's eagle	*Hieraaetus wahlbergi*	Least concern
Black-chested snake eagle	*Circaetus pectoralis*	Least concern
Martial eagle	*Polemaetus bellicosus*	Endangered
Brown snake eagle	*Circaetus cinereus*	Least concern

Due to their extremely rapid rates of decline, six of these species are already regarded as globally threatened. Global estimates have not considered the eight remaining species' worrying national plunges, such as those in the black kite . Despite all these, a disproportionate amount of studies is expended on raptors' studies in Kenya . There are knowledge gaps regarding the interactions between raptors' geographic distribution and their ecological needs over time and space, which, in order to direct conservation and management efforts, must be filled.

Raptors' movements and feeding preferences are known to be influenced by environmental variables, as well as the plausible links between their distribution and environmental predictors such as precipitation, temperature, human influence, and vegetation, which have been demonstrated in numerous studies (e.g. . Understanding the relationships between raptor distribution and environmental variables may aid in determining their ideal niche. Such data would be crucial in creating spatially explicit management and conservation measures when combined with anthropogenic variables . To advance their spatio-temporal management on a landscape scale, more data are needed on significant environmental variables, niche distribution, and anthropogenic predictors.

Accurate species occurrence determination is necessary for proper biodiversity conservation policy decisions, including nature reserve preselection, biologically-based invasion monitoring and the identification of vital habitats for endangered species . Aforesaid data is frequently arbitrarily gathered and made accessible as museum records or through websites that collect biodiversity data, like the Global Biodiversity Information Facility (GBIF) . Seeking out new presence locations for endangered or rare species is critical because a better understanding of their distribution may aid in management and conservation efforts . In order to inform conservation management, species distribution models (SDMs) are employed to deduce the ecological requirements of species as well as predict their geographic distribution. In a variety of applications, such as regional biodiversity assessment in rangelands, conservation planning and wildlife management, these models have grown in significance

The biggest dangers to raptors are habitat loss brought on by logging and agricultural growth, persecution (including shooting, poisoning, and trapping), electrocution and collisions with energy infrastructure, contamination (primarily from lead, pesticides, or veterinary drugs), and illegal harvesting for actions motivated by religious convictions . This study estimates the distribution and ecological requirements of five raptor species in Kenya in order to better understand their niches and threats. It also examines the contribution of continuous remotely sensed predictor variables to their distribution. The objectives of this research are to; 1) identify the ecological niche, geographic distribution, and impact of protected areas in raptor conservation in Kenya.; 2) determine the relative importance of environmental predictors to raptor distribution ; 3) offer recommendations for raptor habitat management and protection in Kenya. The results of this study will improve the understanding of raptors' niche and the critical environmental/anthropogenic variables influencing its distribution to inform sustainable management efforts of its habitats.

DATA AND METHODS

Study area and data acquisition

Approximately 580,367 km^2 in size, Kenya is situated between latitudes 5 N and 5 S and longitudes 34 and 42. Kenya's predominant bimodal rainfall and temperature patterns are determined by the Inter-Tropical Convergence Zone (ITCZ). Kenya's topography is diverse, with elevations ranging from 0 to 5197 meters above sea level. The dry land mass is typically represented by six agro-ecological zones: agroalpine (0.1%), high potential (9.3%), medium potential (9.3%), semi-arid (8.5%), and dry (52.9%). Agro-pastoralists and pastoralists predominately live in the semi-arid to very arid zones which make up 80% of the country . Kenya has 28 national reserves totaling 18,042 km^2 (11.7%), 22 national parks totaling 29,357 km^2 (5.16%), and 160 conservancies totaling 36,300 km^2 (11.0%). Kenya has 68 important biodiversity areas (IBAs), with 55 of them threatened .

All raptor species' occurrence data for the years 2013 to 2020 was acquired from the Global Biodiversity Information Facility's online platform (https://www.gbif.org/, https://doi.org/10.15468/dl.hzyp6v, GBIF, 7th September, 2021). A total of 11529 records were obtained. These data were used to project the overall occurrence distribution of raptor occurrence in Kenya. From these data, we then selected raptor species that were endangered and/or threatened based on their IUCN status and selected the following five raptors: Steppe Eagle (*Aquila nipalensis*) (EN), Secretary bird (*Sagittarius serpentarius*) (EN), Martial Eagle (*Polemaetus bellicosus*) (EN), Bateleur (*Terathopius ecaudatus*) (EN), and Southern ground hornbill

(*Bucorvus leadbeateri*) (VU). As previously stated , in order to fully cover the raptor's entire climatic and environmental range, records for the entire nation of Kenya were downloaded . OpenRefine software Version 2.1 was used for cleaning, which included removing duplicate records and records without georeferences. In order to eliminate data points with spatial correlation, and ensure independence, all records were checked in R for spatial autocorrelation using the K nearest neighbor analyses . We retained the following occurrence points following cleaning: Steppe Eagle, n=169; Martial Eagle n=267; Secretary bird, n=191; Bateleur, n=676; and Southern ground hornbill, n=25, for a total of 1328 occurrence records. We only modelled for species with more than 20 records of occurrence to warrant the precision of the estimates of species niches. These records were then used to produce SDMs.

Ecogeographical variables

A set of criteria was developed to predict raptor habitat suitability which included choosing variables that were potentially useful for raptors' distribution. The Worldclim database version 2.1 (Fick and Hijmans, 2017; https://www.worldclim.com/current) provided 19 bioclimatic variables. Because of their direct effects on species distribution, climate variables are commonly employed in habitat modeling . The Shuttle Radar Topographic Mission's digital elevation model (SRTM DEM, opendata.rcmrd.org/datasets/) was used to extract digital elevation data for Kenya, slope and aspect were derived from the DEM, and the topographic roughness index calculated as the surface area ratio, which is also derived from the DEM . Data for the Normalized Difference Vegetation Index (NDVI) (2013-2020) were obtained from NOAA, as were observations from the Advanced Very High Resolution Radiometer (AVHRR) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellites (https://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_browseByCountry.php). The Human Influence Index (HII), which best represents anthropogenic impacts spanning the years 1995 to 2004, was derived from Last of the Wild v2 (https://sedac.ciesin.columbia.edu/data/collection/wildareas-v2/). ArcGIS was used to rasterize all predictions at a spatial extent n of about 1 km (Version 10.5). We used the '*usdm* ' package in R to carry out a variance inflation factor stepwise procedure to decrease multicollinearity in predictor variables . Variables with variance inflation factors greater than 10 were eliminated. As a result, we only kept the 12 best-fitting covariates based on the raptors' ecological requirements from an initial set of 25 variables.

Model validation and model setting

Generalized Linear Models (GLM), Random Forest (RF), Generalized Additive Models (GAM), Artificial Neural Networks (ANN), Multivariate Adaptive Regression Splines (MARS), Generalized Boosted Models (GBM) , and Maximum Entropy Models (MaxEnt), are the seven modeling techniques employed in this study . SDMs were generated using the '*biomod2* ' package's ensemble forecasting method found in R under the following parameters; MARS models had a highest interaction level of 2, whilst RF models were fitted by growing 750 trees with half the available predictors sampled to split at each node. The default settings and the highest iteration count of 1000 were applied to MaxEnt models. While GAMs were computed using a logistic link function, GLMs were readjusted using a binomial link function. On the other hand, GBMs were generated by performing 5000 three-fold cross-validation procedures to determine the optimal number of trees to keep and a maximum depth of variable interactions of 7. The default specifications were used to fit ANN models. This method has previously been used in other research (e.g. . We added a background set of 10,000 randomly chosen background points to the study area because our dataset only contained presence data

. As in previous research with species distribution modeling, the occurrence dataset was randomly divided into a 30% sample for evaluating the performance of the model and a 70% sample for model calibration . We performed 175 SDMs in total (7 algorithms X 5 splitting replicates for model evaluation X 1 repetition X 5 species).

