

Article

Climate Changes Can Restore Allopatry Between Two Congeneric Birds in the Atlantic Forest

Vitor Araujo-Lima ¹, Rayane dos Santos Oliveira ¹, Marcio Mageski ¹, Rodrigo Barbosa Ferreira ^{1,2} and Charles Duca ^{1,3,*}

¹ Programa de Pós-Graduação em Ecologia de Ecossistemas, Universidade Vila Velha, Campus Boa Vista, Vila Velha 29102-920, ES, Brazil

² Programa de Pós-Graduação em Biologia Animal, Universidade Federal do Espírito Santo, Campus Goiabeiras, Vitória 29075-910, ES, Brazil

³ Instituto de Ciências Biológicas e da Saúde, Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte 30535-901, MG, Brazil

* Correspondence: charlesduca@pucminas.br

Simple Summary

Some species may disperse, adapt, or become locally extinct due to climate changes. We aim to understand how climate changes would affect the potential distribution of two congeneric birds in the Atlantic Forest, Brazil. We use data for both species from the literature and online platforms to model their future distribution under climate change. The models predicted that the two species would respond differently to the ongoing climatic changes. Tropical Mockingbird tended to increase its suitable area by 3.5% in the optimistic scenario (minimum temperature increase by 2060) and 2.5% in the pessimistic scenario (maximum temperature increase by 2060), relative to the 1960–1990 baseline. Chalk-browed Mockingbird tended to decrease its suitable area by 64% in the optimistic scenario and by 65% in the pessimistic scenario. The two future scenarios of temperature increase predicted that the co-occurrence between the species will be rare, with the two species becoming separated by climatically unsuitable areas. Our results highlighted the need for environmental policies considering local context and associated species traits.



Academic Editor: Jukka Jokimäki

Received: 21 May 2025

Revised: 10 August 2025

Accepted: 11 August 2025

Published: 13 August 2025

Citation: Araujo-Lima, V.; Oliveira, R.d.S.; Mageski, M.; Ferreira, R.B.; Duca, C. Climate Changes Can Restore Allopatry Between Two Congeneric Birds in the Atlantic Forest. *Birds* **2025**, *6*, 42. <https://doi.org/10.3390/birds6030042>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract

The climate is expected to change substantially by the end of the current century. In response to climate change, species may disperse, adapt, or become locally extinct. We aim to assess how the climate changes predicted to occur by 2060 may affect the potential distribution of Tropical Mockingbird (*Mimus gilvus antelius*) and Chalk-browed Mockingbird (*Mimus saturninus frater*) within the Atlantic Forest domain, Brazil. Occurrence data for both species were compiled from the scientific literature and online biodiversity databases. A total of 118 georeferenced records were obtained for Tropical Mockingbird and 1080 for Chalk-browed Mockingbird. Species distribution models predicted that the two species would respond differently to the ongoing climatic changes. The Tropical Mockingbird will slightly expand its suitable habitat by 3.5% (3871 km²) under the optimistic scenario (minimum temperature increase by 2060; Representative Concentration Pathways-RCP 2.6) and 2.5% (2765 km²) in the pessimistic scenario (maximum temperature increase by 2060; RPC 8.5), relative to the 1960–1990 baseline. Chalk-browed Mockingbird will reduce its suitable habitat by 64% (70,780 km²) under RCP 2.6 and 65% (71,886 km²) under RPC 8.5. The two future climate scenarios suggest that sympatry between the two species will become increasingly rare, with a shift toward allopatry due to emerging climatically unsuitable areas separating their distributions. Our results highlighted the importance of environmental

policies that incorporate local ecological contexts and species-specific traits to mitigate biodiversity loss under future climate conditions.

Keywords: Chalk-browed Mockingbird; ecological niche; geographical distribution; temperature rise; Tropical Mockingbird; sympatry

1. Introduction

Studies have indicated that changes will occur in the current temperature and rainfall patterns, and the climate is predicted to vary considerably by the end of the current century [1]. The trend of climatic changes depends on the specific region of the globe [2–4] and may affect the current distribution patterns of many species. Because the species are different in their sensitivity to climate variations, they are expected to respond differently to ongoing climatic oscillations. For example, culicid mosquitoes such as *Aedes aegypti* and *Aedes albopictus* tend to expand their distribution in the Neotropical region [5]. Similarly, some mammals and birds tend to reorganize their spatial distribution in other biogeographic regions [6–9], and the same has also been predicted for birds [10,11] and mammals [12] of the Cerrado biome, central Brazil. Preliminary evaluations of the effects of climatic changes on species distribution are useful tools for creating more effective management and conservation strategies [13], especially in the case of threatened species.

In response to climatic changes, species may disperse, adapt, or become locally extinct [14,15]. Species that disperse easily or tolerate climate variations tend to be less affected or may even benefit from the temperature increase predicted to take place by the end of the current century [9,16]. For example, some Passeriformes birds employ altitudinal migration [17,18], restrict their area of occurrence [10], or become sympatric with other species [19,20] in response to the loss of viable habitats.

The Tropical Mockingbird (*Mimus gilvus antelius*) (Oberholser, 1919) is restricted to the Brazilian coast [21], occurring from Rio Grande do Norte to the south of Rio de Janeiro [22,23]. It is usually associated with open coastal plains (i.e., restinga) [23,24] and does not enter forests. Tropical Mockingbird is included in the list of endangered species in the states of Rio de Janeiro and Espírito Santo [25,26]. The Chalk-browed Mockingbird (*Mimus saturninus frater*) (Hellmayr, 1903) has a wider distribution in South America. It is found from the open fields of northern Bolivia to the southeast and northeast of Brazil [23,24]. In some areas, its distribution reaches the Atlantic coast (e.g., Recôncavo Baiano and restingas in Espírito Santo State), where it replaces or occurs sympatrically with Tropical Mockingbird [23,24]. The real reason for this sympatry is not known, but human land use, which removed the natural barrier that separated the two species (i.e., Atlantic Forest), has been suggested as a possible reason [20], as reported for other bird species [19,27].

Considering the hypothesis that species with wider spatial distributions can better withstand the effects of climatic changes [28], we predict that the potential distribution range of the Tropical Mockingbird will decrease by 2060 [29] in a scenario of climatic change, as the spatial distribution of this species is restricted to open coastal plains [30]. In contrast, with its currently broader distribution, Chalk-browed Mockingbird will increase its potential distribution because it adapts to anthropogenic environments with shrubby vegetation [22] or even to urbanized areas [22,31].

The sympatry between the Tropical Mockingbird and the Chalk-browed Mockingbird is relatively recent [32]. This novel competitive effect between these congeneric species has been pointed out as a problem for Tropical Mockingbird conservation [20]. So, pre-

dictions about how climatic changes could affect the future distribution of these two congeneric species can contribute to decision-making regarding the conservation planning of the Tropical Mockingbird. For example, the knowledge of future scenarios can support effective decision-making about the locations to conserve viable populations of Tropical Mockingbirds.

We aimed to understand how the climatic changes predicted to occur by 2060 would affect the potential distribution of the Tropical Mockingbird and Chalk-browed Mockingbird within the Atlantic Forest domain. We used ecological niche modeling to (1) map the current distribution of Tropical Mockingbird and Chalk-browed Mockingbird, (2) understand the current distribution of Tropical Mockingbird and Chalk-browed Mockingbird under an approach that considers the climatic suitability of an area, (3) predict how the climatic changes will affect the future distribution of Tropical Mockingbird and Chalk-browed Mockingbird, and (4) discuss the model's implications for interspecies interactions and suggest conservation strategies.

