Redistribution of Threatened and Endemic Atlantic Forest Birds Under Climate Change

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Abstract

Knowledge of the possible impacts of climate change on biodiversity in the tropics is especially scarce. We used maximum entropy modeling of species distributions to predict the ranges of endemic and threatened Atlantic Forest birds under a "business as usual" emissions scenario for 2050. Of the 51 species with reliable models, 44 were predicted to lose distribution area, with future ranges averaging 45% of their original size. Range contraction would bring two species to IUCN's threshold for threat under the Extent of Occurrence criterion. We also predict that the size of the regions that currently have the maximum number of endemic and threatened birds would be greatly reduced. Several such regions are currently highly deforested, which might reinforce the future threat to biodiversity.

Key words: Species Distribution Modeling, Ecological Niche Modeling, Climate Change, Conservation Status.

Introduction

Global climate change (CC) has gained great visibility within the scientific and public arenas. The last report of the Intergovernmental Panel on Climate Change (IPCC) reveals that ongoing CC has accelerated from previous forecasts and that human influence in the process is clear (IPCC 2007). Furthermore, there is convincing evidence that CC during the XX century impacted biodiversity, including alterations in species distribution and phenology and increased extinction risk (see Vale *et al.* 2009 for a review).

Given the likelihood of serious impacts of CC on biodiversity, knowledge of the association between CC and biodiversity has become an important demand, especially in tropical regions, which house most of the Earth's biological diversity. It is precisely there, however, that knowledge is the scarcest.

There are almost no studies of the possible impacts of CC on Neotropical biological diversity (Vale *et al.* 2009), for example, despite concerns of conservation professionals in the region (Ceballos *et al.* 2009). The Brazilian Atlantic Forest is especially understudied. With its remarkable altitudinal gradient and north-south extension, the Atlantic Forest is under several climatic regimes. Under CC scenarios, the northern portion of the biome presents a drier climate than usual, while the southern portion presents a wetter climate (Marengo 2007).

Species distribution models (SDMs) have been increasingly used to assess the magnitude of biological responses to CC (Araújo *et al.* 2011). The few studies that have performed SDM simulations to predict the impacts of CC on Atlantic Forest species have generally found species ranges contracting (Haddad *et al.* 2008; Colombo & Joly 2010; Marini *et al.* 2010). Here, we add another piece to this incomplete puzzle by conducting SDMs to assess the potential impacts of CC on the distribution and conservation of the endemic and threatened birds of the Atlantic Forest.

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Material and Methods

Data

Following the list of Bencke *et al.* (2006), we compiled occurrence records for the 52 threatened species of bird that are endemic to the Atlantic Forest. The records were compiled from original data, the literature, and representative ornithological collections (see Table S1 in the Additional Supporting Information, available at www.abecol.org.br). We compiled 1,044 unique records for 52 species (with at least five records per species), and excluded 10 species that had fewer than five records (Table S2.).

We created a dataset of six environmental variables to model species' distributions: maximum temperature of warmest month, temperature seasonality, precipitation of the driest month, precipitation of the wettest month, precipitation seasonality, and minimum temperature of coldest month. These six variables were selected from a large set of 19 available bioclimatic variables, based on their biological relevance to bird distribution, and on the minimization of colinearity in the original set of variables. Data for the current time were downloaded from WorldClim (www.worldclim.org). Data for 2050 were downloaded from CIAT-GCM (<http://ccafs-climate.org/>), for the IPCC's A2a greenhouse gas emission scenario using the HadCM3 General Circulation Model (GCM), which shows good performance for South America (Marengo 2007). The A2a scenario, a.k.a. the "business as usual", assumes that current patterns of greenhouse gas emissions will continue in the future (Nakicenovic & Swart 2000).

Distribution modeling and analysis

We modeled species environmental requirements and geographic distributions using the maximum entropy method (Phillips & Dudík 2008). This is among the best performing methods for modeling species' distributions when using presence-only data (e.g. Elith & Graham 2009). The settings used to run Maxent model are shown in Appendix S1 (the Additional Supporting Information).

MaxEnt models were evaluated using the "Area Under the ROC curve" (AUC). The AUC ranges from 0 to 1, with an AUC of 0.5 representing a model that is as good as one generated at random, a value of >0.5 indicates a better-than-random model prediction, and a value <0.5 indicates a worse-than-random model prediction. We only considered models with AUCs ≥ 0.8 , i.e., good to excellent (Swets 1988; but see Lobo *et al.* 2008).

