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RESEARCH ARTICLE

Effects of climate change on the distributional potential of three range-restricted West African bird species

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ABSTRACT

A detailed understanding of species' responses to global climate change provides an informative baseline for designing conservation strategies to optimize protection of biodiversity. However, such information is either limited or not available for many tropical species, making it difficult to incorporate climate change into conservation planning for most tropical species. Here, we used correlative ecological niche models to assess potential distributional responses of 3 range-restricted West African birds, Timneh Parrot (*Pscittacus erithracus timneh*), Ballman's Malimbe (*Malimbus ballmanni*), and White-necked Rockfowl (*Picathartes gymnocephalus*), to global climate change. We used primary biodiversity occurrence records for each species obtained from the Global Biodiversity Information Facility, eBird, and VertNet; for environmental data, we used climatic variables for the present and future, the latter characterized by 2 IPCC representative concentration pathways (4.5, 8.5) future emissions scenarios and 27 general circulation models for a 2050 time horizon. We found broad present-day potential distributions with respect to climate for all 3 species. Future potential distributions for Ballman's Malimbe and White-necked Rockfowl tended to be stable and closely similar to their present-day distributions; by contrast, we found marked climate change–driven potential range loss across the range of Timneh Parrot. Our results suggest that impacts of climate change on the present distributions of West African birds will in some cases be minimal, but that individual species may respond differently to future conditions. Thus, to optimize conservation of these species, and of bird diversity in general, we recommend that regional-to-national species conservation action plans incorporate climate change adaptation strategies for individual species; ecological niche models could provide an informative baseline information for this planning and prioritization.

Keywords: African birds, bird distribution, climate change, conservation, ecological niche modeling, *Malimbus ballmanni*, *Picathartes gymnocephalus*, *Psittacus erithacus timneh*, *Psittacus timneh*

Effets des changements climatiques sur le potentiel de répartition de trois espèces d'oiseaux d'Afrique de l'Ouest ayant une aire de répartition restreinte

RÉSUMÉ

Une compréhension détaillée des réponses des espèces aux changements climatiques fournit une base de référence informative pour concevoir des stratégies de conservation afin d'optimiser la protection de la biodiversité. Cependant, ces informations sont soit limitées, soit non disponibles pour plusieurs espèces tropicales, rendant difficile d'incorporer les changements climatiques dans la planification de la conservation pour la plupart des espèces tropicales. Nous avons utilisé des modèles de niche écologique corrélés pour évaluer les réponses potentielles de répartition face aux changements climatiques de trois oiseaux d'Afrique de l'Ouest à l'aire de répartition restreinte, soit *Pscittacus erithracus timneh, Malimbus ballmanni* et *Picathartes gymnocephalus*. Pour chaque espèce, nous avons utilisé des mentions de biodiversité primaire provenant du Système mondial d'informations sur la biodiversité, d'eBird et de VertNet; pour les données environnementales, nous avons utilisé des variables climatiques actuelles et futures, ces dernières étant caractérisées par deux profils représentatifs d'évolution de concentration (4.5, 8.5) du GIEC et 27 modèles de circulation générale jusqu'à l'horizon 2050. Nous avons trouvé de grandes répartitions potentielles actuelles relativement au climat pour les trois espèces. Les répartitions potentielles futures pour *M. ballmanni* et *P. gymnocephalus* avaient tendance à être stables et très similaires aux répartitions actuelles; au contraire, nous avons constaté une diminution potentielle marquée de l'aire de répartition de *P. erithracus timneh* due aux changements climatiques. Nos résultats suggèrent que les impacts des changements climatiques sur les répartitions actuelles d'oiseaux d'Afrique de l'Ouest seront dans certains cas minimaux, mais que des espèces pourraient répondre différemment aux conditions futures. Ainsi, afin d'optimiser la conservation de ces espèces et de la diversité aviaire en général, nous recommandons que les plans d'action régionaux et nationaux pour la conservation des espèces incluent des stratégies d'adaptation aux changements climatiques pour des espèces individuelles; les modèles de niche écologique pourraient fournir une base de référence informative pour cette planification et l'établissement des priorités.

Mots-clés: changements climatiques, conservation, la distribution des oiseaux, modélisation de la niche écologique, *Malimbus ballmanni*, Oiseaux africains, *Picathartes gymnocephalus*, *Psittacus erithacus timneh*, *Psittacus timneh*

INTRODUCTION

Global climate change is a major threat to the survival and persistence of biodiversity (Thomas et al. 2004, Pimm et al. 2014, BirdLife International 2018, Díaz et al. 2018). For example, a recent report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services projected that by 2100 Africa will lose more than half of its bird and mammal species, primarily as a consequence of effects of global climate change and habitat loss (IPBES 2018). Likewise, the BirdLife International report on the status of world birds anticipated alarming impacts of global climate change on many species (BirdLife International 2018).

Climate change is not only affecting species' distributions but also is impacting their populations (Bellard et al. 2012, Stephens et al. 2016). As such, understanding impacts of climate change on individual species is cardinal in integrative conservation planning for biodiversity (Lovejoy and Hannah 2018). However, this information is lacking for many species, particularly in tropical regions (Harris et al. 2011, Şekercioğlu et al. 2012). In Europe and North America, for example, impacts of climate change on some species are well documented, at least among birds and mammals (Hannah et al. 2002, Stephens et al. 2016, Pacifici et al. 2017, BirdLife International 2018).

In the tropics, however, studies attempting to assess species' responses to climate change are minimal and usually available only at coarse resolutions, despite high vulnerability of tropical species to global climate change (Malcolm et al. 2006, Harris et al. 2011, Şekercioğlu et al. 2012, Pacifici et al. 2017). For instance, in a review of 136 scientific articles assessing impacts of climate change on mammals and birds, 54% were about taxa in Europe and 38% about taxa in the United States, but only 4% were about taxa in South America, 2% in Oceania, and less than 1% in Africa and Asia (Pacifici et al. 2017). Furthermore, at coarse resolutions, studies tend to miss details of impacts of climate change at regional-to-local levels, particularly for range-restricted species that may be particularly susceptible to climate change (Hannah et al. 2002, Thomas et al. 2004, Malcolm et al. 2006, Sekercioglu et al. 2008, Carr et al. 2014).