2. Materials and Methods

2.1. Study Area

We used only the occurrence data for Tropical Mockingbird and Chalk-browed Mockingbird recorded in the Atlantic Forest domain. We used the layer of the Atlantic Forest from IBGE [33], which comprises the Ombrophylus Dense and Mixed Ombrophylus Forests (Araucaria Forest), Seasonal Semideciduous and Deciduous Forests, Restingas (i.e., sand-coastal plain) [34], Mangroves, and Dunes, as well as high-altitude rocky outcrop [35,36]. The Atlantic Forest domain extends along the eastern coast of Brazil from the states of Rio Grande do Norte in the northeast to Rio Grande do Sul in the south, encompassing inland areas such as Minas Gerais and São Paulo, and reaching into parts of Paraguay and Argentina. This domain originally encompassed approximately 1,300,000 km² and is currently considered one of the most threatened biodiversity hotspots worldwide [34–36].

2.2. Study Species

The Tropical Mockingbird is a medium-sized passerine (23–25 cm) with no apparent sexual dimorphism and taxonomically distinct South American populations [24]. It is omnivorous, feeding on arthropods, seeds, and fruits [23], and is considered a keystone species in the restinga ecosystem [37]. In Brazil, it occurs in coastal plains from the states of Rio Grande do Norte to Rio de Janeiro [23,24] and exhibits cooperative breeding, with helpers participating in territorial defense and parental care [38]. Its nest is cup-shaped and placed on branches up to 1.3 m above the ground [23,39], most often in *Icica* (*Protium icicariba*), although it has been recorded in 30 plant species [39]. The breeding season lasts about 6.5 months, with up to two peaks of active nests between August and March [39,40]. The mean clutch size is 2.4 eggs, and each female may make up to four nesting attempts in the same breeding season [39,41]. Predation is the main cause of nest failure (75%), with nest success ranging from 26.6% to 31% [40,41]. The species is currently considered threatened in the states of Rio de Janeiro and Espírito Santo [25,26], mainly due to restinga habitat fragmentation, urbanization, and competition with the Chalk-browed Mockingbird in overlapping areas [20,42]. With an annual survival rate of 77% and fecundity of 0.64 [41], some populations at the southern limit of its distribution are declining [41,42].

The Chalk-browed Mockingbird is widely distributed in South America, inhabiting savannas, grasslands, farmlands, and urban areas [23,24]. Its diverse omnivorous diet includes arthropods, fruits, and occasionally vertebrates, making it an important seed disperser [43]. Breeding occurs between late August and December [43,44], with cup-shaped nests built from twigs in bushes up to 1.3 m above the ground [23,44]. The mean

clutch size is 2.9 eggs, and nestlings can be parasitized by botfly larvae (*Philornis* sp.) [44]. The species rejects parasitic eggs of the Shiny Cowbird (*Molothrus bonariensis*) regardless of clutch composition [45] and may experience simultaneous co-parasitism by *Philornis* sp. and cowbirds, negatively affecting reproductive fitness [46]. The species exhibits cooperative breeding, and even communal breeding has been recorded [44].

2.3. Bird Species Data

Occurrence data of the Tropical Mockingbird and the Chalk-browed Mockingbird were compiled from georeferenced records available on online platforms, specifically Species-Link [47] and the Global Biodiversity Information Facility (GBIF) [48], and supplemented with data from the scientific literature [23,49–54]. The literature search was conducted between January and March 2021 using the Scopus, Web of Science (the core collection), and Google Scholar databases. Keywords used in the search included combinations of the species' scientific names (*Mimus gilvus antelius* and *Mimus saturninus frater*), common English names (Tropical Mockingbird and the Chalk-browed Mockingbird), and terms such as “distribution”, “geographic distributions”, “occurrence”, and “historical occurrence”. We included peer-reviewed articles, theses, and dissertations that provided occurrence data for the studied species. The resulting raw dataset was subjected to a pre-processing pipeline to ensure data quality and suitability for species distribution modeling. Recognizing the variability in sampling methods and effort among sources, we applied a series of filtering and cleaning steps, which excluded the following: (i) records with incomplete information; (ii) duplicate records, identified by identical or near-identical geographic coordinates; and (iii) low-precision records, defined as those with spatial uncertainty exceeding a predefined threshold or referring to broad, non-specific locations [55].

Occurrence data were restricted to the period from 1890 to 2017 to ensure temporal standardization and to maximize the comparability and validity of distribution models. Including more recent records—often generated using different collection methods and varying sampling efforts—could introduce biases that compromise the temporal framework. We aimed to preserve dataset homogeneity and integrity, thereby enhancing the reliability of inferences regarding changes in species distribution over time.

2.4. Climate Data

Climate variables were extracted from the WorldClim database at a spatial resolution of 2.5 arc-minutes [56]. We used the 1960–1990 baseline to model the current species distribution. Projections of future distributions were based on the 2041–2060 baseline, consistent with widely accepted climate projection intervals [8,9]. We acknowledge that the temporal range of species occurrence records (1890–2017) does not perfectly align with the climate baselines (1960–1990 for current and 2041–2060 for future scenarios), a common limitation in species distribution modeling. This reflects the historical nature of occurrence data in contrast to standardized climate datasets. Nonetheless, our approach is centered on the climatic envelope defining suitable environmental conditions, enabling the projection of species' climatic preferences onto distinct temporal climatic scenarios, including historical baselines and future projections. This framework facilitates the understanding of how known climatic requirements interact with both past and projected future climates, rather than attempting to model population dynamics over the entire historical timeframe.

Variable selection was conducted independently for each species to ensure that the chosen predictors were ecologically relevant to their specific biological requirements [23,54] and to enhance model performance. To minimize multicollinearity, only variables with a Pearson correlation coefficient (r) < 0.63 were retained for further analysis. Highly

correlated bioclimatic layers were excluded to reduce the risk of model overfitting and overparameterization [57,58].

For Tropical Mockingbird, we used isothermality (Bio 3), maximum temperature of the warmest month (Bio 5), minimum temperature of the coldest month (Bio 6), annual temperature range (Bio 7), mean temperature of the wettest quarter (Bio 8), annual precipitation (Bio 12), precipitation of the wettest month (Bio 13), precipitation of the wettest quarter (Bio 16), precipitation of the warmest quarter (Bio 18), and precipitation of the coldest quarter (Bio 19). For Chalk-browed Mockingbird, we used the annual mean diurnal temperature range (Bio 2), annual temperature range (Bio 7), mean temperature of the warmest quarter (Bio 10), precipitation of the wettest month (Bio 13), precipitation of the driest month (Bio 14), precipitation seasonality (Bio 15), and precipitation of the warmest quarter (Bio 18) [59].

The use of distinct climate variable datasets for Tropical Mockingbird and Chalk-browed Mockingbird is based on their differences in habitat use and geographic distribution [20,23,31,54]. Tropical Mockingbird is typically associated with sand-coastal plains (restinga) [22–24], suggesting a sensitivity to specific temperature extremes and precipitation patterns characteristic of these more localized habitats. In contrast, the Chalk-browed Mockingbird has a much wider distribution across varied open phytophysiognomies, including anthropogenic landscapes and savannas [23,32,54], indicating a broader ecological niche and potentially different limiting climatic factors. The adjustment of the climate variables to the biology of each species provides more accurate and robust distribution predictions. While this approach leads to distinct variable sets between species, it is ecologically justified by their divergent habitat preferences and aims to capture the unique drivers of each species.

2.5. Statistical Analysis and Modeling Work

Future climatic projections were based on the Community Climate System Model (CCSM) [1,60], aligning with the established future prediction patterns of the Intergovernmental Panel on Climate Change [1]. Two distinct future scenarios were employed: an optimistic scenario reflecting a minimum temperature increase ($1.8\text{ }^{\circ}\text{C} \pm 0.7\text{ }^{\circ}\text{C}$ -RCP 2.6) and a pessimistic scenario representing a maximum temperature increase ($3.7\text{ }^{\circ}\text{C} \pm 0.9\text{ }^{\circ}\text{C}$ -RCP 8.5) predicted for the modeled period.