For each species, we generated maps of the current distribution and the projected potential distribution in 2050. First, we modeled the species' distributions over a geographical extent that encompasses the Atlantic Forest and surrounding areas. Next, we cut the distribution maps using the boundaries of this biome and from these clipped

maps we estimated species' distribution area within the current distribution of Atlantic forest and established possible losses or gains in distribution under the CC scenario. We also generated species richness maps by summing the distribution maps of all species. We restricted the analysis to the Atlantic Forest boundaries because: 1) there are no predictions of an expansion of forested habitats under climate change for South America, and 2) the modeled species are mainly forest endemics and therefore, the availability of new climatically favorable areas under CC outside of the current limits of the Atlantic Forest will not necessarily translate into new areas for colonization.

We estimated each species' IUCN threat status for 2050 using the Extent of Occurrence (EO) criterion (criterion B1, IUCN 2001). We identified those species that would reach the threshold size for EO by 2050 by equating a species' distribution area with its EO, and assuming that a reduction in a species' geographic distribution area under the CC scenario sufficiently indicates the continuing decline and fragmentation of the EO (Vale *et al.* 2008). The threshold sizes for the different threat categories are ≤ 100 km² or restricted to a single locality for Critically Endangered, $\leq 5,000$ km² for Endangered, and $\leq 20,000$ km² for Vulnerable (IUCN 2001).

Results

In general, SDMs showed excellent performance, with an average AUC of 0.945 for the 52 species (Table S2). Only the *Curaeus forbesi*'s model had an AUC < 0.8 (Table S2,) and we discarded its results.

The contribution of different bioclimatic variables to the final SDMs was somewhat equitable (Table S3) and all species showed changes in distribution in 2050 (Table S2). Of the 51 species with reliable models, 44 were predicted to lose distribution area. For these species, the analysis shows an average estimated reduction of ca. 165,000 km² of the original area of species distributions, and the future distributions are equivalent, on average, to 45% of the original area.

The reduction in the distribution of many species generates a change in spatial patterns of species richness, with a forecasted drop in species richness that is unevenly distributed across the Atlantic Forest. Currently, the peak of endemic and threatened bird richness occur in two major areas along the coastal portion of the Atlantic Forest: 1) a southern area from Santa Catarina to Rio de Janeiro states, with localized "hotspots" of high species richness in coastal São Paulo and Rio de Janeiro states, and 2) a northern area from Bahia to Pernambuco states, with large hotspots in Bahia and localized hotspots in Alagoas and Pernambuco (Figure 1a). Under the CC scenario, the areas with the greatest richness are greatly reduced, and all hotspots disappear with the exception of the one in Bahia, which nonetheless is greatly reduced (Figure 1a). The greatest losses are in the São Paulo hotspot, and especially in the Pernambuco

Figure 1. Richness of 51 Atlantic Forest endemic and threatened birds calculated from the sum of individual species distribution models. Only the area within the Atlantic Forest biome is colored, and no turnover of species from other biomes is considered. a) Left: bird richness in the present (max = 40 species); Right: bird richness in the future (2050) under a climate change scenario (max = 35 species). b) Difference in bird species richness in the present and the future, depicting areas that lose and gain species under a climate change.

hotspot (Figure 1b). Few localized areas, however, show an increase in richness (Figure 1b).

If the predictions are correct, reductions in distribution areas of two species would reinforce their threatened status by bringing them to the IUCN threshold for threat under the EO criterion: *Stymphalornis acutirostris* and *Phylloscartes kronei*. These species are endemic to coastal environments (see Appendix S2 in the Additional Supporting Information, for details). None of the few species that gained distribution area would leave the red list of threatened species because they are threatened under other criteria (see Table S2).

Discussion

Our study shows a potential for major range contraction of threatened birds endemic to the Atlantic Forest under CC, with two species that might reinforce their threatened status due to that range contraction. The few studies that have modeled species' distributions under CC of the Atlantic Forest reached similar conclusions. Haddad *et al.* (2008) predicted 56% range contraction for amphibians within the genus *Brachycephalus*, with possible extinctions. Colombo & Joly (2010) predicted contraction of more than 50% for half of the 38 Atlantic Forest trees species modeled. Analyzing the possible impacts of CC on the Red-spectacled Parrot, *Amazona pretrei*, Marini *et al.* (2010) predicted a 47% contraction in the species' year-round distribution, which is very close to our own prediction for the species

(Table S2). None of these studies have incorporated sea level rise into the models. The two bird species predicted in this study to reinforce threatened status, however, occur in coastal environments (Appendix S2 in the Additional Supporting Information) and, therefore, are also subject to habitat loss due to sea level rise under CC.