Model Evaluation

The Area under the receiver operating characteristic curve (AUC) was used to assess the models' predictive performance of the models (Hanley and McNeil, 1982) and the True Skill Statistic (TSS; . The sensitivity, or the percentage of known presences predicted as presences, is plotted on the ROC curve against specificity, or the percentage of pseudo-absences predicted as absences. These validation techniques are well-known and perform very well . Models with an AUC of less than 0.7 were disqualified. It has been demonstrated that weighing the individual model projections according to their AUC scores is a particularly trustworthy technique . Additionally, the ensemble model's relative importance of the variables was calculated from the '*biomod2* ' package devoted functionality . The ensemble models' projections from the two-stage sampling mentioned above were averaged to produce the final potential distribution. To evaluate the spatiotemporal habitat dynamics, the ensemble models were projected at roughly 1 km resolution.

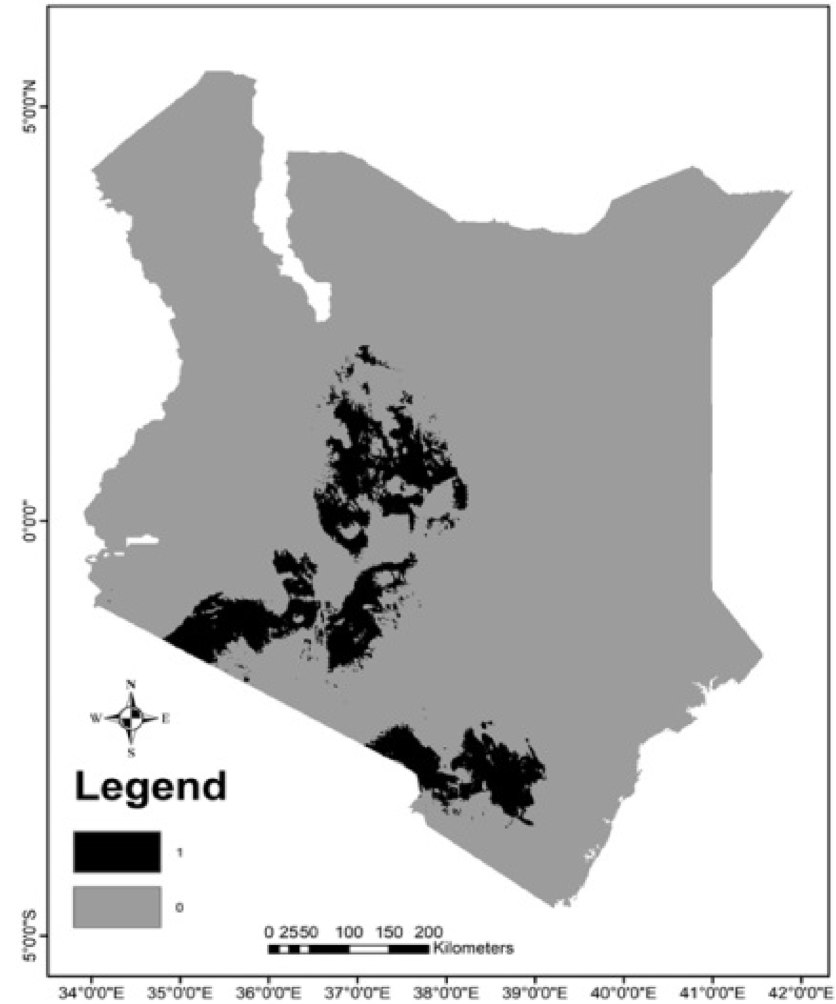
Assessing the effectiveness of protected areas

We overlaid the protected areas with the current distributions of raptors from the above mentioned ensemble model obtained, to assess the efficacy of protected areas under the prevailing climatic conditions. We clipped the distribution of the five raptors with the Protected areas network from (https://geoportal.icpac.net/layers/geonode%3Aken_protected_areas) in order to identify the distribution occurring within and outside of protected areas.

RESULTS

Spatial distribution

Raptors can be found throughout Kenya, but they are most prevalent in the south-western and central regions. The northern and western regions of the nation only have a small population. The Martial eagle had the largest realized niche range at approximately 49,169 km^2, followed by the Bateleur at approximately 43,576 km^2, the Steppe eagle at approximately 29,018 km^2, and the Secretary bird at approximately 28,826 km^2. The Southern ground hornbill had the smallest realized niche range, measuring approximately 4,145 km^2.The Steppe Eagle's projected realized niche was in South-western Kenya, extending to South-central, and some species were found in Kenya's Southern region, giving it the widest projected distribution. The Southern ground hornbill has the least distribution, with a projected niche primarily in Kenya's south-western region (Fig. 2).


5°0'0"N
0°0'0"
5°0'0"S
N
W
E
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Legend
1
0
0 2550 100 150 200
Kilometers
34°0'0"E
35°0'0"E
36°0'0"E
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40°0'0"E
41°0'0"E
42°0'0"E