In this study, we used correlative ecological niche models to assess current and potential future distributions of 3 range-restricted birds (Timneh Parrot [*Psittacus erithacus timneh*], Ballman's Malimbe [*Malimbus ballmanni*], and White-necked Rockfowl [*Picathartes gymnocephalus*]) in West Africa in response to global climate change (Peterson et al. 2001, 2002, 2011; Pearson and Dawson 2003). We selected these species as examples of bird species that are globally threatened (Endangered or Vulnerable), poorly known, range-restricted endemics, and likely highly susceptible to habitat loss and climate change (IUCN 2018). Our aim was to characterize climate change impacts on each species at regional-to-local scales to inform future research and integrative conservation planning and decision-making (Hannah et al. 2002, Guisan et al. 2013). Like most regions in Africa, future climate change projections for West Africa anticipate temperature increases with high confidence, but are more equivocal with rainfall (Buontempo et al. 2015, Janes and Hartley 2015): different projections indicate significant increases or decreases in future rainfall, with little consensus among models (Janes and Hartley 2015).

METHODS

Input Data

We obtained primary biodiversity occurrence records for the 3 range-restricted and globally threatened birds from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org), eBird (https://ebird.org), and VertNet (http://vertnet.org). Timneh Parrot is an endangered subspecies of Grey Parrot endemic to the Upper Guinea forest (IUCN 2018), sometimes elevated to *Psittacus timneh* (Melo and O'Ryan 2007). Grey Parrots are experiencing rapid population declines owing to a combination of habitat loss and heavy trapping for the international pet trade (CITES 2013, BirdLife International 2018, IUCN 2018, Martin 2018). They inhabit primary and secondary moist lowland forest, moving out of drier areas during the dry season (del Hoyo et al. 1997, Gatter 1997). The parrots roost in large trees near villages and water, feeding mainly on seeds and fruits, such as oil-palm (*Elaeis guineensis*; Gatter 1997, Freeman 2018a). They are social and breed in loose colonies, with the breeding season corresponding to the dry season (Sep–Feb). Current population estimates for Timneh Parrots are of 100,000–500,000 individuals (IUCN 2018).

White-necked Rockfowl is also an Upper Guinea forest endemic, classified as Vulnerable by IUCN due to population declines caused by habitat loss and fragmentation (IUCN 2018). The Picathartidae includes just 2 species of rockfowl endemic to West Africa. White-necked Rockfowl is a largely insectivorous colonial breeder with preference for rocky primary forest habitats, where it builds mud nests on rock faces and cave roofs during the wet season (Allport 1991, Thompson 1993). A current population estimate for the species is 10,000 individuals (IUCN 2018).

Ballman's Malimbe is an Upper Guinea forest endemic, classified as Endangered by IUCN due to population declines as a result of habitat loss and fragmentation (Field 1979, Gatter and Gardner 1993, Freeman et al. 2018a, IUCN 2018). Ballman's Malimbe has also been recorded in moderately to heavily logged forests (Gatter and Gardner 1993). It is insectivorous, usually foraging in mixed-species flocks in middle canopies (8–22 m; Gatter and Gardner 1993, Gatter 1997, Freeman et al. 2018a). The species builds hanging nests 8–21 m above the ground in lianas; its breeding season spans March to November, including both rainy and dry seasons (Gatter and Gardner 1993, Gatter 1997). Current population estimates are 10,000–15,000 individuals (IUCN 2018).

Data for these species were error-checked and improved to meet appropriate standards for ecological niche modeling. To this end, we assembled data from the 3 databases for each species and split the merged datasets into georeferenced and non-georeferenced portions. Georeferenced data were checked for errors and data consistency for geographic coordinates (Chapman 2005). Where possible, errors were fixed; otherwise, problematic data points were removed from the datasets. Non-georeferenced data that had detailed location information (e.g., town/village, county, country) were georeferenced using Google Earth. The 2 datasets were combined and spatially rarefied to remove duplicate points using SDM Toolbox 2.2b in ArcGIS 10.4.1 (Brown 2014). Following the cleaning process, we were left with 22 occurrence points for White-necked Rockfowl, 10 for Ballman's Malimbe, and 10 for Timneh Parrot. Numbers of occurrences (particularly for Ballman's Malimbe and Timneh Parrot) were low for ecological niche modeling; however, we used a robust jackknife approach for small sample sizes (Pearson et al. 2007; see detail below). In this "leave-one-out" approach, each observed locality is removed once from the set of occurrences, and a model is built using the remaining $n - 1$ localities. The predictive performance of models developed from this process is then tested using a randomization test (Pearson et al. 2007). Note that the data cleaning and standardization process for each species was informed by the experience of one of the authors who has worked on these species in the region.

To characterize environmental landscapes, we acquired 15 climatic variables at 2.5′ (4.6 km) spatial resolution, characterizing temperature and precipitation, and their seasonality for present-day climatic conditions, from Hijmans et al. (2005) (see Supplemental Material Table 1). To characterize future climate conditions, we drew data for 2 IPCC representative concentration pathways (RCP 4.5, 8.5) emissions scenarios and 27 global circulation models (GCMs), all for one future time period (2050; see Supplemental Material Table 2). These RCPs summarize low and high emissions scenarios for greenhouse gases. The GCMs represent independent simulations of global climate processes, and thus allow understanding of uncertainty in future climate patterns. We used these 2 RCPs because tropical West Africa has been projected to experience novel warm climates ~2 decades earlier (i.e. late 2030s to early 2040s) under both RCP4.5 and RCP8.5 than the global average (Diffenbaugh and Giorgi 2012, Mora et al. 2013, Barros et al. 2014). In fact, Diffenbaugh and Giorgi (2012) identified Western Africa as a hotspot of climate change under both RCP4.5 and RCP8.5.