It is generally accepted that species can develop four responses to CC: dispersal, acclimation, adaptation, or extinction (Peterson *et al.* 2001). If a species has great dispersal ability, it may be able to abandon areas that become unsuitable and colonize new favorable areas. Indeed, several SDM simulations show shifts in the distributions of many species towards higher latitudes and higher elevations to compensate for a warmer climate. According to the few simulations for the Atlantic Forest, however, new climatically favorable areas will generally not become available under current CC scenarios. Furthermore, there are no predictions of any expansion of Neotropical forested habitats under climate change. On the contrary, there are predictions of forest contraction through savannization of the Amazon. Although there are no reasons to expect the savannization in the Atlantic Forest under CC (Carlos Nobre *in lit.*), there are also no indications that additional forest habitats will become available in neighboring biomes like the Cerrado, Pantanal or Pampa. Therefore, the availability of new climatically favorable areas under CC outside of the current limits of the Atlantic Forest won't translate into new areas for colonization when it comes to forest dwellers.

In addition to biological uncertainties, there are several sources of methodological uncertainty due to differences in data sources and statistical methods used for niche and climate modeling (SDMs, GCMs, emission scenarios), with a consensus that different SDMs represent the main source of uncertainty in forecasts of species range shifts (e.g. Diniz-Filho *et al.* 2009a; Buisson *et al.* 2010). In this sense, our results should be taken with caution as they are based on only one SDM (MaxEnt). Even so, according to Diniz-Filho *et al.* (2009a), the Atlantic Forest is one of the few regions in the New World where methods for niche modeling tend to give similar results and their differences are of minor concern.

Our study, like others for the Atlantic Forest, does not consider deforestation, assuming that the entire suitable area for a species corresponds to its geographic distribution. This is especially problematic for Atlantic Forest studies, as >80% of the original vegetation cover is gone, and most remnant forest is within small and isolated fragments (Ribeiro *et al.* 2009). Even if we assume no further deforestation in the Atlantic Forest (and we have no reason to be so optimistic), our figures for species' distribution sizes would be gross overestimates because large portions of the predicted distributions will not have suitable habitat for the species. By overestimating the distribution size, we reduced the chance that a species would reach the threshold distribution size for threat. Deforestation is especially high in the northernmost portion of the Atlantic Forest, in the Pernambuco biogeographic sub-region (Ribeiro *et al.* 2009). This is precisely where we predicted an important decline in richness of threatened endemic birds (Figure 2c). In this region deforestation and CC might work synergistically to reinforce the threat to biodiversity. A similar situation occurs with the small areas that show an increase in bird richness under CC (Figure 2c). These areas in Bahia and Rio de Janeiro are already mostly deforested (Ribeiro *et al.* 2009), and therefore might not fulfill their role as a climatic refuge under CC. Some of the small areas in southern Brazil that show increase in richness under CC, however, are not so heavily deforested and might play a conservation role in the future.

It is important to note that our predictions do not incorporate likely dispersion of species from neighboring biomes into the Atlantic Forest, so that patterns of species turnover among regions (*i.e.*, biomes) could affect predicted changes in overall richness patterns (e.g., Diniz-Filho *et al.* 2009b). Our analyses are restricted to the current species pool found in Atlantic Forest, within the current limits of the biome. The future distribution of species will be determined not only by climate, dispersal ability and habitat availability, but also by ecological interactions. In a study of distributional responses of Cerrado birds to CC, Marini *et al.* (2009) reported a tendency for a southeastern displacement of species distributions, apparently connected to a shift of typical Cerrado climatic conditions towards the Atlantic Forest. The incursion of Cerrado birds in the Atlantic Forest due to CC would likely impact the local avifauna through

biotic interactions (e.g. competition or even predation). Colombo & Joly (2010) report similar predictions regarding Atlantic Forest trees under CC, with southern displacements that could also impact Atlantic Forest avifauna, this time through changes in resource availability. Similarly complex community level changes associated with CC might have happened in the past, but this time they are occurring over a much shorter time scale. Above all, these changes are occurring in landscapes that are highly modified by people, which might hamper the ability of birds to survive these changes.

Studies of the possible impacts of CC on Neotropical biodiversity are scarce (Vale *et al.* 2009), and despite its limitations, distribution modeling represents one of the best available predicting tools, especially in tropical countries where empirical data from long term monitoring programs are scarce. Other studies are needed, with different taxa, to draw a more complete picture of the possible impacts of CC on the distribution and threat status of Neotropical species, and particularly studies that can identify areas that are likely to act as climatic refuges for biodiversity under CC.

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