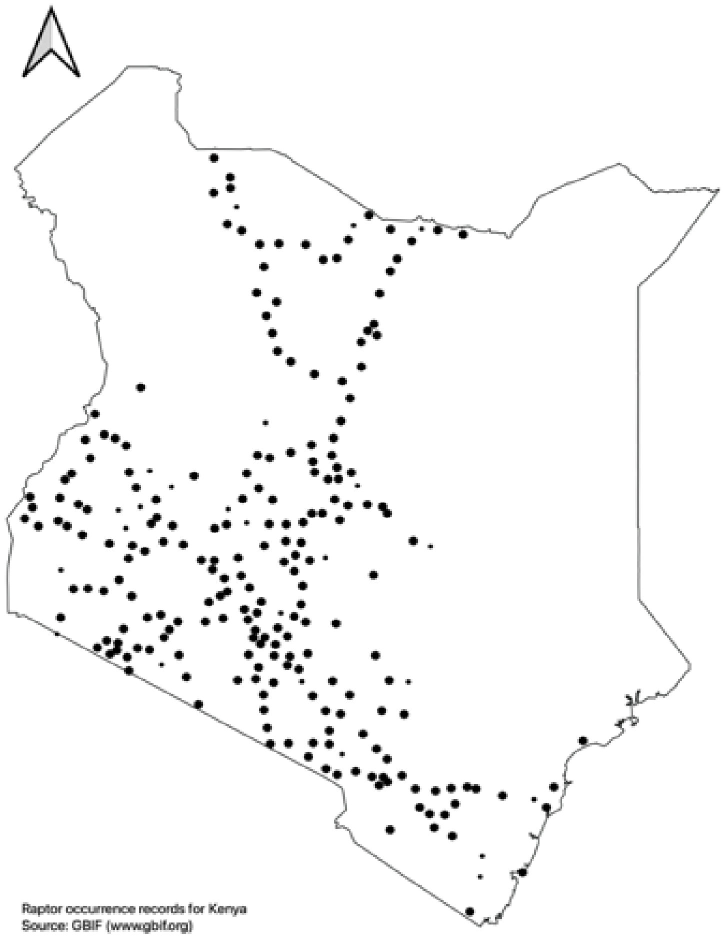
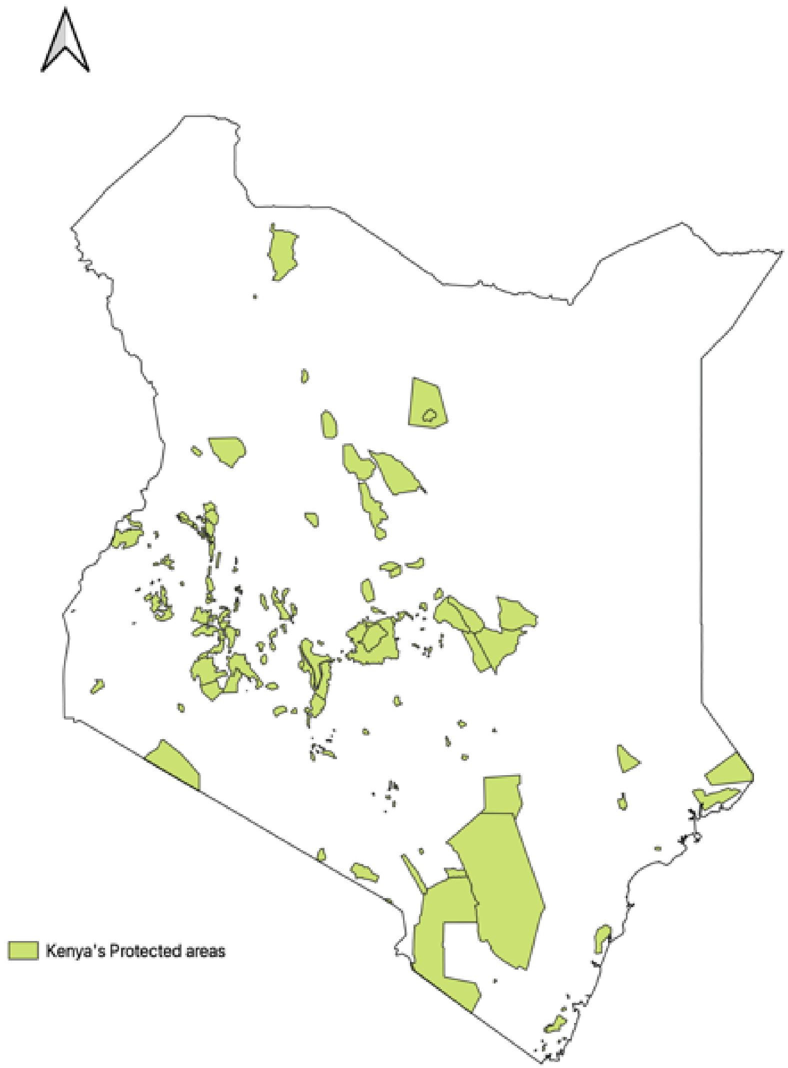


Figure 2: Projected occurrence of all raptors species and five selected species in Kenya. Habitat suitability indicated by 0 – not suitable (lack of niche); and 1 – suitable (presence of niche). Niche distribution maps ordered from the biggest to the smallest niche range for each species.

Raptors distribution with protected areas

Martial Eagle, Steppe Eagle, Bateleur and Secretary birds have their niche distributed outside protected areas of Central Kenya. Niche distribution for species occurring in the Southern and South western region of Kenya occur within the protected areas. Secretary bird and Martial eagle had the highest niche range occurring outside protected areas at ca. 23,320 km^2 (77.57%) and ca. 37,660 km^2 (76.89%) respectively. The species with most of its distribution in protected areas was the Southern ground hornbill at ca. 2, 074 km^2 (50.35%) distribution in protected areas. Steppe eagle and Bateleur occurring outside protected areas was at ca. 18, 339 km^2 (63.46%) and ca. 25, 436 km^2 (58.55%) (Fig. 3).


Kenya's Protected areas

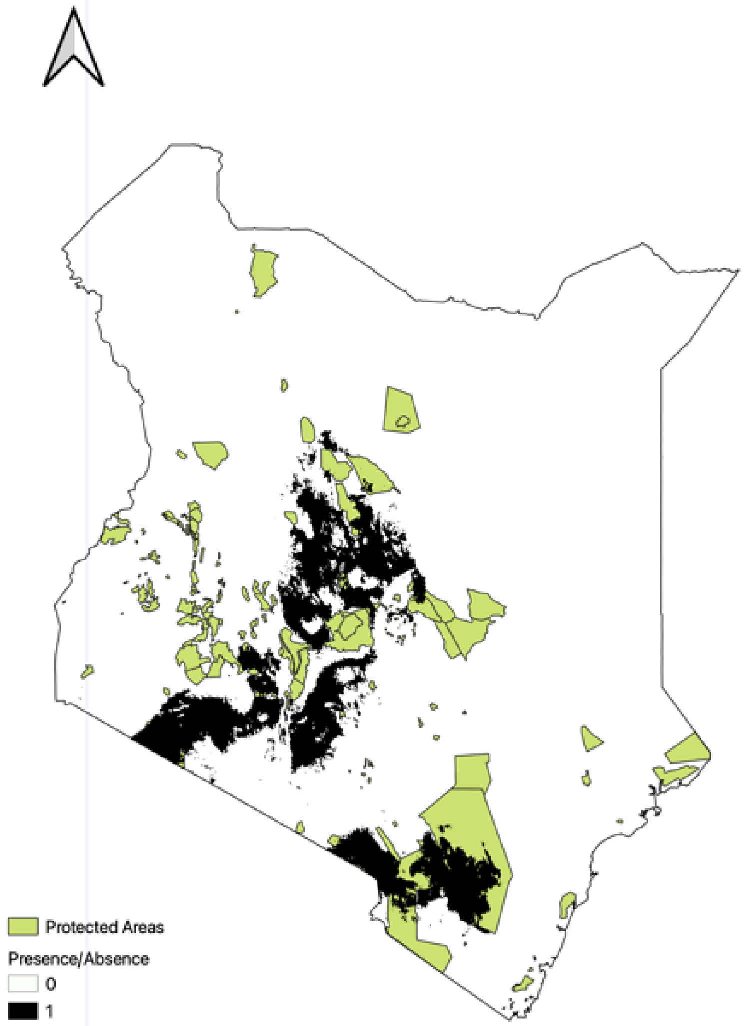
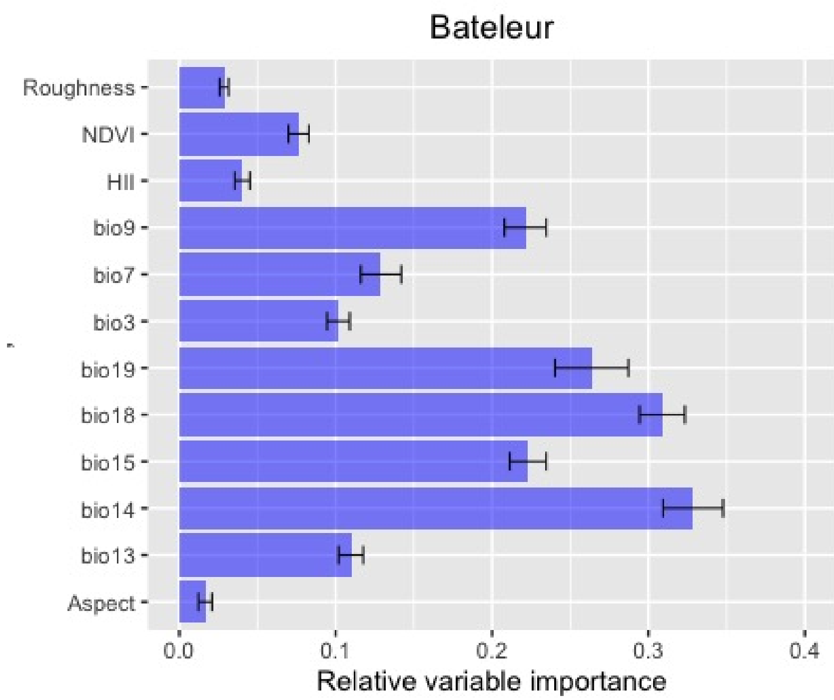