Data Analysis

An important step in ecological niche modeling is to delineate a realistic calibration region (**M**; that is, the set of sites accessible to a species) over which models are calibrated (Barve et al. 2011). In this study, we delineated **M** using the ecoregions of West Africa (Olson and Dinerstein 2002). For each species we buffered the ecoregions with highest concentrations of occurrence points by one ecoregion on each side (Peterson et al. 2011). Our 3 focal species had the same general distributional pattern; as a result, we used the same calibration area for the 3 species in our analysis. Following delineation of **M**, we masked all environmental variables to the extent of our **M** in ArcGIS 10.5.1. For future climate projections, we transferred our models to the full extent of West Africa.

To determine subsets of important environmental variables with which to calibrate our models, we eliminated one variable from each pair of the 15 climatic variables presenting Pearson correlation coefficients above 0.8. To this reduced set, we applied jackknife approaches, using the occurrence points for each species (Pearson et al. 2007, Shcheglovitova and Anderson 2013). Based on the test gain distributions in these analyses, we selected 3 subsets of uncorrelated variables for each species to enable optimal model calibration and then generate many candidate models for evaluation.

Ecological Niche Modeling

We used the Maxent algorithm (version 3.3.3k) to model ecological niches of our target species (Phillips et al. 2006). To calibrate models and choose optimal parameter values, we ran 2 sets of analyses: one for only White-necked Rockfowl because it had a reasonable sample size for regular niche modeling protocols, and another for Ballman's Malimbe and Timneh Parrot (individually) with their smaller sample sizes. For White-necked Rockfowl, we split the occurrence data into 2 portions: 70% for model calibration and 30% for evaluation. For Ballman's Malimbe and Timneh Parrot we used the cross-validate function to implement a leave-one-out jackknife approach in Maxent, using all occurrence records for each species to calibrate models (Pearson et al. 2007, Shcheglovitova and Anderson 2013), and a number of replicates in each model equal to the number of occurrences.

To optimize model complexity for all 3 species, we assessed 29 combinations of Maxent's 5 feature classes (linear, quadratic, product, threshold, and hinge) as they interacted with 17 regularization multipliers values (0.1, 0.2, 0.3…1, 2, 4, 5, 6, plus 8 and 10). Using these combinations is an optimal approach to generating diverse candidate models from which to select models that best explain our data (Muscarella et al. 2014, Cobos et al. 2019). For White-necked Rockfowl, we evaluated candidate models and selected best models using the Akaike Information Criterion corrected for small sample sizes (Hurvich and Tsai 1989), performed significance tests using partial ROC (Peterson et al. 2008), and evaluated performance using a 5% training presence threshold to evaluate omission (Peterson et al. 2011). For Ballman's Malimbe and Timneh Parrot, we applied the Pearson et al. (2007) small-sample significance test. Specifically, we used the prevalence (proportion of area predicted as suitable by a model) and the minimum training presence training omission (a metric of performance) from the Maxent output. Ideally, the Pearson et al. (2007) small-sample significance test is meant to filter the models; however, all candidate models for the species were significant. Hence, to reduce the set of candidate models to the best few, we calculated the median prevalence for all replicates, calculated deviations from the median, and selected models closest to the median as the best for future analysis.

To generate binary maps for each of the present and future time periods, we projected final ("best") models for each species to the present and future climate data sets. We again applied a 5% training omission threshold based on the occurrence data used to calibrate models for each species (Peterson et al 2011, Peterson 2014). To assess vulnerability of each species to global climate change, we combined medians of the present and 27 future projections for each emissions scenario to create a visualization that shows the potential for range expansion, range retraction, and range stability (see Campbell et al. 2015). Last, we calculated the range of median values across all GCMs for each species for RCP 4.5 and 8.5 as a measure of model uncertainty. All analyses were performed in the kuenm R Package (R Development Core Team 2014, Cobos et al. 2019) and ArcGIS 10.4.1.

RESULTS

Using combinations of 29 feature classes, 17 regularization multipliers, and 3 environmental data sets, we assessed a total of 1,479 candidate models for each species. Best models for all species were significantly different from random ($P < 0.001$) and met the ≤5% omission criteria set for the different species. Jackknife analyses identified annual precipitation, temperature seasonality, and mean temperature of the coldest quarter as the environmental variables most important for Timneh Parrot (Supplemental Material Table 1, Supplemental Material Figures 1–3), whereas annual precipitation, temperature seasonality, and precipitation seasonality were most important for Ballman's Malimbe (Supplemental Material Table 1, Supplemental Material Figures 4–6). Temperature annual range, maximum temperature of the warmest month, and precipitation of the driest quarter were the variables most important for White-necked Rockfowl (Supplemental Material Table 1, Supplemental Material Figures 7–9).

All 3 species showed broad present-day potential distributions with respect to climate (Figure 1), suggesting that their original potential geographic ranges prior to widespread forest destruction were quite broad in the region. For Timneh Parrot and White-necked Rockfowl, present-day potential distributions matched closely the distribution of Upper Guinea lowland forest (southwestern Sierra Leone to southwestern Togo), extending northwest to Guinea Bissau, beyond the known range of White-necked Rockfowl (Figure 1). For Ballman's Malimbe, present-day potential distributions were broad across southeastern Liberia and narrower in northwestern Liberia, southeastern Guinea, and southwestern Côte d'Ivoire (Figure 1). Interestingly, our models projected an isolated far eastern distributional area (in southern Ghana) beyond the known range of this species (Figure 1). Future potential distributions for Ballman's Malimbe and White-necked Rockfowl, taking into account climate change processes, tended to be stable, and similar to their present-day distributions (Figure 2). In contrast, we found marked climate change–driven potential range loss across the range of Timneh Parrots with no areas becoming newly suitable (Figures 1 and 2). Our models suggested that Timneh Parrot will be almost entirely restricted to Liberia by 2050 (Figures 1 and 2). The projections of the 2 RCPs were closely similar in all cases (Figure 1). Climate change–driven range gains of Ballman's Malimbe and White-necked Rockfowl were concentrated in southeastern Côte d'Ivoire, southwestern Togo, and northern and northeastern Liberia.