Models of both species distributions were developed by relating occurrence records and climate variables using the bioclimatic envelope algorithm (BIOCLIM) in the R package *dismo* [61]. Because the BIOCLIM algorithm results in more conservative predictions [13,62–64] when predicting species' distributions when presence-only data are available, it is currently the most widely used tool to estimate future changes in species distribution [13,65,66], giving better performances concerning other algorithms [67]. The BIOCLIM algorithm has been applied to build species distribution models [68–70], mainly when used in conjunction with bioclimatic variables [68,71].

The models were fitted with 75% of the training data and 25% of the test data, with 1000 iterations. Tropical Mockingbird and Chalk-browed Mockingbird were modeled in three ways: occurrence according to the current climate; occurrence according to the future climate, with a minimum temperature increase expected by 2060 (optimistic scenario) and; occurrence according to the future climate, with a maximum temperature increase expected by 2060 (pessimistic scenario). We evaluated the models using the AUC (area under the receiver operating characteristic [ROC] curve) [72]. All models had high AUC values (>0.85) and have high rates of prediction of true presences (=low omission error).

Spatial analysis was performed using QGIS 3.2.3 [73] and the R Statistical Environmental Version 3.4.3 [74].

3. Results

We found 118 occurrence points for Tropical Mockingbird and 1080 for Chalk-browed Mockingbird within the Atlantic Forest. The current distribution of the Tropical Mockingbird spans the coastal region from Rio de Janeiro to Rio Grande do Norte (Figure 1). Our models predicted a potential expansion of suitable habitat for the Tropical Mockingbird, particularly to the west of its current distribution (Figure 2), and gains in suitability over large areas with the temperature increase predicted from the northern coast of Pernambuco to the state of Espírito Santo. Tropical Mockingbird will increase 3.5% (3871 km²) its suitable habitat compared to its current range (1960–1990 baseline) under the optimistic scenario (RCP 2.6) and also increase 2.5% (2765 km²) under the pessimistic scenario (RCP 8.5).

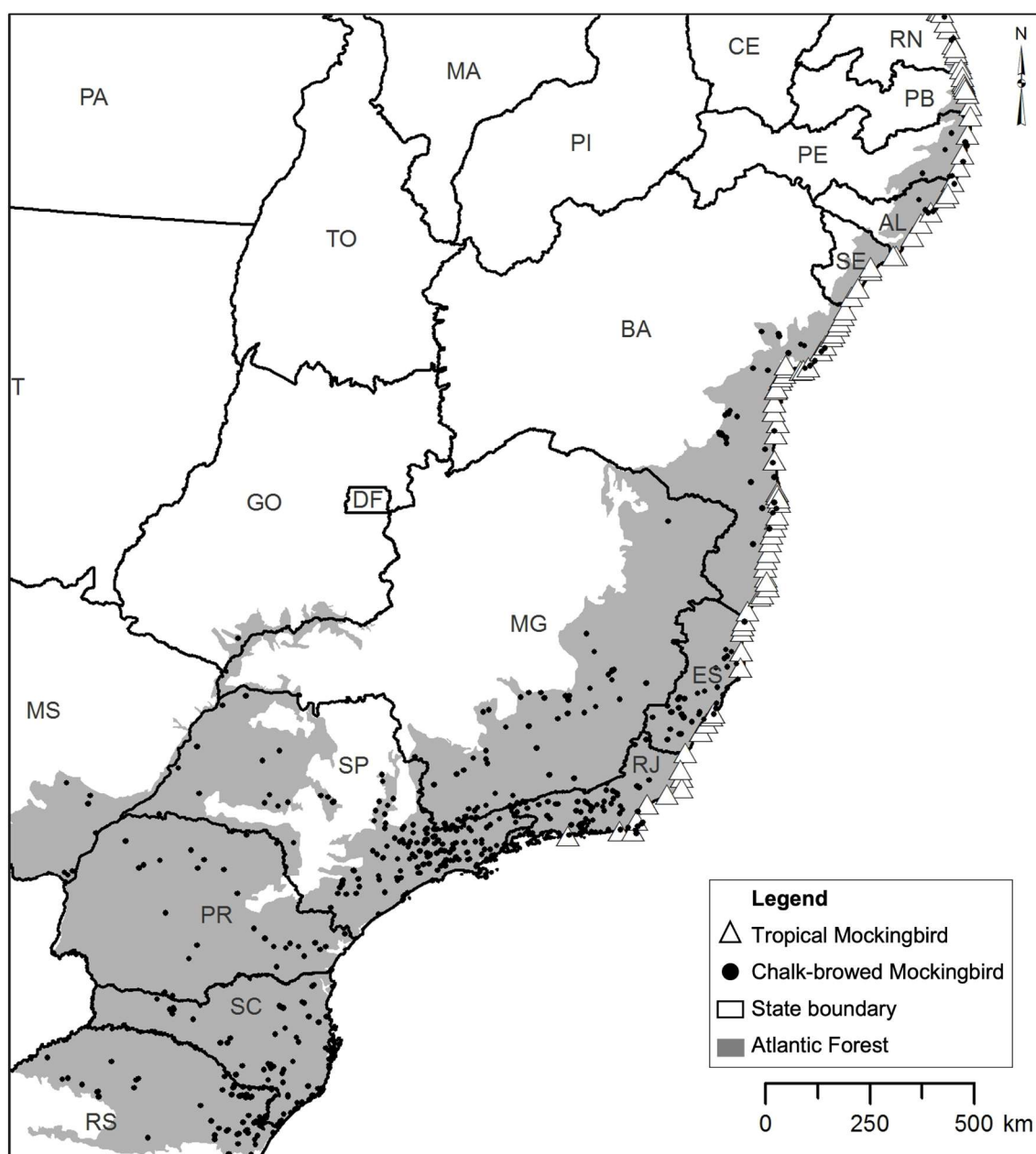


Figure 1. Distribution of records of the Tropical Mockingbird (*Mimus gilvus antelius*) and the Chalk-browed Mockingbird (*Mimus saturninus frater*) on Brazilian Atlantic Forest biome from 1890 to 2017. Each abbreviation on the map corresponds to the name of a state of Brazil. For instance, ES refers to the state of Espírito Santo and MG to the state of Minas Gerais, and so on.

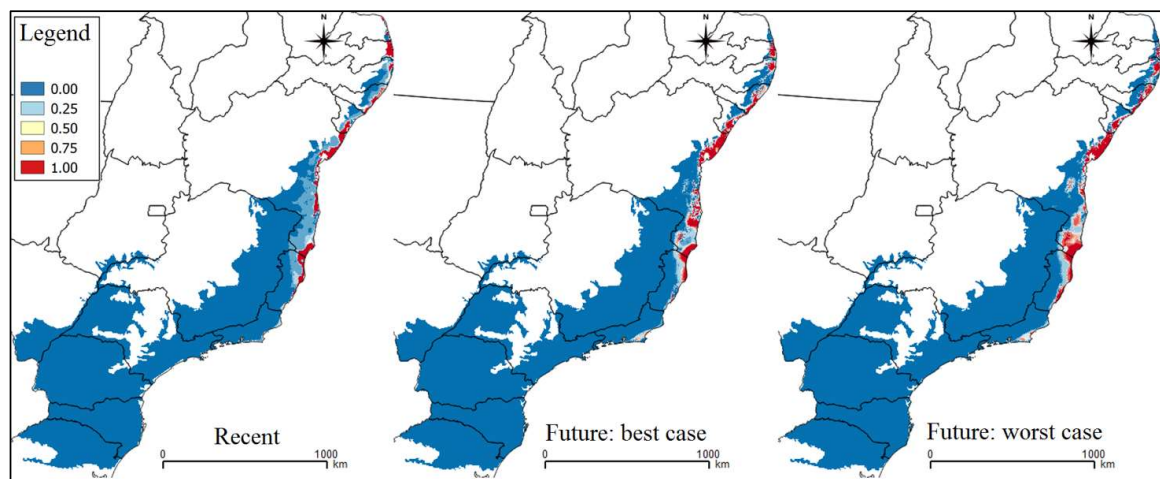


Figure 2. Maps of habitat-suitability on the Brazilian Atlantic Forest for the Tropical Mockingbird (*Mimus gilvus antelius*) in recent past time (1960–1990), and the prediction for the future (2041–2060) under the best (optimistic scenario) and the worst (pessimistic scenario) cases of expected increases in temperature. The blue color indicates the Atlantic Forest biome, and reddish indicates areas with the best habitat-suitability.