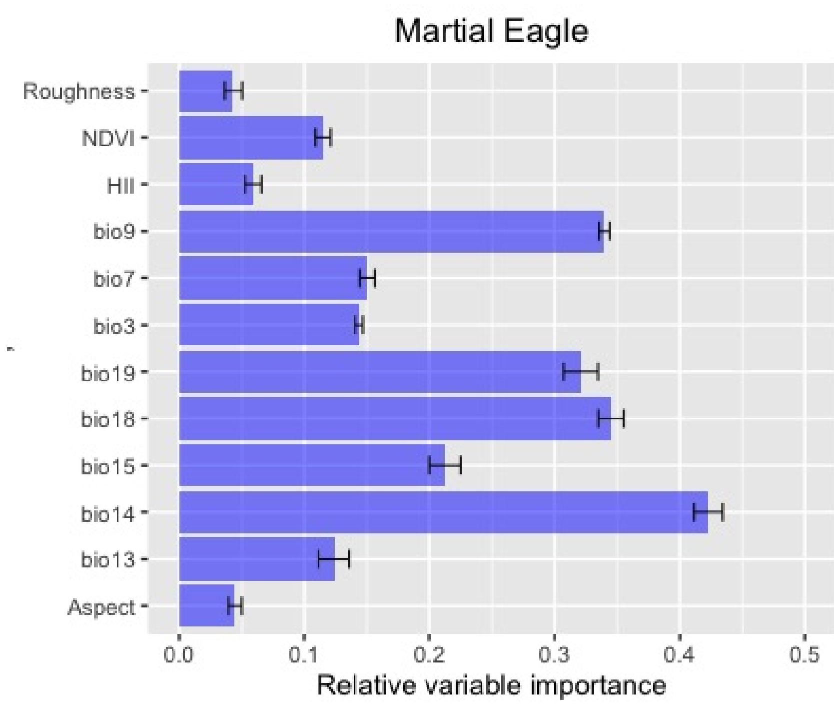
Figure 3: Distribution of protected areas in Kenya and overlap of niches of the five species of raptors.

Relative Importance of Environmental Predictors

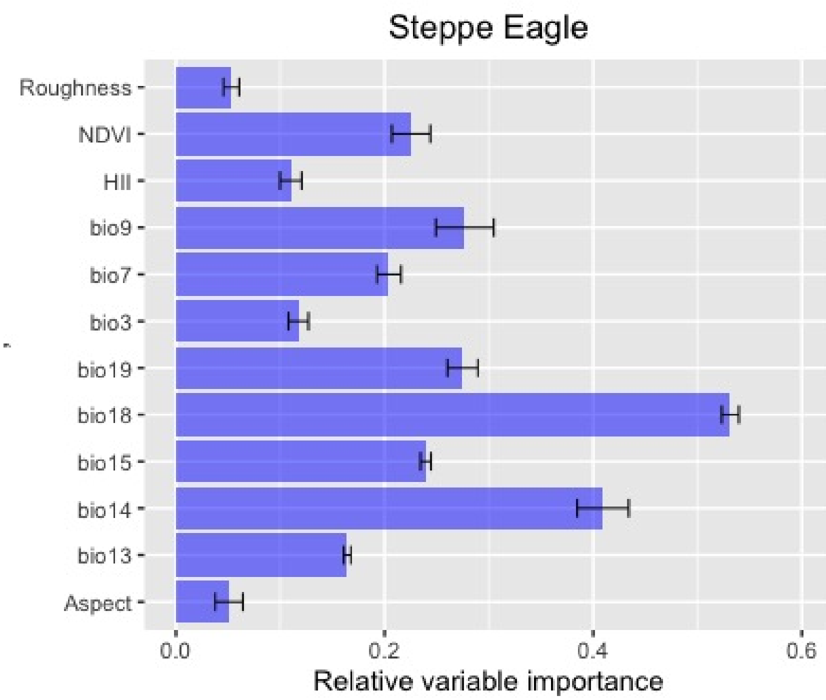
The most crucial factors in predicting distribution in all species across all model types were precipitation of the warmest quarter (bio18), precipitation of the driest month (bio14), and precipitation of the coldest quarter (bio19), with species-specific differences in relative significance. For Secretary bird and Southern ground hornbill, Precipitation of the driest month (bio14) and precipitation of the coldest quarter (bio19) were the most significant predictors whereas Bateleur, Martial Eagle, and Steppe Eagle were best predicted by; precipitation of the warmest quarter (bio18) and precipitation of the driest month (bio14). The annual temperature range (bio7) and mean temperature of the driest quarter (bio9) were found to be the best predictors of temperature variables that affect the distribution of raptor species (Fig. 4).

