An Acad Bras Cienc (2023) 95(2): e20210519 DOI 10.1590/0001-3765202320210519
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ECOSYSTEMS

Threats from climate change for lizard species of a Neotropical mountain range

SAMUEL C. GOMIDES, JOÃO CARLOS PIRES-OLIVEIRA & TALITA M. MACHADO

Abstract: Climate change is one of the greatest threats to biodiversity, especially for species of high altitudes. However, biodiversity conservation policies that consider mitigation strategies for long-term climate impacts are still scarce. To analyze the effects of climate change on lizards in tropical mountainous areas, we selected two species from Serra do Espinhaço (Brazil) with different thermoregulation strategies and distributions (*Tropidurus montanus* and *Rhachisaurus brachylepis*). Serra do Espinhaço mountain range is recognized as an important center of endemism and can act as a refuge for species that manage to survive climate change. We produce models of environmental suitability from bioclimatic, edaphic, and topographic variables, and create projections for the present and for the year 2070 under an optimistic (RCP 4.5) and a pessimistic (RCP 8.5) climatic scenario. The results indicate that both future climate scenarios foresee a reduction of areas of environmental suitability for the studied species, but especially for the restricted distribution one (*R. brachylepis*). Although our results indicate that the studied species are recorded in areas of integral protection that possess climatic stability, the future will see a reduction of areas with environmental suitability, especially under the pessimistic scenario.

Key words: Environment suitability, modelling species distribution, protected areas, *Rhachisaurus brachylepis,* Squamata, *Tropidurus montanus*.

INTRODUCTION

Climate change is one of the greatest threats to biodiversity for the next century and is likely to cause a substantial loss of extant species (Warren et al. 2018, Román-Palacios & Wiens 2020). However, environmental policies for biodiversity conservation still lack clear and objective mitigation strategies and goals for long-term climate impacts. The conservation of a species requires predicting present and future threats, considering its natural history, biology, and geographic distribution (Caldas 2014, Pontes-da-Silva et al. 2018). The adaptive capacity of a species to adjust to climate change depends on its specific biology (e.g., genetic or phenotypic variability and its ability to disperse), in addition to other factors that will interfere with the survival of the species, such as those linked to anthropogenic pressures (e.g., overexploitation and habitat fragmentation) (Caldas 2014). It is essential to understand how these mechanisms act in fragile environments, such as regions of high altitudes and with high endemism of species, as is the case of mountain ranges (Raxworthy et al. 2008, Bitencourt et al. 2016).

Species from mountainous areas in tropical regions are vulnerable to climate change (Raxworthy et al. 2008, Bitencourt et al. 2016). These high areas have milder temperatures than the low areas around them (Raxworthy et al. 2008). Thus, the deforestation of low areas can affect organisms in higher areas since the vegetation that provides humidity to compose banks of orographic clouds that act in maintaining the temperature of adjacent high areas is no longer present (Nair et al. 2003). One of the expected responses to increased global temperature is the movement of organisms to higher altitudes to compensate for warming in lower areas (Raxworthy et al. 2008, Perrigo et al. 2020). Additionally, montane species of cold-associated habitats are shifting upslope in response to recent temperature increases to track their optimal climate, and these changes in local biotic interactions can lead to species extinction (Freeman et al. 2018). Finally, endemic species restricted to areas of high altitudes are proportionally more sensitive to climate change and more likely to go extinct first (Parmesan 2006, Raxworthy et al. 2008).

Serra do Espinhaço (SdE) is a set of elevated areas in eastern Brazil, with altitudes that can reach more than 2000 m that extends for more than 1000 km from the center of the state of Minas Gerais to the central portion of the state of Bahia (Miola et al. 2020). The natural environments of SdE are likely to be strongly impacted by predicted climate change and may experience a reduction of about 50% of their original area (Bitencourt et al. 2016). For instance, there are predictions of gradual reduction and displacement of suitable areas for endemic birds, and altitudinal change in richness pattern in this region (Hoffmann et al. 2020). In addition to climate change, one of the concerns regarding the conservation of this environment is the consequences of mining on the vertebrate fauna, which can lead to the extinction of several species endemic to these high areas (Pena et al. 2017). Considering that mountainous areas are more susceptible to the effects of climate change, lizards would be a good model to evaluate the impact of this phenomenon because they are ectothermic, their thermal ecology is relatively well studied, and the negative effects of climate change on the group are already known (Huey et al. 2009, 2012, Sinervo et al. 2010, Pontes-da-Silva et al. 2018). Tropical species are vulnerable to climate change, but data are still lacking about how this phenomenon affects most of them (see Sinervo et al. 2010, Huey et al. 2012).

It is important to understand how organisms that are directly affected by environmental temperature and are geographically related to tropical mountain environments can be affected by climate change. In this way, we can guide future actions to deal with the expected climate challenges for the next decade. Therefore, we investigated two species of lizards with different strategies for regulating body temperature. Cryptozoic and secretive species, like many gymnophthalmids, tend to have lower body temperatures that vary depending on the occupied environment due to the infrequency of emerging from the leaf litter or shelter to thermoregulate (Huey et al. 2009). In contrast, heliophilous lizard species (such as tropidurids) use open areas and generally have more active thermoregulation behaviors and higher body temperatures (Huey et al. 2009).