The current distribution of Chalk-browed Mockingbird extends broadly across the Atlantic Forest and is not restricted to the coast (Figure 1). Our models predicted a potential distribution with higher suitability in the central area of the Atlantic Forest in the states of Paraná and São Paulo (Figure 3). The suitability area decreased in the north of the biome, especially under the scenario of pessimistic temperature increase (maximum temperature increase, RCP 8.5) (Figure 3). Losses in suitability for Chalk-browed Mockingbird occurred in the states of Rio Grande do Sul, southern Mato Grosso do Sul, western São Paulo, western Paraná, coastal Bahia and Espírito Santo, and northern Rio de Janeiro. However, gains in suitability were also predicted, especially in São Paulo and Paraná (Figure 3). Chalk-browed Mockingbird will reduce its suitable area by 64% (70,780 km²) in the optimistic scenario and 65% (71,886 km²) in the pessimistic scenario, compared to their current suitable area.

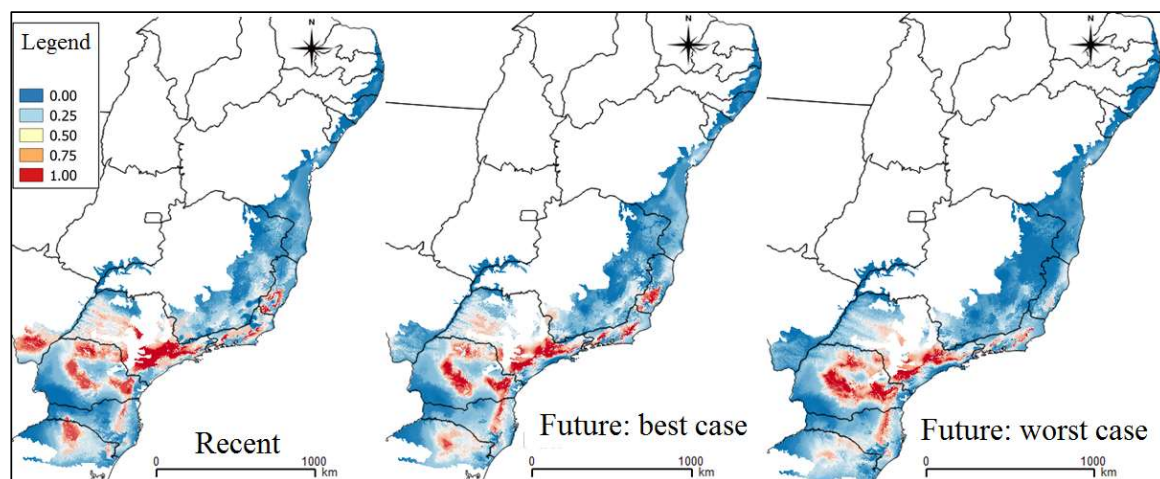


Figure 3. Maps of habitat-suitability on the Brazilian Atlantic Forest for the Chalk-browed Mockingbird (*Mimus saturninus frater*) in recent past time (1960–1990), and the prediction for the future (2041–2060) under the best (optimistic scenario) and the worst (pessimistic scenario) cases of expected increases in temperature. The blue color indicates the Atlantic Forest biome, and reddish indicates areas with the best habitat-suitability.

The Tropical Mockingbird tended to expand its distribution with increasing temperatures, whereas the Chalk-browed Mockingbird exhibited a substantial contraction within the Atlantic Forest domain. Furthermore, the two species are projected to overlap in only a few areas (Figure 4).

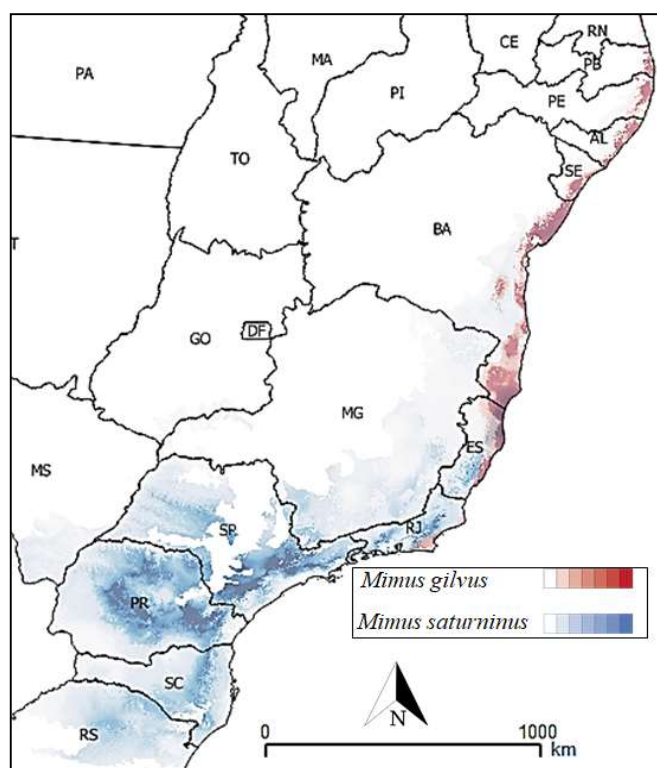


Figure 4. Map of habitat-suitability on Brazilian Atlantic Forest predicted for the Tropical Mockingbird (*Mimus gilvus antelius*) and the Chalk-browed Mockingbird (*Mimus saturninus frater*) in the future (2041–2060) under an expected maximum increase in temperature. Each abbreviation on the map corresponds to the name of a state of Brazil. For instance, ES refers to the state of Espírito Santo and MG to the state of Minas Gerais, and so on.

4. Discussion

Our models predicted different responses to ongoing climate changes for the two species. Tropical Mockingbird tended to expand distribution to the northeaster and decrease towards its southeastern distribution. On the other hand, the Chalk-browed Mockingbird tended to reduce the distribution in the northeast and concentrate its distribution in the southeast and central-south of the Atlantic Forest domain. Species-specific sensitivity to climate changes and fragmentation has been shown for different bird communities, where ecological traits such as habitat specialization and dispersal limitation have different explanatory power [9]. These findings align with a growing body of literature on avian responses to climate change across diverse biomes [75–78]. For instance, several studies have documented how boreal birds respond to warming temperatures, altered snow regimes, and shifts in prey availability, often reporting range contractions in cold-adapted species and expansions in generalist ones [66]. In addition to gradual temperature increases, extreme and abrupt weather events, such as prolonged droughts [79,80] and intense heatwaves, can severely affect avian populations by disrupting water sources, food availability, and breeding success [77,79]. These dynamics warrant greater attention in future analyses to fully capture the complexity of climate change impacts [75,78]. Our findings from the Atlantic Forest contribute to this broader understanding by illustrating how

these climatic factors drive divergent distributional patterns, highlighting the importance of incorporating broader geographic scales in conservation planning.