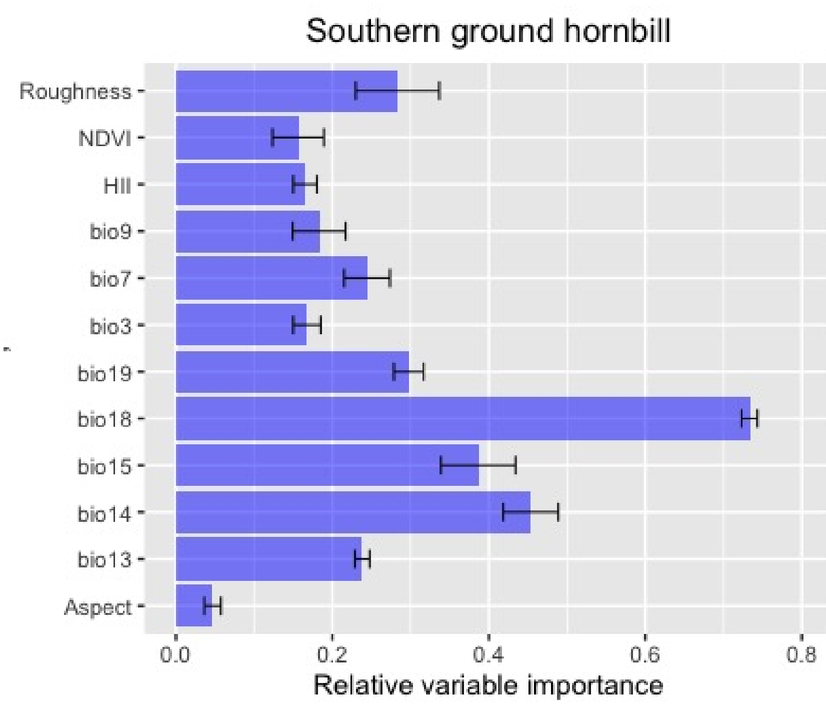


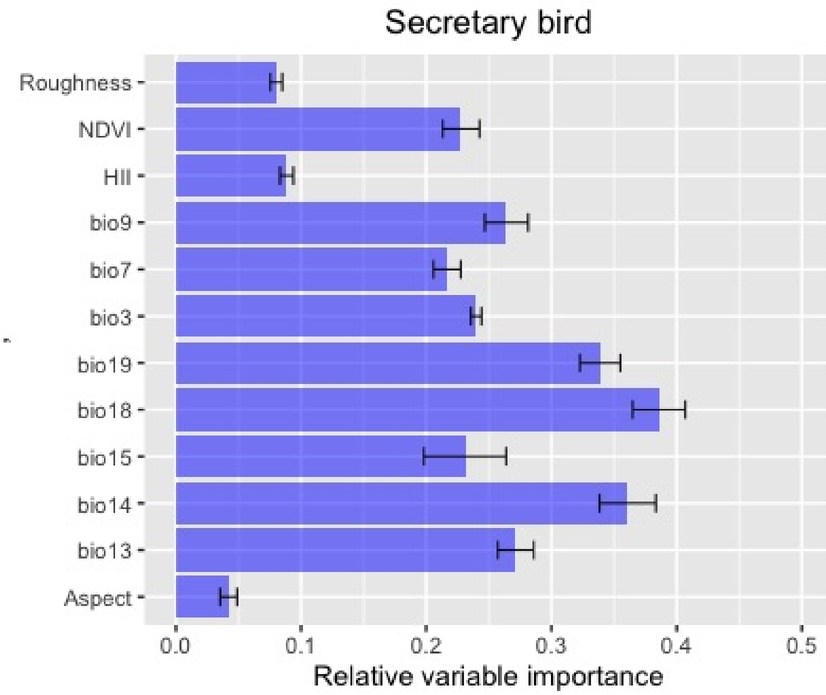
Bateleur
Roughness
NDVI
HII
bio9
bio7
bio3
bio19
bio18
bio15
bio14
bio13
Aspect
0.0
0.1
0.2
0.3
0.4
Relative variable importance



Martial Eagle
Roughness
NDVI
HII
bio9
bio7
bio3
bio19
bio18
bio15
bio14
bio13
Aspect
0.0
0.1
0.2
0.3
0.4
0.5
Relative variable importance

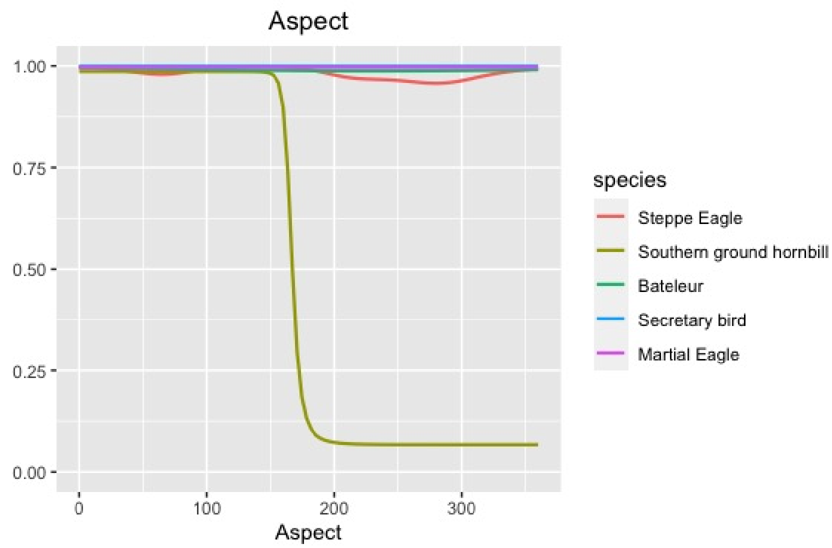

Steppe Eagle
Roughness
NDVI
HII
bio9
bio7
bio3
bio19
bio18
bio15
bio14
bio13
Aspect
0.0
0.2
0.4
0.6
Relative variable importance

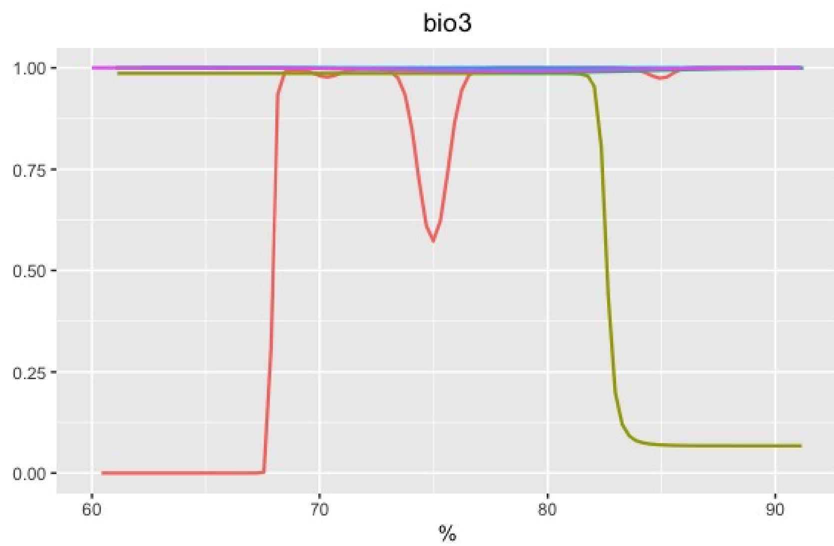

Southern ground hornbill
Roughness
NDVI
HII
bio9
bio7
bio3
bio19
bio18
bio15
bio14
bio13
Aspect
0.0
0.2
0.4
0.6
0.8
Relative variable importance