Levels of uncertainty in model predictions differed between species (Figure 3). White-necked Rockfowl showed high uncertainty in RCP 4.5 compared to RCP 8.5, and this uncertainty was high in central and northern Liberia (Figure 3). For Ballman's Malimbe, uncertainty was high in southeastern Liberia, whereas for Timneh Parrot uncertainty was high in northern and southeastern Liberia (Figure 3).

DISCUSSION

Data deficiency is a major challenge in modeling ecological niches and estimating potential distributions of

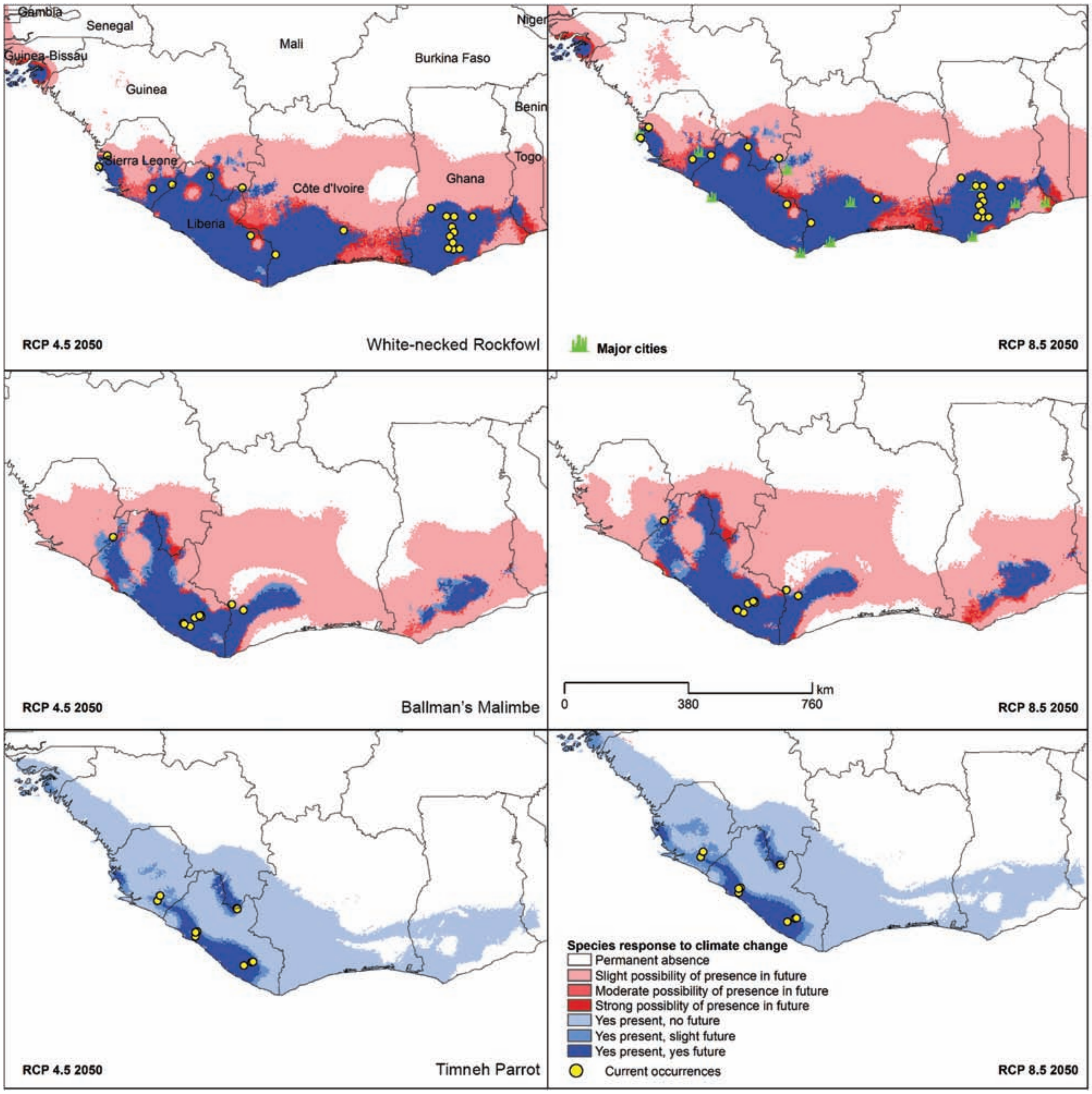

FIGURE 1. Current and future potential distributions of White-necked Rockfowl, Ballman's Malimbe, and Timneh Parrot for 2 emissions scenarios (left side, RCP 4.5; right side, RCP 8.5) in 2050.

range-restricted species. In this study, we noted data limitations for each of our study species; however, the approaches adopted in this study are robust to relatively small samples (Pearson et al. 2007, Shcheglovitova and Anderson 2013). Pearson et al. (2007), for example, using similar approaches with only 6 occurrence records, successfully developed detailed predictions of distributions of geckos in Madagascar. Like Pearson et al. (2007), our results provide a baseline with which to inform future survey planning across the region, which is in itself an opportunity to test the predictive ability of our models and generate more data for these species. For instance, since it was first described by Gatter and Gardner (1993), Ballman's Malimbe is known as endemic to Liberia, Guinea, Sierra Leone, and Côte d'Ivoire. Our models identified the possibility of an extension of the species' range in southern Ghana, such that surveys in those regions can target this species. Indeed, the Nimba Flycatcher (*Melaenornis annamarulae*), long believed endemic to Liberia, Guinea, Sierra Leone, and Côte d'Ivoire, was recently discovered in Atewa Range Forest