Our predicted distribution patterns for both species diverged from our initial hypotheses, which anticipated a reduction in suitable habitat for the Tropical Mockingbird due to its narrower distribution and an expansion for the Chalk-browed Mockingbird given its broader geographic range and recognized ecological plasticity [21–24]. This apparent contradiction may reflect more complex ecological dynamics than initially assumed. Discrepancies between expected and modeled responses are increasingly acknowledged in climate ecology, as demonstrated by recent syntheses on various avian groups, including mountain birds [81]. These studies highlight that species' responses are rarely linear or predictable, being shaped by a complex interplay of physiological tolerances, microhabitat availability, biotic interactions, and local environmental heterogeneity.

For the Tropical Mockingbird, the predicted increase in habitat suitability—particularly in northeastern and more inland regions—suggests a potential tolerance to warmer environments, such as sand-coastal plains (restinga ecosystem). This thermal tolerance may confer resilience or even a selective advantage under rising temperatures in specific areas [20]. Nonetheless, despite the overall gain in suitable areas, our models also indicated a loss of habitat suitability in the southernmost part of its range (state of Rio de Janeiro), where the species is currently listed as endangered [25]. This finding aligns with previous concerns regarding population decline in that region [42].

In contrast, the projected contraction of the Chalk-browed Mockingbird in the northern Atlantic Forest, despite its known ecological plasticity and widespread occurrence in other biomes, suggests that future climate conditions may impose unfavorable environmental constraints within this domain. Although the species adapted to anthropogenic environments [20] and thrives in savannas and disturbed areas [22,23], such adaptability may not confer universal advantages under all climate scenarios within the Atlantic Forest. It is plausible that specific combinations of climatic variables—such as altered precipitation regimes or extreme temperatures, which may not have been limiting in other habitats—could exceed the species physiological thresholds in this biome. Additionally, biotic interactions, such as interspecific competition, or unmodeled anthropogenic pressures, may further influence these projections. These results underscore the complexity and heterogeneity of species response to climate change, which are shaped by interaction between species-specific traits and local environmental conditions.

Tropical Mockingbird and Chalk-browed Mockingbird occur in sympatry across the Atlantic coast [19,20]. However, under both optimistic and pessimistic future temperature-increase, these two species are projected to exhibit an allopatric distribution, with a restricted contact zone along the coast of the state of Espírito Santo. As temperature expected to continue rising beyond 2060, a complete separation between both species is likely after that year. Therefore, the spatial distribution of Tropical Mockingbird and Chalk-browed Mockingbird will diverge in the near future due to climate change.

In general, our models predicted a gain in habitat suitability for the Tropical Mockingbird. Although we predicted an increase in the distribution of the Tropical Mockingbird to the northeast, evidenced by an increase in suitable areas inland, an increase in unsuitable habitat is predicted to its southern distribution limit (state of Rio de Janeiro), which may result in population decline. Estimations of the Tropical Mockingbird population in Rio de Janeiro predicted its population decrease of up to 46% over a 10-year period [42]. Our climate distribution model supports this prediction, which indicates a decrease in the suitability area of coastal regions such as the central-north coast of Rio de Janeiro [82] that will become climatically unsuitable as the temperature increases.

Beyond the climate effects on the distribution of the Tropical Mockingbird, factors such as fragmentation of the restinga ecosystem and urbanization of coastal regions may limit the occupation of some predicted areas as suitable habitats [20]. In the Nearctic ecozone, there is physiological evidence that the Northern Mockingbird (*Mimus polyglottos*) and the Curve-Billed Thrasher (*Toxostoma curvirostre*) are more stressed in the urban habitats [83]. Most of the predicted suitable habitat for Tropical Mockingbird is in an urbanized or semi-urbanized region, where the urbanization index tends to increase in the future. These predictions can become a problem for the Tropical Mockingbird conservation because its abundance is negatively related to urbanization index [20].

For the Chalk-browed Mockingbird, it is predicted a gain in suitability areas located in the central-southern and southern regions of the Atlantic Forest (i.e., the states of São Paulo and Paraná) and a decrease in suitable habitat in the southeastern (i.e., the states of Minas Gerais and Espírito Santo) and northeastern coastal regions. The Chalk-browed Mockingbird has shown resistance to habitat modification and sometimes has benefited from the deforestation of the Atlantic Forest [54], showing good adaptive plasticity in urban areas [20] and farmlands [22,54]. This species has a wider ecological niche, which is evidenced by its presence in many natural savannas (i.e., Cerrado, Caatinga, and Pantanal) and disturbed (i.e., grasslands, farmlands, and urban areas) environments [31,32,54].

Considering the ecological traits of the Chalk-browed Mockingbird, the fact that it is not an endangered species, and its wide distribution outside the limits of the Atlantic Forest, the decrease in its suitable habitat in the Atlantic Forest domain is not a problem for this species. The predicted allopatric distribution of these two congeneric species, with a contact zone limited to the coast of Espírito Santo under the future temperature scenario, may favor the conservation of the Tropical Mockingbird. Although direct empirical data on the intensity and mechanisms of interspecific competition between the Tropical Mockingbird and the Chalk-browed Mockingbird are scarce, current sympatry has been identified as a potential threat to the Tropical Mockingbird [20]. This threat is inferred from the geographic expansion of the Chalk-browed Mockingbird into deforested areas along the Atlantic coast, creating a novel competitive context. Competition may occur through various mechanisms, including resource competition (e.g., food and nesting site) or behavioral interference, particularly in altered environments where resources are scarce or habitat structure favors one species over the other. Therefore, a reduction in geographic overlap, although not yet confirmed by detailed field studies on direct interaction, could reduce the competitive pressure on the Tropical Mockingbird, potentially enhancing its abundance and long-term population viability. Future studies aimed at quantifying interspecific competition in sympatric zones will be essential to empirically validate this inference.

Our models indicate that the Tropical Mockingbird would have some advantages as the temperature increases. The future increase in highly suitable areas for this species may be related to its ability to survive in warmer environments, such as in sand-coastal plains. On the other hand, the decrease in suitable habitats in the southern distribution of the Tropical Mockingbird will increase the extirpation risk of its southern populations. As predicted for Neotropical savanna birds [10,11], there is also a concern that areas that will become suitable for many species in the future have not yet been protected to effectively ensure their population persistence [84]. As the Tropical Mockingbird is threatened in southeastern Brazil [25,26], this scenario further highlights the conservation importance of the restinga ecosystem as a strategy to decrease the extinction risk of the Tropical Mockingbird in its southern distribution limit [20,42].

Our results demonstrate the divergent responses of two congeneric species to projected climate changes, highlighting the potential for the restoration of allopatry in a novel ecological context. These findings underscore the urgent need for dynamic environmental

policies that are tailored to local ecological context and species-specific traits. Based on the results of this study, coupled with the recent reports for Tropical Mockingbird [20,42], we strongly advocate for the immediate creation of fully protected reserves within the restinga ecosystem. Moreover, continuous monitoring of the Tropical Mockingbird populations is essential to support adaptive conservation strategies, such as the establishment of protected areas with flexible boundaries or protection levels that can be adjusted in response to climate-induced shifts in species distribution [85]. This proactive and adaptive approach is important not only for the conservation of this endangered species but also for the development of a more resilient biodiversity management framework in the face of ongoing climate change, offering valuable insights applicable to similar contexts worldwide.

Author Contributions: Conceptualization, V.A.-L. and C.D.; methodology, V.A.-L., M.M. and C.D.; formal analysis, V.A.-L. and M.M.; data curation, V.A.-L. and R.d.S.O.; writing—original draft preparation, V.A.-L., R.B.F. and C.D.; writing—review and editing, C.D. and R.B.F.; visualization, C.D., R.d.S.O. and M.M.; supervision, C.D.; funding acquisition, V.A.-L. and C.D. All authors have read and agreed to the published version of the manuscript.