Thus, to analyze the effects of climate change on lizards in tropical mountainous areas, we selected two species of SdE that have different thermoregulation strategies and distributions. The first species, *Rhachisaurus brachylepis* (Dixon, 1974), belongs to the family Gymnophthalmidae and lives among rocks and leaf litter. It has a low local abundance and few occurrence records (Gomides et al. 2020). According to data on its biology, and for closely evolving species, we can infer that it is a thermoconformer, meaning that its body temperature varies according to the temperature of the environment (Goicoechea et al. 2016, Gomides et al. 2020). The second species selected, *Tropidurus montanus* (Rodrigues 1987), belongs to the family Tropiduridae and has many occurrence records throughout SdE. This thermoregulator species actively exposes itself to the sun and has abundant local populations (Filogonio et al. 2010, Carvalho 2013). Essentially, *R. brachylepis* and *T. montanus* have opposite thermoregulation strategies.

Rhachisaurus brachylepis and *T. montanus* usually occur in the same habitat, known as campo rupestre, a mosaic of grassy–shrubby vegetation in mountainous areas with soil poor in nutrients but with high species endemism (see Miola et al. 2020). Conservation policies must take climate change into account to ensure the future of species of unique environments, such as campo rupestre, in the Neotropical mountains (Bitencourt et al. 2016, Miola et al. 2020). Thus, the objectives of this study were to: (1) assess the vulnerability of the studied species to extinction considering the effects of climate change under different projected future scenarios (2070); (2) to identify areas of climatic stability that favor the long-term conservation of these species; and (3) assess whether there are Environmental Suitability Areas (ESAs) that can direct research to find new populations of these species. We hypothesize that both species will suffer negative impacts - such as a reduction in ESA - in the face of climate change, but the cryptozoic species with a restricted geographic distribution, and specific habitat requirements (*R. brachylepis*) (Gomides et al. 2020) will be proportionally more impacted because of the dependence on the specific characteristics of the microhabitat where it occurs.

MATERIALS AND METHODS

Study area and species occurrence data

Much of the distribution of the two studied species covers campos rupestres of SdE. Campos rupestres occur mainly on quartzitic rock outcrops at altitudes above 900 m, characterized by shallow, ancient, and oligotrophic soil of poor fertility (Silveira et al. 2016). Although campos rupestres are naturally isolated and fragmented sky islands (Miola et al. 2020), we used the Neotropics as a study area in order to detect if there are ESAs beyond the areas where species currently have geographic records. The same area was used to train and project the models. The models were projected only over two different time intervals (present and future). No projections have been created for another area in geographic space.

All data on the distribution of the studied species were obtained through specific literature, biological collections, and from Species Link and GBIF (Appendix 1) online databases. Only data that had no doubts as to its accuracy and taxonomic determination were considered. We checked the reliability of occurrence records and chose those belonging to samples inserted in scientific collections and identified by specialists.

Environmental variables

We used 19 bioclimatic variables extracted from CHELSA, as the species in this study are associated with mountainous areas and the use of this dataset better represents the variables in high areas (Karger et al. 2017). The distribution of many species may be influenced by soil conditions, so models based only on climatic data may overestimate future areas of suitability (Zuquim et al. 2020). Thus, we also included six soil variables (*BulkDensity, Clay, Coarse, Sand, Silt, BDRICM*) taken from soil grids (https://soilgrids.org/), and three topographic variables: *Elevation* from NASA Shuttle Radar Topographic Mission (SRTM) (http://srtm.csi.cgiar.org/); and *Slope* and *Aspect*, which were obtained from *Elevation*, using the “terrain” function of the "raster" package (Hijmans & van Etten 2012). All variables were dimensioned to represent the Neotropics at a spatial resolution of 0.083° x 0.083° (~10 km).

To assess whether predicted climate change will impact the distribution of the studied species, we used the CHELSA bioclimatic variables projected for the year 2070 and selected two scenarios of Representative Concentration Pathway (RCP) CO_2 emissions for purposes of comparison considering RCP 8.5 as a pessimistic scenario and RCP 4.5 as an optimistic scenario (Riahi et al. 2011). To avoid using redundant information, we selected the least intercorrelated global circulation models (GCMs): CanESM2, CSIRO-Mk3-6-0, and IPSL-CM5A-LR. The selection was made through Principal Coordinate Analysis (PCoA), where the axes were used as descriptors in a UPGMA. Thus, we selected the least similar GCMs from the generated groups to avoid the inclusion of redundant information in the creation of future projections (J.C. Pires-Oliveira, unpublished data, Gomides et al. 2021).