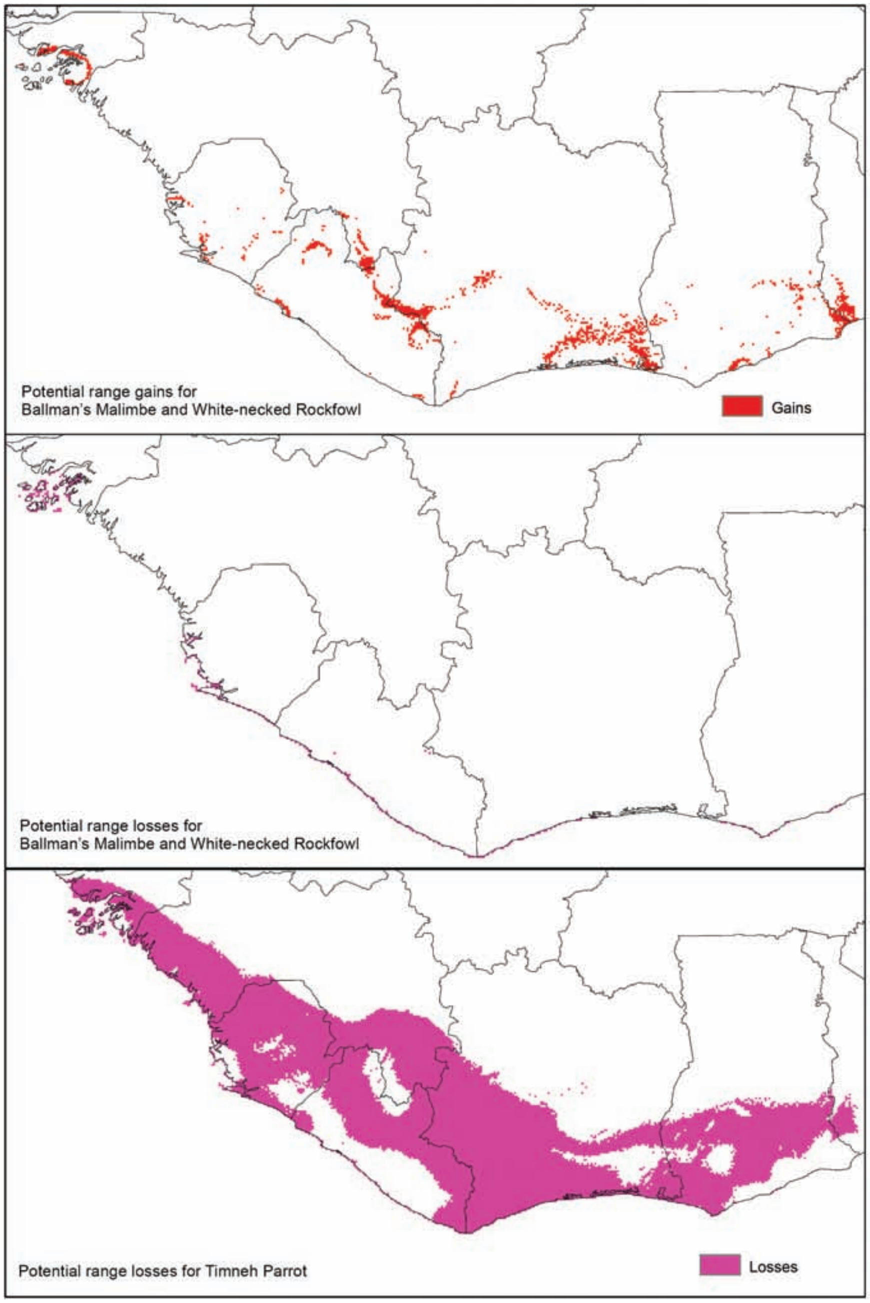

FIGURE 2. Climate change–driven range gains and losses for White-necked Rockfowl, Ballman's Malimbe, and Timneh Parrot in 2050 based on areas unsuitable in the present, but with a strong chance of suitability in the future (gains) and areas predicted to be suitable in present and completely unsuitable in the future (losses). Gains and losses for White-necked Rockfowl and Ballman's Malimbe were combined because they showed similar pattern. Note that no gains are anticipated for Timneh Parrot.

Reserve in southern Ghana (Demey and Hester 2008). Many Upper Guinea forest species of diverse taxonomic groups (e.g., birds, plants, mammals) show similar distributional patterns.

This study provides a first regional-to-local assessment of impacts of global climate change on distributions of range-restricted, globally threatened West African birds at fine spatial resolution. We found broad present-day potential distributions with respect to climate variables for all 3 species, although their landscape-level responses to land cover considerably reduce their actual distributions. A similar pattern has been observed in other studies looking at vulnerability to climate change of mammals, birds, and amphibians of the region (Carr et al. 2014, Baker et al. 2015). For example, compared to other taxonomic groups (amphibians and mammals), Carr et al. (2014) found birds