Funding: This study received support from the Concessionária Rodovia do Sol (RODOSOL) and the National Council for Scientific and Technological Development (CNPq, Process 45.6446/2014-1). The Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) funded a PhD scholarship to V.A.-L. (grant 23038.004514/2018-40). The Fundação de Amparo à Pesquisa e Inovação do Espírito Santo (FAPES) and CAPES funded post-doctoral fellowship to R.B.F. (grant 0823/2015, and 101860/2024-2), and FAPES funded a master's scholarship to R.d.S.O. (grant 8887.285553/2018-00). C.D. received a research fellowship from the Brazilian research agency, National Council for Scientific and Technological Development (CNPq) (grant number: 308997/2023-9).

Institutional Review Board Statement: The study was conducted according to the ethics committee of Universidade Vila Velha (License number 74/2009).

Data Availability Statement: Data are available by request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Stocker, T.F.; Qin, D.; Plattner, G.K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. Climate change 2013: The physical science basis. In *Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: New York, NY, USA, 2013; pp. 159–254.
2. Thomas, C.D.; Lennon, J.J. Birds extend their ranges northwards. *Nature* **1999**, *399*, 213. [[CrossRef](#)]
3. McCarty, J.P. Ecological consequences of recent climate change. *Conserv. Biol.* **2001**, *15*, 320–331. [[CrossRef](#)]
4. Diniz, M.H. Defaunação: A atual crise da biodiversidade. *Rev. Bras. Dir. Animal* **2017**, *12*, 15–52.
5. Glasser, C.M.; Gomes, A.D.C. Clima e sobreposição da distribuição de *Aedes aegypti* e *Aedes albopictus* na infestação do Estado de São Paulo. *Rev. Saúde Pú. b.* **2002**, *36*, 166–172. [[CrossRef](#)] [[PubMed](#)]
6. Frey, J.K. Response of a mammalian faunal element to climatic changes. *J. Mammal.* **1992**, *73*, 43–50. [[CrossRef](#)]
7. Hamilton, C.D.; Kovacs, K.M.; Ims, R.A.; Aars, J.; Lydersen, C. An Arctic predator-prey system in flux: Climate change impacts on coastal space use by polar bears and ringed seals. *J. Anim. Ecol.* **2017**, *86*, 1054–1064. [[CrossRef](#)]
8. López-Ramírez, S.; Chamorro, D.; Real, R.; Muñoz, A.R. Southern Europe is becoming climatically favourable for African birds: Anticipating the establishment of a new species. *Front. Zool.* **2023**, *20*, 18. [[CrossRef](#)] [[PubMed](#)]
9. Weeks, T.L.; Betts, M.G.; Pfeifer, M.; Wolf, C.; Banks-Leite, C.; Barbaro, L.; Barlow, J.; Cerezo, A.; Kennedy, C.M.; Kormann, U.G.; et al. Climate-driven variation in dispersal ability predicts responses to forest fragmentation in birds. *Nat. Ecol. Evol.* **2023**, *7*, 1079–1091. [[CrossRef](#)] [[PubMed](#)]
10. Marini, M.Â.; Barbet-Massin, M.; Lopes, L.E.; Jiguet, F. Major current and future gaps of Brazilian reserves to protect Neotropical savanna birds. *Biol. Conserv.* **2009**, *142*, 3039–3050. [[CrossRef](#)]
11. Marini, M.Â.; Barbet-Massin, M.; Lopes, L.E.; Jiguet, F. Predicted climate-driven bird distribution changes and forecasted conservation conflicts in a Neotropical savanna. *Conserv. Biol.* **2009**, *23*, 1558–1567. [[CrossRef](#)]
12. Loyola, R.D.; Lemes, P.; Faleiro, F.V.; Trindade-Filho, J.; Machado, R.B. Severe loss of suitable climatic conditions for marsupial species in Brazil: Challenges and opportunities for conservation. *PLoS ONE* **2012**, *7*, e46257. [[CrossRef](#)] [[PubMed](#)]

13. Téllez-Valdés, O.; Dávila-Aranda, P. Protected areas and climate change: A case study of the Cacti in the Tehuacán-Cuicatlán Biosphere Reserve, México. *Conserv. Biol.* **2003**, *17*, 846–853. [[CrossRef](#)]
14. Berg, M.P.; Kiers, E.T.; Driessen, G.; Van Der Heijden, M.; Kooi, B.W.; Kuenen, F.; Liefting, M.; Verhoef, H.A.; Ellers, J. Adapt or disperse: Understanding species persistence in a changing world. *Glob. Change Biol.* **2010**, *16*, 587–598. [[CrossRef](#)]
15. Merilä, J.; Hendry, A.P. Climate change, adaptation, and phenotypic plasticity: The problem and the evidence. *Evol. Appl.* **2014**, *7*, 1–14. [[CrossRef](#)] [[PubMed](#)]
16. Oliveira, H.R.; Cassemiro, F.A. Potenciais efeitos das mudanças climáticas futuras sobre a distribuição de um anuro da Caatinga *Rhinella granulosa* (Anura, Bufonidae). *Iheringia Sér. Zool.* **2013**, *103*, 272–279. [[CrossRef](#)]
17. Peh, K.S. Potential effects of climate change on elevational distributions of tropical birds in Southeast Asia. *Condor* **2007**, *109*, 437–441. [[CrossRef](#)]
18. La Sorte, F.A.; Jetz, W. Avian distributions under climate change: Towards improved projections. *J. Exp. Biol.* **2010**, *213*, 862–869. [[CrossRef](#)] [[PubMed](#)]
19. De Kort, S.R.; Den Hartog, P.M.; Ten-Cate, C. Diverge or merge? The effect of sympatric occurrence on the territorial vocalizations of the vinaceous dove *Streptopelia vinacea* and the ring-necked dove *S. capicola*. *J. Avian Biol.* **2002**, *33*, 150–158. [[CrossRef](#)]
20. Araujo-Lima, V.; Ferreira, R.B.; Oliveira, R.S.; Ferreira-Santos, K.; Garbin, M.L.; Duca, C. Spatial segregation between the native Tropical mockingbird and the invader Chalk-browed mockingbird along a Neotropical natural-urban gradient. *Zoologia* **2023**, *40*, e22061. [[CrossRef](#)]
21. Cody, M. Family Mimidae (Mockinbird and Thrashers). In *Handbook of the Birds of the World: Cuckoos-Shrikes to Thrashers*; del Hoyo, J.D., Elliot, A., Christie, A.D., Eds.; Lynx Editions: Barcelona, Spain, 2005; Volume 10, pp. 448–495.
22. Argel-de-Oliveira, M.M. A Família Mimidae. *Boletim CEO* **1994**, *10*, 3–15.
23. Sick, H. *Ornitologia Brasileira*; Editora Nova Fronteira: Rio de Janeiro, Brazil, 1997; p. 912.
24. Ridgely, R.S.; Tudor, G. *Birds of South America—Passerines*; Christopher Helm Publishers Ltd.: London, UK, 2009; p. 750.
25. Alves, M.A.S.; Pacheco, J.F.; Gonzaga, L.A.P.; Cavalcanti, R.B.; Raposo, M.; Yamashita, C.; Maciel, N.C.; Castanheira, M. Aves. In *A Fauna Ameaçada de Extinção do Estado do Rio de Janeiro*; Bergallo, H.G., Rocha, C.F.D., Alves, M.A.S., Van-Sluis, M., Eds.; Editora UERJ: Rio de Janeiro, Brazil, 2000; pp. 113–124.
26. Chaves, F.G.; Duca, C.; Pinto, G.O.; Rosa, G.A.B.; Magnago, G.R.; Daros-Filho, H.J.; Passamani, J.A.; Silva, J.N.; Silva, J.P.; Bissoli, L.B.; et al. Aves ameaçadas de extinção no estado do Espírito Santo. In *Fauna e Flora Ameaçada de Extinção no Estado do Espírito Santo*; Fraga, C.N., Formigoni, H., Chaves, F.G., Eds.; Instituto Nacional da Mata Atlântica: Santa Teresa, Brazil, 2019; pp. 295–313.
27. Rhymer, J.M.; Simberloff, D. Extinction by hybridization and introgression. *Ann. Rev. Ecol. Syst.* **1996**, *27*, 83–109. [[CrossRef](#)]
28. Jetz, W.; Wilcove, D.S.; Dobson, A.P. Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biol.* **2007**, *5*, e157. [[CrossRef](#)]
29. Gonzaga, L.P.; Castiglioni, G.D.A.; Reis, H.B.R. Avifauna das restingas do Sudeste: Estado do conhecimento e potencial para futuros estudos. In *Ecologia de Restingas e Lagoas Costeiras*; Esteves, F.A., Lacerda, L.D., Eds.; Computer & Publish Editoração Gráfica, Núcleo de Pesquisas Ecológicas de Macaé (NUPEM/UFRJ): Rio de Janeiro, Brazil, 2000; Volume 1, pp. 151–163.
30. Reis, H.B.R.; Gonzaga, L.P. Análise da distribuição geográfica das aves das restingas do Estado do Rio de Janeiro. In *Ecologia de Restingas e Lagoas Costeiras*; Esteves, F.A., Lacerda, L.D., Eds.; Computer & Publish Editoração Gráfica; Núcleo de Pesquisas Ecológicas de Macaé (NUPEM/UFRJ): Rio de Janeiro, Brazil, 2000; Volume 1, pp. 165–178.
31. Leveau, L.M.; Leveau, C.M. Comunidades de ave en un gradient urbano de la Ciudad de Mar del Plata, Argentina. *Hornero* **2004**, *19*, 13–21. [[CrossRef](#)]
32. Argel-de-Oliveira, M.M.; Pacheco, J.F. Um resumo da situação: *Mimus saturninus* e *M. gilvus* no litoral sudeste brasileiro. *Bol. FBCN* **1998**, *25*, 53–69.
33. IBGE-Instituto Brasileiro de Geografia e Estatística. *Mapa de Vegetação do Brasil*; IBGE: Brasília, Brazil, 1988.
34. Pereira, O.J. Restinga: Origem, estrutura e diversidade. In *Desafios da Botânica Brasileira no Novo Milênio: Inventário, Sistematização e Conservação da Diversidade Vegetal*; Jardim, M.A.G., Bastos, N.N.C., Santos, J.U.M., Eds.; Embrapa, Museu Paraense Emílio Goeldi, UFRA: Belém, Brazil, 2003; pp. 177–179.
35. Oliveira-Filho, A.T.; Fontes, M.A.L. Patterns of floristic differentiation among Atlantic Forests in Southeastern Brazil and the influence of climate 1. *Biotropica* **2000**, *32*, 793–810. [[CrossRef](#)]
36. Mantovani, W. Delimitação do bioma Mata Atlântica: Implicações legais e conservacionistas. In *Ecossistemas Brasileiros: Manejo e Conservação*, 1st ed.; Expressão Gráfica e Editora: Fortaleza, Brazil, 2003; pp. 287–295.
37. Gomes, V.S.M.; Loiselle, B.A.; Alves, M.A.S. Birds foraging for fruits and insects in shrubby resting vegetation, southeastern Brazil. *Biota Neotrop.* **2008**, *7*, 21–31. [[CrossRef](#)]
38. Morton, E.S.; Stutchbury, B.J.M.; Piper, W.H. Cooperative breeding in the Tropical Mockingbird (*Mimus gilvus*) in the Panama canal zone. *Ornitol. Neotrop.* **2004**, *15*, 417–421.
39. Moraes, R.; Araújo, L.C.; Silva, G.R.; Duca, C. Multiple nesting attempts and long breeding seasons of *Mimus gilvus* (Aves: Mimidae) in southeastern Brazil. *Zoologia* **2019**, *36*, e25717. [[CrossRef](#)]