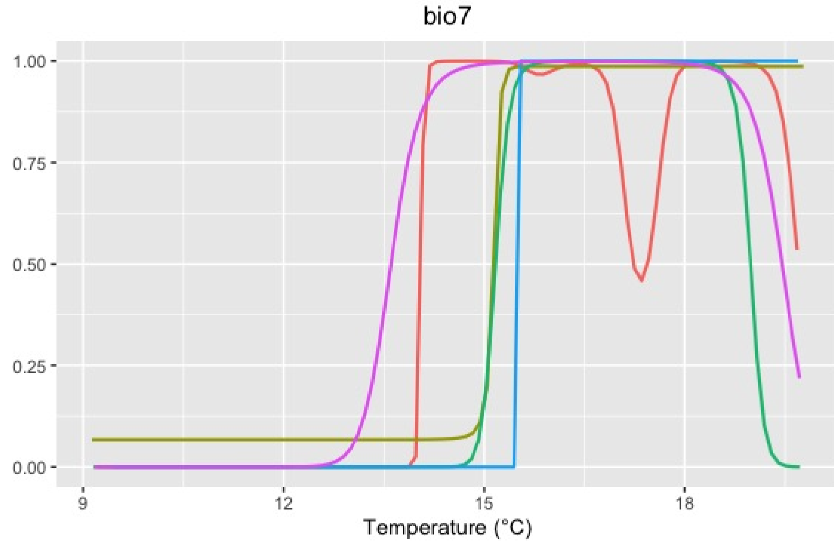


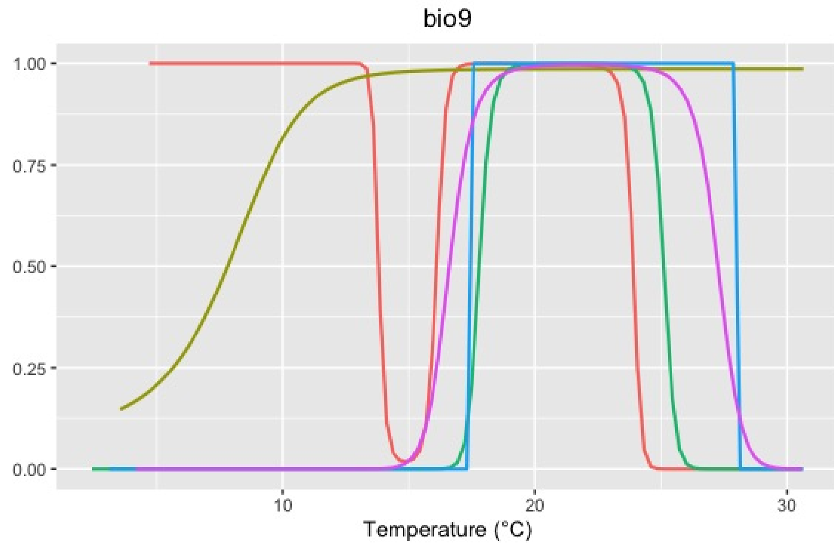
Response curve variables

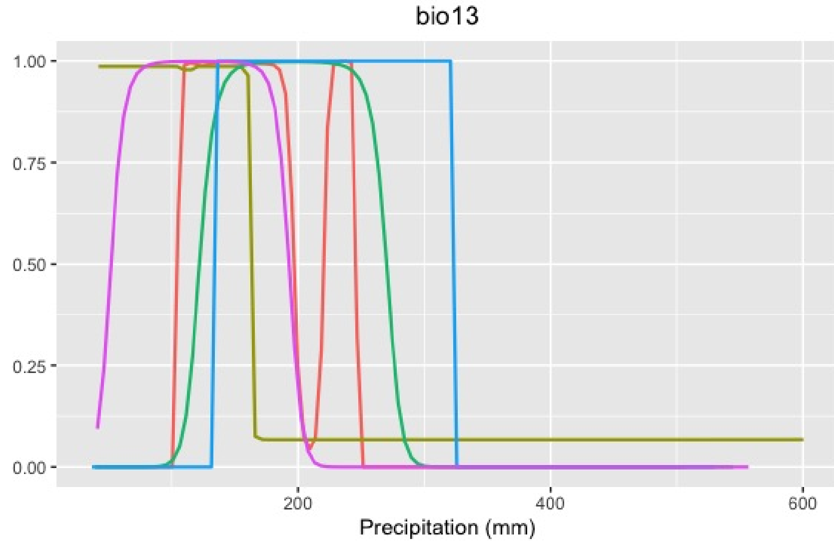
With the exception of the Steppe eagle, most species were positively impacted by the precipitation of the warmest quarter's (bio18), with an ideal mean range of 250mm-375mm. At precipitation levels below 25 mm, the majority of raptor species' distributions begin to decrease during the driest month (bio 14). When precipitation falls below 200 mm, the majority of species' distributions also start to decline during the coldest quarter (bio 19). The majority of species preferred temperatures between 13 and 19 °C (bio 7). The Secretary bird and the Southern ground hornbill were unaffected by the high temperatures, which had an impact on the distribution of the rest of the species. The majority of species demonstrated a preference for regions with high vegetation indices between (0.2-0.3). A high human influence index had a detrimental effect on the distribution of bateleur and steppe eagle (Fig. 5).

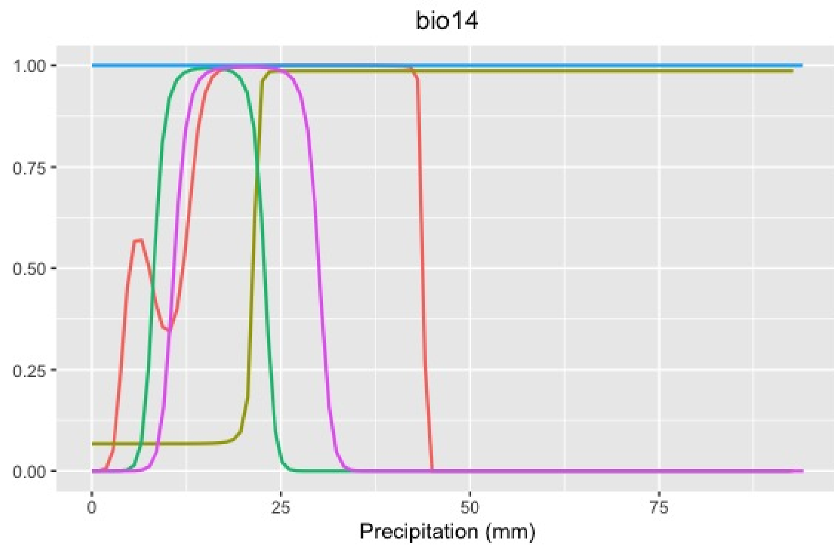

Aspect
1.00
0.75
0.50
0.25
0.00
0
100
200
300
Aspect
species
Steppe Eagle
Southern ground hornbill
Bateleur
Secretary bird
Martial Eagle

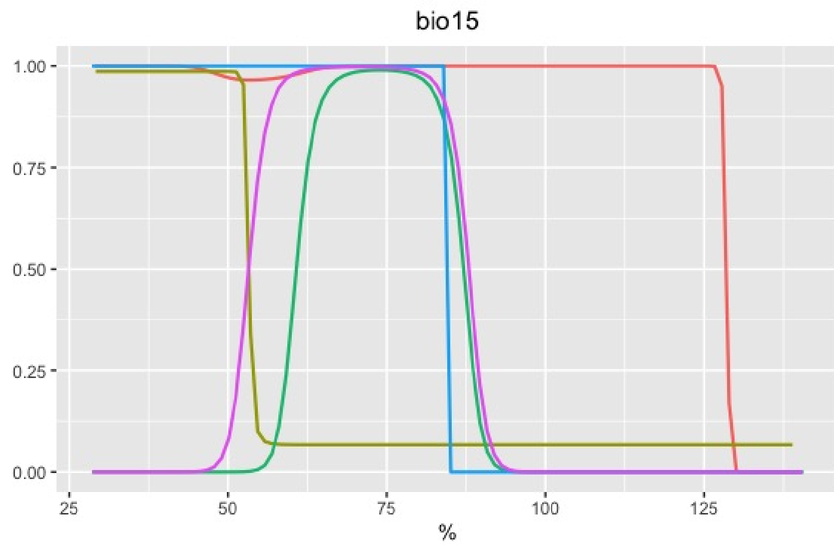

bio3
1.00
0.75
0.50
0.25
0.00
60
70
80
90
%

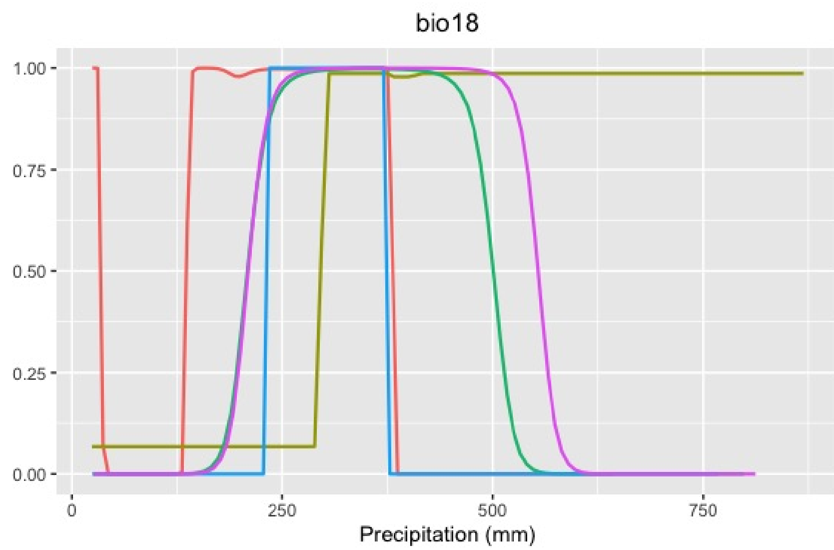

bio7
1.00
0.75
0.50
0.25
0.00
9
12
15
18
Temperature (°C)