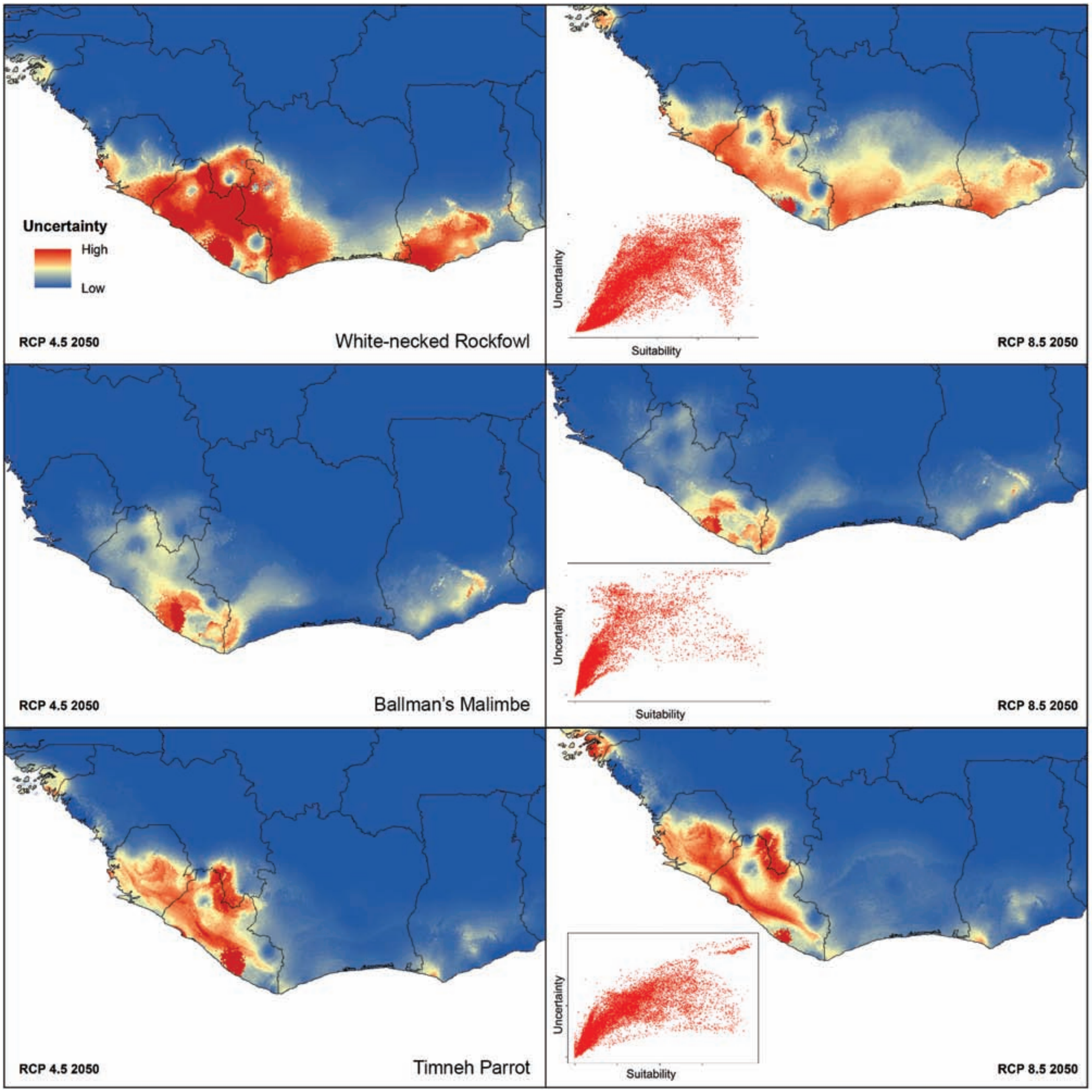

FIGURE 3. Uncertainty of models in range of median values of general circulation models for each species for RCP 4.5 and 8.5. Graphs inserted in the right-hand column show the relationship between uncertainty and suitability for each species.

to have a low overall sensitivity to climate change in the region, but high sensitivity to forest cover. This low sensitivity could explain the minimal climate change–driven range loss and broader future potential distributions that we observed for Ballman's Malimbe and White-necked Rockfowl. In agreement with Carr et al. (2014), our results suggest that forest cover and its reduction are probably much more significant drivers of bird species' range loss in this region (Figure 4). What is not clear yet, however, is whether current threats to the ranges of these species will be exacerbated by future climate change. This outcome is likely if efforts are not made to reduce rates of forest loss in the region, as primary forests are irreplaceable for tropical species (Gibson et al. 2011). Moreover, West Africa has been predicted to experience unprecedented departures from its present/historical climate range as early as 2030s, about 2 decades earlier then the global average (Mora et al. 2013). As such, if forests are not protected, their destruction could coincide with dramatic changes in the region's climate.

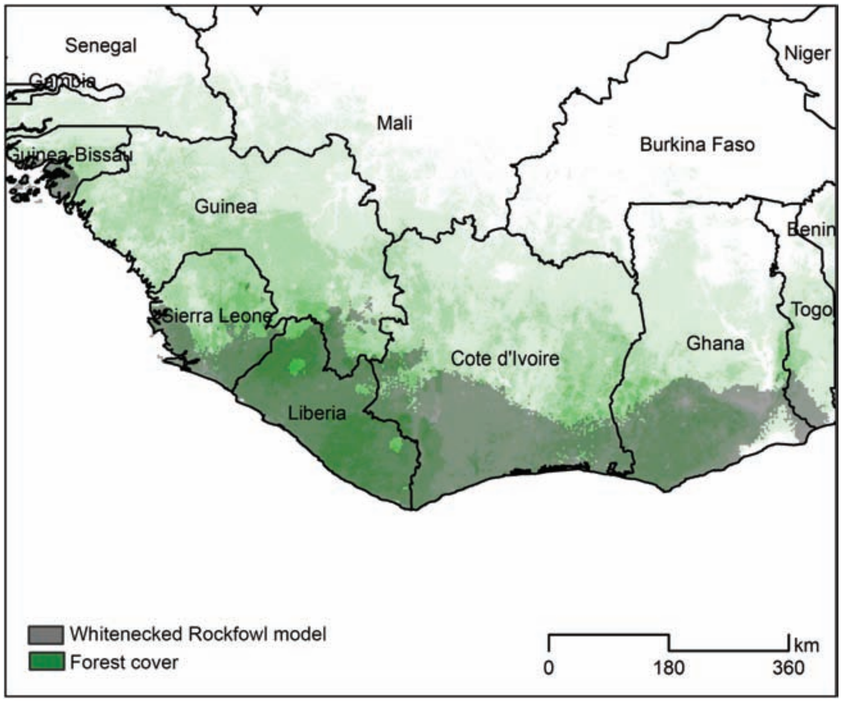

FIGURE 4. Map showing Upper Guinean forest cover across West Africa (Hansen et al. 2013) and ecological niche model for White-necked Rockfowl. The dark green areas in the map represent high density forest cover; gray areas represent the potential distributions of White-necked Rockfowl under climate change.

On the other hand, we noted marked climate change–driven future potential range loss across the range of Timneh Parrot, with no areas of range gain. Our future projections anticipate that the species' range will be almost entirely restricted to Liberia by 2050 (Figures 1 and 2). Interestingly, Carr et al. (2014) found Grey Parrot to be one of few bird species sensitive to climate change in the region. This finding is troubling for a species that is already under massive pressure from overexploitation for the pet trade and habitat loss (CITES 2013) Projected impacts of climate change on this species, together with ongoing threats to its habitat and pressure from the pet trade, should provide increased incentive for conservation focus on this species. For all species, we emphasize that areas presenting a combination of high suitability and low uncertainty (see graphics in Figure 3) should be survey priorities. In addition to authenticating models, data on the ecology, habitat requirements, life history strategies, and threats affecting each species would inform conservation decisions (e.g., Behl and Benkman 2018).