40. Oliveira, D.V.; Pichorim, M. Breeding biology of the tropical mockingbird *Mimus gilvus* (Aves: Mimidae) in northeastern Brazil. *Ornithol. Res.* **2024**, *32*, 179–189. [\[CrossRef\]](#)
41. Araujo, L.C. Conservação do Sabiá-da-Praia *Mimus gilvus* (Aves: Mimidae) em uma Reserva de Restinga na Região Sudeste do Brasil. Ph.D. Thesis, Universidade Vila Velha, Vila Velha, ES, Brazil, 2016.
42. Zanon, M.S.; Valeand, M.M.; Alves, M.A.S. Missing for the last twenty years: The case of the southernmost populations of the Tropical mokingbird *Mimus gilvus* (Passeriformes: Mimidae). *Zoologia* **2015**, *32*, 1–8. [\[CrossRef\]](#)
43. Argel-de-Oliveira, M.M. Eco-Etologia do Sabiá-do-Campo *Mimus saturninus* (Lichtenstein, 1823) (Passeriformes, Mimidae) no Estado de São Paulo. Master's Thesis, Universidade Estadual de Campinas, Campinas, SP, Brazil, 1989.
44. Rodrigues, S.S.; Lopes, L.E.; Marini, M.Â. Breeding biology of Chalk-browed Mockingbird *Mimus saturninus* in a natural savanna of central Brazil. *Rev. Brasil. Ornith.* **2017**, *25*, 237–244. [\[CrossRef\]](#)
45. de la Colina, M.A.; Pompilio, L.; Hauber, M.E.; Reboreda, J.C.; Mahler, B. Parasitic egg rejection decisions of chalk-browed mockingbirds *Mimus saturninus* are independent of clutch composition. *Anim. Cogn.* **2018**, *21*, 301–309. [\[CrossRef\]](#) [\[PubMed\]](#)
46. Herman, J.M.; Fiorini, V.D.; Crudele, I.; Reboreda, J.C.; Pladas, S.A.; Watson, A.P.; Bush, S.E.; Clayton, D.H. Co-parasitism in the face of predation: Effects of natural enemies on a neotropical mockingbird. *J. Anim. Ecol.* **2023**, *92*, 1992–2004. [\[CrossRef\]](#) [\[PubMed\]](#)
47. CRIA (Centro de Referência e Informação Ambiental). Available online: <http://splink.cria.org.br> (accessed on 31 July 2018).
48. GBIF Occurrence Download. Available online: <http://doi.org/10.15468/dl.ackhc2> (accessed on 12 February 2018).
49. Chapman, F.M. A List of Birds Observed at Santarem, Brazil. *Auk* **1890**, *7*, 131–137. [\[CrossRef\]](#)
50. Hellmayr, C.E. An account of the birds collected by Mons. G.A. Baer in the state of Goyaz, Brazil. *Novit. Zool.* **1908**, *15*, 13–102.
51. Rogers, S. *CM Birds Collection, Version 9.1*; Carnegie Museums: Pittsburgh, PA, USA, 1926.
52. Smyth, C.H. Descripción de una colección de huevos de aves argentinas. *Hornero* **1928**, *4*, 125–152. [\[CrossRef\]](#)
53. Cicero, C. *MVZ Bird Collection (Arctos), Version 43.9*; Museum of Vertebrate Zoology: Berkeley, CA, USA, 1930.
54. Ridgely, R.S.; Tudor, G. *The Birds of South America: The Oscine Passerines*; University of Texas Press: Austin, TX, USA, 1989; Volume 1, p. 516.
55. Mageski, M.M.; Varela, S.; Roper, J.J. Consequences of dispersal limitation and habitat fragmentation for the Brazilian heart-tongued frogs (*Phyllodytes* spp.). *Austral Ecol.* **2018**, *43*, 547–557. [\[CrossRef\]](#)
56. Hijmans, R.J.; Cameron, S.; Parra, J.; Jones, P.G.; Jarvis, A.; Richardson, K. *WorldClim, Version 1.3*; University of California: Berkeley, CA, USA, 2005.
57. Martínez-Gutiérrez, P.G.; Martínez-Meyer, E.; Palomares, F.; Fernández, N. Niche centrality and human influence predict rangewide variation in population abundance of a widespread mammal: The collared peccary (*Pecari tajacu*). *Divers. Distrib.* **2018**, *24*, 103–115. [\[CrossRef\]](#)
58. Wright, A.N.; Hijmans, R.J.; Schwartz, M.W.; Shaffer, H.B. Multiple sources of uncertainty affect metrics for ranking conservation risk under climate change. *Divers. Distrib.* **2015**, *21*, 111–122. [\[CrossRef\]](#)
59. O'Donnel, M.S.; Ignizio, D.A. Bioclimatic predictors for supporting ecological applications in the conterminous United States. *US Geol. Surv. Data Ser.* **2012**, *691*, 10.
60. Ornelas, J.F.; Licona-Vera, Y.; Ortiz-Rodriguez, A.E. Contrasting responses of generalized/specialized mistletoe-host interactions under climate change. *Écoscience* **2018**, *25*, 223–234. [\[CrossRef\]](#)
61. Hijmans, R.J.; Phillips, S.J.; Leathwick, J.R.; Elith, J. *Dismo: Species Distribution Modeling*, R package version 1.0-15; 2016. Available online: <https://CRAN.R-project.org/package=dismo> (accessed on 12 February 2018).
62. Booth, T.H. Why understanding the pioneering and continuing contributions of BIOCLIM to species distribution modelling is important. *Austral Ecol.* **2018**, *43*, 852–860. [\[CrossRef\]](#)
63. Williams, S.E.; Bolitho, E.E.; Fox, S. Climate change in Australian tropical rainforests: An impending environmental catastrophe. *Proc. R. Soc. Lond. Ser. B Biol. Sci.* **2003**, *270*, 1887–1892. [\[CrossRef\]](#) [\[PubMed\]](#)
64. Thomas, C.D.; Cameron, A.; Green, R.E.; Bakkenes, M.; Beaumont, L.J.; Collingham, Y.C.; Erasmus, B.F.N.; Siqueira, M.F.; Grainger, A.; Hannah, L.; et al. Extinction risk from climate change. *Nature* **2004**, *427*, 145–148. [\[CrossRef\]](#) [\[PubMed\]](#)
65. Beaumont, L.J.; Hughes, L.; Poulsen, M. Predicting species distributions: Use of climatic parameters in BIOCLIM and its impact on predictions of species' current and future distributions. *Ecol. Model.* **2005**, *186*, 251–270. [\[CrossRef\]](#)
66. Palhano, S.; Raposo, M.A.; Cordeiro, P.H.; Weksler, M. Genealogical and niche modeling analyses reveal recent expansion and limited genetic divergence in the *Formicivora serrana* complex (Passeriformes: Thamnophilidae). *J. Ornithol.* **2018**, *159*, 79–92. [\[CrossRef\]](#)
67. Vale, M.M.; Souza, T.V.; Alves, M.A.S.; Crouzeilles, R. Planning protected areas network that are relevant today and under future climate change is possible: The case of Atlantic Forest endemic birds. *PeerJ* **2018**, *6*, e4689. [\[CrossRef\]](#) [\[PubMed\]](#)
68. Kindt, R. Ensemble species distribution modelling with transformed suitability values. *Environ. Modell. Softw.* **2018**, *100*, 136–145. [\[CrossRef\]](#)