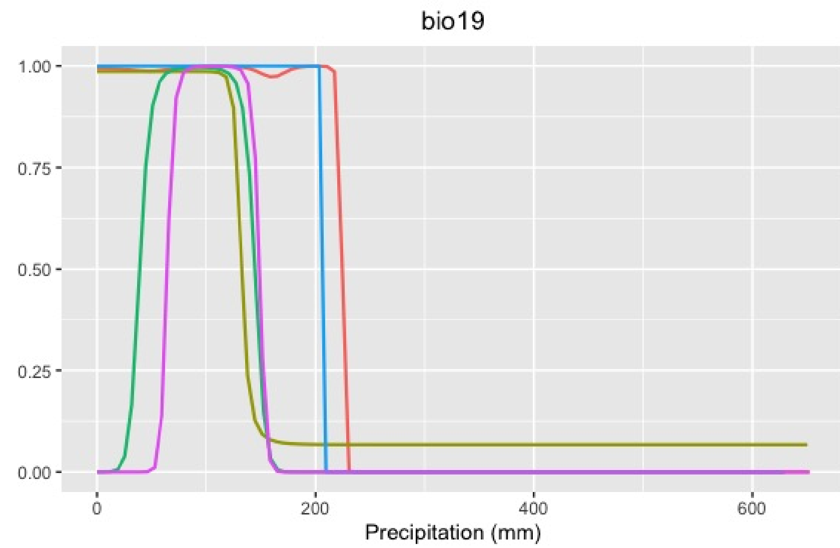

bio9
1.00
0.75
0.50
0.25
0.00
10
20
30
Temperature (°C)

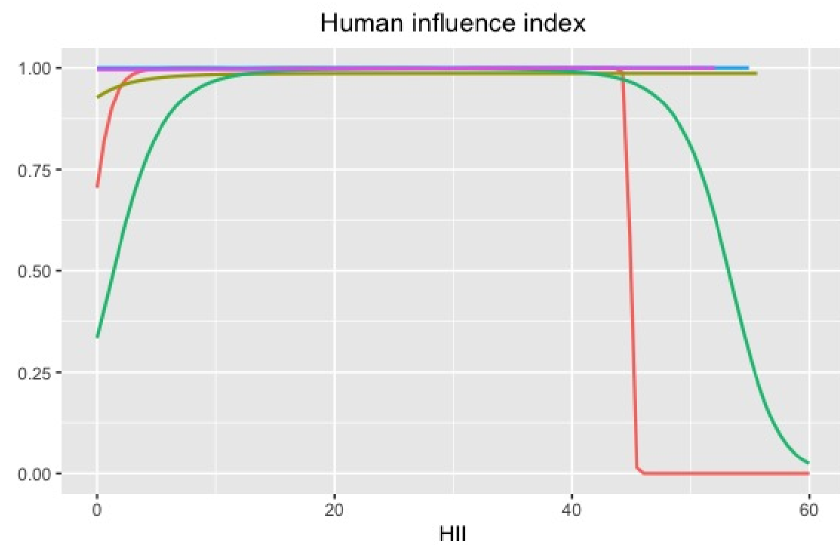

bio13
1.00
0.75
0.50
0.25
0.00
200
400
600
Precipitation (mm)


bio14
1.00
0.75
0.50
0.25
0.00
0
25
50
75
Precipitation (mm)


bio15
1.00
0.75
0.50
0.25
0.00
25
50
75
100
125
%


bio18
1.00
0.75
0.50
0.25
0.00
0
250
500
750
Precipitation (mm)


bio19
1.00
0.75
0.50
0.25
0.00
0
200
400
600
Precipitation (mm)


Human influence index
1.00
0.75
0.50
0.25
0.00
0
20
40
60
HII

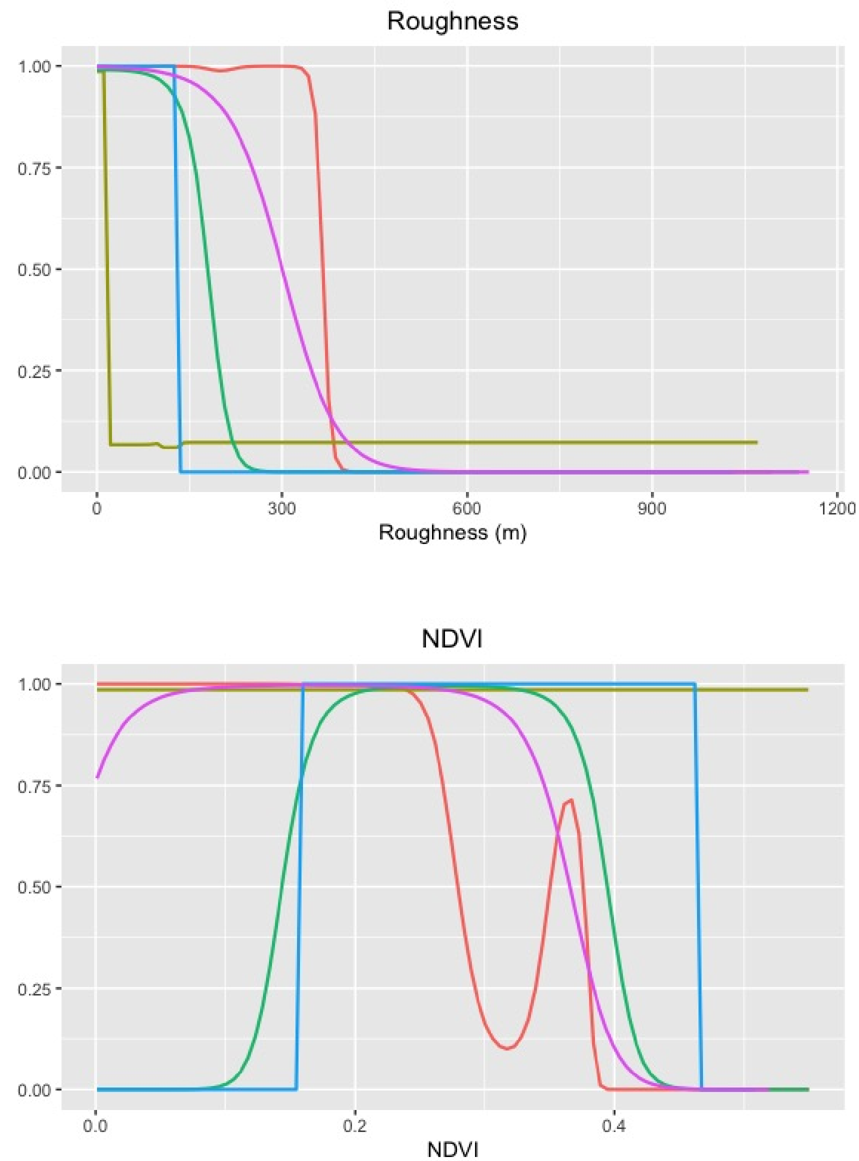


Figure 5: Response curves depicting the dynamic range of influence of predictor variables on raptor species distribution. Predictor variables are represented on the X-axis, and habitat suitability is represented on the Y-axis.

DISCUSSION

Spatial distribution of raptors and conservation planning.

This study's main goal was to identify suitable habitats for five endangered raptors while also taking protected areas into account for their preservation. Priority areas, which are pivotal habitat for the five species, were mostly found in Kenya's south, southwest, and central regions. This might be a result of Kenya's diverse range of environmental conditions. For instance, temperatures in the northern and eastern parts of the country can reach 33°C with little to no rainfall (less than 100 mm each season, . In contrast, South central and South western regions of the nation experience slightly lower temperatures, with highs up to 25°C and more precipitation overall of more than 200 mm in every season . The western and south central regions of

Kenya, extending to the north central region, can be recognized for a program of raptor conservation as a result of the modeled results, particularly when comparing potential distributions under current conditions and when overlaying with nature reserves. The Central, Western, and South Western regions of Kenya had the highest taxa, phylogenetic, and rich diversity of terrestrial animals, according to . However, preventing human encroachment on animal habitats may be difficult because these areas are surrounded by buffer zones that are densely populated and farmed.