Particularly, Timneh Parrots should be given urgent attention given the predicted high risk impacts of climate change on the distribution potential of the taxon. Furthermore, note that the colonization of uninhabited suitable areas predicted in these models depends on the dispersal abilities of each species and opportunities (e.g., suitable corridors) available to them. As such, conservation efforts in the region should not only focus on protecting individual habitat fragments suitable to these species but also prioritize creating corridors for connectivity between suitable habitats (Freeman et al. 2018b). Knowledge of dispersal abilities of these species is limited, although Timneh Parrots have been observed to travel long distances in search of food resources in southeastern Liberia (Freeman et al. 2018a). Ballman's Malimbe and White-necked Rockfowl are more specialized and probably less vagile forest dwellers less likely to use other habitats.

Of the 3 species assessed in this study, only White-necked Rockfowl has a regional species conservation action plan, although it has yet to be implemented (Thompson et al. 2004). Hence, to optimize conservation of the 3 species, we recommend that regional and national species conservation action plans incorporating climate change adaptation strategies and an implementation roadmap be developed for each species. Our models should provide informative baseline information for planning and prioritization.

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Data depository: Data used in this study were obtained from and are available on https://www.gbif.org; https://ebird.org; and http://vertnet.org.

LITERATURE CITED

Allport, G. (1991). The status and conservation of threatened birds in the Upper Guinea forest. Bird Conservation International 1:53–74.

Baker, D. J., A. J. Hartley, N. D. Burgess, S. H. M. Butchart, J. A. Carr, R. J. Smith, E. Belle, and S. G. Willis (2015). Assessing climate change impacts for vertebrate fauna across the West African protected area network using regionally appropriate climate projections. Diversity and Distributions 21:991–1003.

Barros, V. R., C. B. Field, D. J. Dokke, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, and R. C. Genova (2014). Climate change 2014: Impacts, adaptation, and vulnerability-Part B: Regional aspects-contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Barve, N., V. Barve, A. Jiménez-Valverde, A. Lira-Noriega, S. P. Maher, A. T. Peterson, J. Soberón, and F. Villalobos (2011). The crucial role of the accessible area in ecological niche modeling and species distribution modeling. Ecological Modelling 222:1810–1819.

Behl, N. J., and C. W. Benkman (2018). Habitat associations and abundance of a range-restricted specialist, the Cassia Crossbill (*Loxia sinesciuris*). The Condor: Ornithological Applications 120:666–679.

Bellard, C., C. Bertelsmeier, P. Leadley, W. Thuiller, and F. Courchamp (2012). Impacts of climate change on the future of biodiversity. Ecology Letters 15:365–377.

BirdLife International (2018). State of the World's Birds: Taking the Pulse of the Planet. BirdLife International, Cambridge, UK.

Brown, J. L. (2014). SDMtoolbox: A python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. Methods in Ecology and Evolution 5:694–700.

Buontempo, C., C. Mathison, R. Jones, K. Williams, C. Wang, and C. McSweeney (2015). An ensemble climate projection for Africa. Climate Dynamics 44:2097–2118.

Campbell, L. P., C. Luther, D. Moo-Llanes, J. M. Ramsey, R. Danis-Lozano, and A. T. Peterson (2015). Climate change influences on global distributions of dengue and chikungunya virus vectors. Philosophical Transactions of the Royal Society B 370:20140135.

Carr, J. A., A. F. Hughes, and W. B. Foden (2014). A climate change vulnerability assessment of West African species. UNEP-WCMC technical report. Cambridge, UK.

Chapman, A. D. (2005). Principles of data cleaning–Primary species and species occurrence data, version 1.0. Report for the Global Biodiversity Information Facility, Copenhagen. http://www.gbif.org/resource/80528

CITES (2013). Strengthening capacity for monitoring and regulation of international trade of African Grey Parrot. Report prepared by BirdLife Africa Partnership Secretariat, Geneva, Switzerland.

Cobos, M. E., A. T. Peterson, N. Barve, and L. Osorio-Olvera (2019). Kuenm: An R package for detailed development of ecological niche models using maxent. PeerJ 7:e6281.

del Hoyo, J., A. Elliott, J. Sargatal, and J. H. Haffer, Editors (1997). Handbook of the Birds of the World, Volume 4: Sandgrouse to Cuckoos. First edition. Lynx Edicions, Barcelona, Spain.

Demey, R., and A. Hester (2008). First records of Nimba Flycatcher *Melaenornis annamarulae* for Ghana. Bulletin of the African Bird Club 15:95–96.

Díaz, S., U. Pascual, M. Stenseke, B. Martín-López, R. T. Watson, Z. Molnár, R. Hill, K. M. A. Chan, I. A. Baste, K. A. Brauman, et al. (2018). Assessing nature's contributions to people. Science 359:270–272.

Diffenbaugh, N. S., and F. Giorgi (2012). Climate change hotspots in the CMIP5 global climate model ensemble. Climatic Change 114:813–822.

Field, G. D. (1979). A new species of *Malimbus* sighted in Sierra Leone and a review of the genus. Malimbus 1:2–13.

Freeman, B., D. F. Danjuma, and M.-O. Mary (2018a). Status of globally threatened birds of Sapo National Park, Liberia. Ostrich 2018:1–6.

Freeman, B., P. R. Roehrdanz, and A. T. Peterson (2018b). Modeling endangered mammal species distributions and forest connectivity across the humid Upper Guinea lowland rainforest of West Africa. Biodiversity and Conservation. https://doi.org/10.1007/s10531-018-01684-6

Gatter, W. (1997). Birds of Liberia. Yale University Press, London, UK.

Gatter, W., and R. Gardner (1993). The biology of the Gola Malimbe *Malimbus ballmanni* Wolters 1974. Bird Conservation International 3:87–103.

Gibson, L., T. M. Lee, L. P. Koh, B. W. Brook, T. A. Gardner, J. Barlow, C. A. Peres, C. J. Bradshaw, W. F. Laurance, and T. E. Lovejoy (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. Nature 478:378.