69. Giliba, R.A.; Yengoh, G.T. Predicting suitable habitats of the African cherry (*Prunus africana*) under climate change in Tanzania. *Atmosphere* **2020**, *11*, 988. [\[CrossRef\]](#)
70. Esperon-Rodriguez, M.; Tjoelker, M.G.; Lenoir, J.; Baumgartner, J.B.; Beaumont, L.J.; Nipperess, D.A.; Power, S.A.; Richard, B.; Rymmer, P.F.; Gallagher, R.V. Climate change increases global risk to urban forests. *Nat. Clim. Change* **2022**, *12*, 950–955. [\[CrossRef\]](#)
71. Booth, T.H. Species distribution modelling tools and databases to assist managing forests under climate change. *Forest Ecol. Manag.* **2018**, *430*, 196–203. [\[CrossRef\]](#)
72. Liu, C.; Berry, P.M.; Dawson, T.P.; Pearson, R.G. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography* **2005**, *28*, 385–393. [\[CrossRef\]](#)
73. QGIS 3.2.3 Development Team. *QGIS Geographic Information System, Version 3.2.3*; Open-Source Geospatial Foundation: Beaverton, OR, USA, 2009.
74. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2017.
75. Ding, C.; Newbold, T.; Ameca, E.I. Assessing the global vulnerability of dryland birds to heatwaves. *Glob. Change Biol.* **2024**, *30*, e17136. [\[CrossRef\]](#)
76. Hällfors, M.H.; Heikkinen, R.K.; Kuussaari, M.; Lehikoinen, A.; Luoto, M.; Pöyry, J.; Virkkala, R.; Saastamoinen, M.; Kujala, H. Recent range shifts of moths, butterflies, and birds are driven by the breadth of their climatic niche. *Evol. Lett.* **2024**, *8*, 89–100. [\[CrossRef\]](#) [\[PubMed\]](#)
77. Naeem, M. Understanding the effect of climate change on migratory birds: A review. *Int. J. Zool. Animal Biol.* **2024**, *7*, e000560. [\[CrossRef\]](#)
78. Naves-Alegre, L.; García-Mayoral, H.; Morant, J.; Pérez-García, J.M.; Dias, A.; Cano-Montes, E.; Sánchez, A.; García-Matarranz, V. Differential flight responses of sympatric raptor species to weather conditions and extreme temperature events. *Ecol. Evol.* **2025**, *15*, e70658. [\[CrossRef\]](#) [\[PubMed\]](#)
79. Duca, C.; Yokomizo, H.; Marini, M.Â.; Possingham, H.P. Cost-efficient conservation for the White-banded Tanager (*Neothraupis fasciata*) in the Cerrado, central Brazil. *Biol. Conserv.* **2009**, *142*, 563–574. [\[CrossRef\]](#)
80. Duca, C.; Mairni, M.Â. Variation in breeding of the Shrike-like Tanager in central Brazil. *Wilson J. Ornithol.* **2011**, *123*, 259–265. [\[CrossRef\]](#)
81. Chamberlain, D.; Lehikoinen, A.; Scridel, D.; Martin, K. Mountain birds and their habitats. In *Ecology and Conservation of Mountain Birds*; Chamberlain, D., Lehikoinen, A., Martin, K., Eds.; Cambridge University Press: Cambridge, UK, 2023; pp. 1–34.
82. Bencke, G.A.; Maurício, G.N.; Develey, P.F.; Goerck, J.M. *Áreas Importantes para a Conservação das Aves no Brasil, Parte I—Estados do Domínio da Mata Atlântica*; SAVE Brasil: São Paulo, SP, Brazil, 2006.
83. Fokidis, H.B.; Greiner, E.C.; Deviche, P. Interspecific variation in avian blood parasites and haematology associated with urbanization in a desert habitat. *J. Avian Biol.* **2008**, *39*, 300–310. [\[CrossRef\]](#)
84. Hannah, L. Protected areas and climate change. *Ann. N. Y. Acad. Sci.* **2008**, *1134*, 201–212. [\[CrossRef\]](#) [\[PubMed\]](#)
85. Pressey, R.L.; Cabeza, M.; Watts, M.E.; Cowling, R.M.; Wilson, K.A. Conservation planning in a changing world. *Trends Ecol. Evol.* **2007**, *22*, 583–592. [\[CrossRef\]](#) [\[PubMed\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.