All five raptor species studied here had at least some of their niche outside protected areas; with Secretarybird having the highest proportion outside protected areas at 77.57% and the Southern ground hornbill having the lowest distribution outside protected areas at 49.64%. The Southern ground hornbill fared best, with almost half of its core range protected (50.35%), followed by the Bateleur at 41.45%, and all other species below 37%, with the Secretarybird having the lowest protection (22.43%). The vast majority of priority habitats for Kenya's five raptors are located outside of protected area networks, which is consistent with recent research showing that raptors exist outside of protected areas in Kenya and are in decline . , who modeled Eastern and Central European birds that are endangered or threatened came to similar conclusions. The author's research discovered vulnerable bird focal points outside of protected areas in Eastern Central and Europe. Birds like the Secretarybird, which have suitable niches in Central Kenya, would quickly disappear if grasslands were transformed to agricultural production as nesting season disturbance would increase, like observed.

Relative importance of environmental covariates

The availability of suitable nesting sites and trophic nutrients determines distribution and abundance patterns, notably for raptors . Temperature can directly affect animal growth and reproduction, as well as indirectly by affecting the food chain, which can have an impact on animal survival. Extreme precipitation generally poses a threat to bird survival . The description of raptor species declines in response to periods of extremely low or high precipitation, as shown by the curves of precipitation in the wettest quarter (bio18), precipitation in the driest month (bio14), and precipitation in the coldest quarter (bio19), supports the conclusions of our studies

The ensemble model's relative contributions from each environmental covariate are consistent with our theoretical understanding of each species' biology. The limiting factors of precipitation and temperature have a significant impact on the distribution of all five species. The fact that bio18 (Precipitation of the warmest quarter) has such a strong impact on all species (Fig. 3) may indicate that these species prefer habitats with the right amount of precipitation and temperature. Compared to the rest of the other species, the Steppe Eagle and the Secretarybird appreciated the inclusion of NDVI (Table 1). This might lend credence to the idea that these two birds prefer environments with some kind of woody vegetation. In Africa, Steppe eagles typically inhabit savannas and grasslands, with occasional use of dry woodlands. The Secretarybird migrates in response to rainfall and the increase in prey. It favors open grasslands, savannas, and shrubland over forests and dense shrubbery, which could obstruct its fleeting existence.

For all species, the effect of the human influence index was surprisingly low. Our results are in line with those of , and show that human influence did not have a significant impact on the distribution of suitable habitat for the five species. Raptor interactions, such as potential prey competition, have the potential to influence the distribution of suitable habitats . Given that precipitation and temperature were the most significant predictors for all five species, the ramifications of changing climate is likely to have a significant impact on how raptors are distributed and may cause their ranges to contract .

The predicted spatial distributions of the five species of raptors differed in size. These differences might be primarily brought on by variations in the predicted distributions' environmental ranges. The Martial eagle, for instance, had a much wider coverage range than the Southern ground hornbill. Species with wider geographic ranges are more resilient to climate change . Due to the lack of protection in raptor priority areas, conservation efforts should be functional outside of the current conservation areas. It is likely that extensive conservation and governmental measures will be needed to preserve raptors and the ecosystem services they provide. Legislation may be passed, for instance, to control the distribution and utilization of veterinary drugs, which are reducing the number of vultures in Africa . Additionally, thorough environmental impact assessments (EIAs) should be carried out before developing energy infrastructure in order to recognize and eliminate risks to raptors especially vultures . Our biodiversity will continue to face serious threats and challenges, particularly in Kenya's key biodiversity areas (KBAs) as they are put under increasing pressure by an increase in infrastructure developments like roads, power and wind energy, pipelines, land use changes, and illegal activities like logging . Furthermore, it will be crucial to work with stakeholders to recognize and address regional problems like conflict between people and wildlife, which may be a factor in the decline of raptors.

A more complete study of the spatial distributions of threats will be a crucial next step in improving raptor conservation in Kenya. Raptors in Sudan, for instance, have been shown to be electrocuted by power lines and similarly alarming levels of electrocution have been recorded in Kenya . Flying birds like raptors and other species can be severely harmed by high voltage transmission lines, even though increasing renewable energy is generally a desirable plan of action for Kenya's global environmental sustainability and development for a host of reasons .

Conclusion

Using niche models, five raptor species in Kenya were analyzed for their distribution in suitable habitat. Our results indicate that a) of the five species of raptors, the Martial Eagle and Bateleur had the most suitable habitat (or, in our case, a realized niche). In contrast, the southern ground hornbill had a small area of suitable habitat. This indicates the two species' excellent climate adaptation to a wide range of environments in Kenya. Even though there was a predictor for anthropogenic influence, it is obvious that this predictor had no appreciable impact on the five species' suitable habitat. b) The majority of raptors are found outside of protected areas, with a high concentration in Kenya's southwestern and central regions. c) Temperature and precipitation-related variables influenced the habitat suitability of the five species the most. Our results have significant ramifications for Kenya's management and conservation of raptors. To begin with, raptor management, whether using a single species, multispecies, or ecosystem-based approach, can be aided by identifying raptors' spatial ranges and overlap with protected areas. Further, as temperature and precipitation in Kenya are altered with climate change, continued work to update spatial ranges will be necessary. Our research on the niche distribution of various species outside of protected areas shows that Kenya is a crucial habitat for raptor species, emphasizing the need for ecosystem-based management both inside and outside of protected areas. Second, understanding the key environmental factors that link raptor distribution may aid in estimating how future climate change will affect the occurrence of species. According to the A1 Global IBA Criterion for globally threatened species, the five priority areas for raptor conservation identified here could be the basis for several additional IBAs.

Authors' Contribution

The concepts and methodology were developed by Peggy Ngila and David Chiawo; the data were analyzed by Peggy Ngila and Jane Mugo; and the manuscript was written under their direction of David Chiawo, Margaret Owuor and Oliver Wasonga. Libby Ellwood contributed greatly in improving this manuscript.

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Conflict of Interest

The researchers acknowledge that they are not aware of any personal or financial conflicts that might have affected the research presented in this document.

References

Appendix

Table 1. The percentage contribution of environmental variables used in the five raptor species distribution model. Environmental variables are calculated at a resolution of about 1km.

Abbrev	Variables predictors	Percent contribution (%) Bateleur	Percent contribution Martial Eagle
Aspect	Aspect (° from 0 to 360)	0.9	1.9
bio13	Precipitation of the wettest month (mm)	5.9	5.3
bio14	Precipitation of the driest month (mm)	17.8	18.2
bio15	Precipitation seasonality (cv)[a]	12.1	9.2
bio18	Precipitation of the warmest quarter (mm)	16.7	14.9
bio19	Precipitation of the coldest quarter (mm)	14.3	13.8
bio3	Isothermality (%)[b]	5.5	6.2
bio7	Annual Temperature range (°C)	7.0	6.5
bio9	Mean temperature of the driest quarter (°C)	12.0	14.6
HII	Human influence index	2.2	2.5
NDVI	Normalized difference vegetation index (2013-2020)	4.1	4.9
Roughness	Roughness (m)	1.6	1.9

[a] Precipitation seasonality (Coefficient of variation)

[b] Isothermality (Mean diurnal range/Temperature annual range) (X100)

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