Guisan, A., R. Tingley, J. B. Baumgartner, I. Naujokaitis-Lewis, P. R. Sutcliffe, A. I. T. Tulloch, T. J. Regan, L. Brotons, E. McDonald-Madden, C. Mantyka-Pringle, et al. (2013). Predicting species distributions for conservation decisions. Ecology Letters 16:1424–1435.

Hannah, L., G. F. Midgley, T. Lovejoy, W. J. Bond, M. Bush, J. C. Lovett, D. Scott, and F. I. Woodward (2002). Conservation of biodiversity in a changing climate. Conservation Biology 16:264–268.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, et al. (2013). High-resolution global maps of 21st-century forest cover change. Science 342:850–853.

Harris, J. B. C., C. H. Sekercioglu, N. S. Sodhi, D. A. Fordham, D. C. Paton, and B. W. Brook (2011). The tropical frontier in avian climate impact research. Ibis 153:877–882.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25:1965–1978.

Hurvich, C. M., and C. L. Tsai (1989). Regression and time series model selection in small samples. Biometrika 76: 297–307.

IPBES (2018). Assessment report on biodiversity and ecosystem services for Africa. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net/assessment-reports/africa
IUCN (2018). The IUCN Red List of Threatened Species. http://www.iucnredlist.org/
Janes, T., and A. Hartley (2015). Regional Climate Projections for West Africa. UN Environment World Conservation Monitoring Centre, Cambridge, UK.
Lovejoy, T. E., and L. Hannah (2018). Avoiding the climate failsafe point. Science Advances 4:eaau9981.
Malcolm, J. R., C. Liu, R. P. Neilson, L. Hansen, and L. E. E. Hannah (2006). Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology 20:538–548.
Martin, R. O. (2018). Grey areas: Temporal and geographical dynamics of international trade of Grey and Timneh parrots (*Psittacus erithacus* and *P. timneh*) under CITES. Emu–Austral Ornithology 118:113–125.
Melo, M., and C. O'Ryan (2007). Genetic differentiation between Príncipe Island and mainland populations of the Grey Parrot (*Psittacus erithacus*), and implications for conservation. Molecular Ecology 16:1673–1685.
Mora, C., A. G. Frazier, R. J. Longman, R. S. Dacks, M. M. Walton, E. J. Tong, J. J. Sanchez, L. R. Kaiser, Y. O. Stender, J. M. Anderson, et al. (2013). The projected timing of climate departure from recent variability. Nature 502:183–187.
Muscarella, R., P. J. Galante, M. Soley-Guardia, R. A. Boria, J. M. Kass, M. Uriarte, and R. P. Anderson (2014). ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. Methods in Ecology and Evolution 5:1198–1205.
Olson, D. M., and E. Dinerstein (2002). The global 200: Priority ecoregions for global conservation. Annals of the Missouri Botanical Garden 1:199–224.
Pacifici, M., P. Visconti, S. H. Butchart, J. E. Watson, F. M. Cassola, and C. Rondinini (2017). Species' traits influenced their response to recent climate change. Nature Climate Change 7:205.
Pearson, R. G., and T. P. Dawson (2003). Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful? Global Ecology and Biogeography 12:361–371.
Pearson, R. G., C. J. Raxworthy, M. Nakamura, and A. T. Peterson (2007). Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in Madagascar. Journal of Biogeography 34:102–117.
Peterson, A. T. (2014). Mapping Disease Transmission Risk: Enriching Models Using Biogeography and Ecology. Johns Hopkins University Press, Baltimore, MD, USA.
Peterson, A. T., M. A. Ortega-Huerta, J. Bartley, V. Sánchez-Cordero, J. Soberón, R. H. Buddemeier, and D. R. Stockwell (2002). Future projections for Mexican faunas under global climate change scenarios. Nature 416:626.
Peterson, A. T., M. Papeş, and J. Soberón (2008). Rethinking receiver operating characteristic analysis applications in ecological niche modeling. Ecological Modelling 213:63–72.
Peterson, A. T., V. Sánchez-Cordero, J. Soberon, J. Bartley, R. W. Buddemeier, and A. G. Navarro-Sigüenza (2001). Effects of global climate change on geographic distributions of Mexican Cracidae. Ecological Modelling 144:21–30.
Peterson, A. T., J. Soberón, R. G. Pearson, R. P. Anderson, E. Martínez-Meyer, M. Nakamura, and M. B. Araújo (2011). Ecological Niches and Geographic Distributions. Princeton University Press, Princeton, NJ, USA.
Phillips, S. J., R. P. Anderson, and R. E. Schapire (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231–259.
Pimm, S. L., C. N. Jenkins, R. Abell, T. M. Brooks, J. L. Gittleman, L. N. Joppa, P. H. Raven, C. M. Roberts, and J. O. Sexton (2014). The biodiversity of species and their rates of extinction, distribution, and protection. Science 344:1246752.
R Development Core Team (2014). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Şekercioğlu, Ç. H., R. B. Primack, and J. Wormworth (2012). The effects of climate change on tropical birds. Biological Conservation 148:1–18.
Şekercioğlu, C. H., S. H. Schneider, J. P. Fay, and S. R. Loarie (2008). Climate change, elevational range shifts, and bird extinctions. Conservation Biology 22:140–150.
Shcheglovitova, M., and R. P. Anderson (2013). Estimating optimal complexity for ecological niche models: A jackknife approach for species with small sample sizes. Ecological Modelling 269:9–17.
Stephens, P. A., L. R. Mason, R. E. Green, R. D. Gregory, J. R. Sauer, J. Alison, A. Aunins, L. Brotons, S. H. Butchart, and T. Campedelli (2016). Consistent response of bird populations to climate change on two continents. Science 352:84–87.
Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, et al. (2004). Extinction risk from climate change. Nature 427:145–148.
Thompson, H. S. (1993). Status of White-necked Picathartes–Another reason for the conservation of the Peninsula Forest, Sierra Leone. Oryx 27:155–158.
Thompson, H. S., A. Siaka, A. Lebbie, S. Evans, D. Hoffmann, and E. Sande (2004). International Species Action Plan for the White-Necked Picathartes *Picathartes gymnocephalus*. BirdLife International, Cambridge, UK.