To avoid collinearity among predictor variables, we summarized the 19 bioclimatic variables through a principal component analysis (PCA) (Dormann et al. 2013), of which the first six axes were selected, representing ~ 96% of the variance. We used the "PCAProjection" function in the *ENMGadgets* package (https://github.com/narayanibarve/ENMGadgets) to generate the axes of the PCA for the present and to create projections of the axes in the variables of the future, maintaining the proportion of the variance and the importance of each variable in the present and future axes (Zwiener et al. 2018). The nine edaphic and topographic variables were also summarized in PCA axes. The first two axes were selected using the *Broken-Stick* criterion, as they explained the variation better than the null model produced.

Environmental suitability modeling (ESM)

Eight algorithms from the package *biomod2* were used in the ESM of each species (Thuiller et al. 2016): Multiple Adaptive Regression Splines (MARS), Flexible Discriminant Analysis (FDA), Generalized Linear Model (GLM), Generalized Additive Model (GAM), Classification tree Analysis (CTA), Random Forest (RF), Artificial Neural Network (ANN) and Maximum Entropy (MAXENT).

We adopted two strategies in the construction of the models according to the number of spatially unique points available for each species. For *T. montanus* we used the conventional modeling described by Pires-Oliveira et al. (2019). In this approach, 70% of the points are used to train the models, and 30% are used to test the built models. In addition, we used True Skill Statistics (TSS) to assess the performance of the built models (Allouche et al. 2006), and only the models with TSS values above 0.4 were selected for the present and future projections (Zhang et al. 2015). For *R. brachylepis*, which has less than 25 points, we use an approach known as jackknife or leave-one-out (Pearson et al. 2007). Model validation was performed by calculating the p-value with a significance level of 5% (see Pearson et al. 2007) using the "compute p-value" function in R environment version 3.5.3 (R Core Team 2019). Only the models that were able to predict the occurrence of the deleted record were used for the projection of future scenarios.

For each algorithm in conventional modeling, we applied five runs, and the sets of pseudo-absences were defined using the *disk* approach from the biomod2 package of the R environment (Thuiller et al. 2016). This approach to selecting pseudo-absences consists of generating a buffer around each point of presence and establishing maximum and minimum circular limits, within which pseudo-absences will be sampled. For each species, the buffer's internal limit is selected as the minimum distance in kilometers between all occurrence records. The external boundary of the buffer is set to the average distance in kilometers between all occurrence records. The same number of presences was used to define the number of pseudo-absences for the CTA, GBM, and RF algorithms. For the other algorithms, we used 10,000 pseudo-absences as indicated by Barbet-Massin et al. (2012). In modeling with less than 25 occurrence records, we performed one run each time we remove one of the occurrence points.

We combined all projections produced from all models to build consensus maps for the present and future for each species and within each climatic scenario. Finally, we transformed consensus maps into binary maps (i.e., presence-absence) through the threshold that maximizes sensitivity and specificity (maxSpecSens).

We performed a MOP analysis to identify excesses of extrapolation in the environmental variables following Owens et al. (2013). We did this analysis using the “kuenm_mop” function from the kuenm package from the R environment (Cobos et al. 2019). Finally, we performed an uncertainty analysis to verify the regions where the uncertainty components (time, RCP, GCM, and methods) are more adapted. To perform the analysis of uncertainty we follow Diniz-Filho et al. (2009).

Conservation

To assess the protection of the studied species in the face of climate change, we overlaid the maps generated by the present and 2070 models for all scenarios with the shapes of federal and state protected areas of restricted use provided by Ministério do Meio Ambiente do Brasil (http://mapas.mma.gov.br/i3geo/datadownload.htm?_ga=2.5380848.2131302673.1606425745-1722719745.1601323127). We establish the areas of interest for the conservation of these species by superimposing the geographical occurrence records with areas of climate suitability for the present and different future scenarios. The consensus of these areas indicates priority areas for conservation and indicates areas with potential for species conservation, but which are currently not protected.

RESULTS

We obtained 17 spatially unique occurrence points for *R. brachylepis* and 157 for *T. montanus*. The models generated for *R. brachylepsis* using the jackknife approach showed good performance (p <0.0001), as did the models generated for *T. montanus* (TSS> 0.4), indicating that our models were statistically significant, with better performance than by chance.

MOP analysis has not revealed severe inconsistencies between the present and future variables for the RCP-4.5 scenario on the largest partition of the study area. For the RCP-8.5 scenario, there was a large region with greater inconsistency, but this inconsistency did not occur over the known geographical distribution of the two species addressed here (Supplementary Material - Figure S1).

Current environmental suitability models

The final map based on the consensus of all the models generated in our analysis indicated an ESA (Environmental Suitability Area) for *R. brachylepsis* of 46,888 km^2 (Fig. 1, Table I), with 19.08% of this area being within protected areas. The current models indicated ESAs outside the region that currently houses the known records of the species (Fig. 1b). These ESAs are elevated regions such as Chapada dos Veadeiros in the state of Goiás and Serra da Canastra in the state of Minas Gerais. Although the occurrence of *R. brachylepsis* is registered only within the Parque Nacional da Serra do Cipó, current models

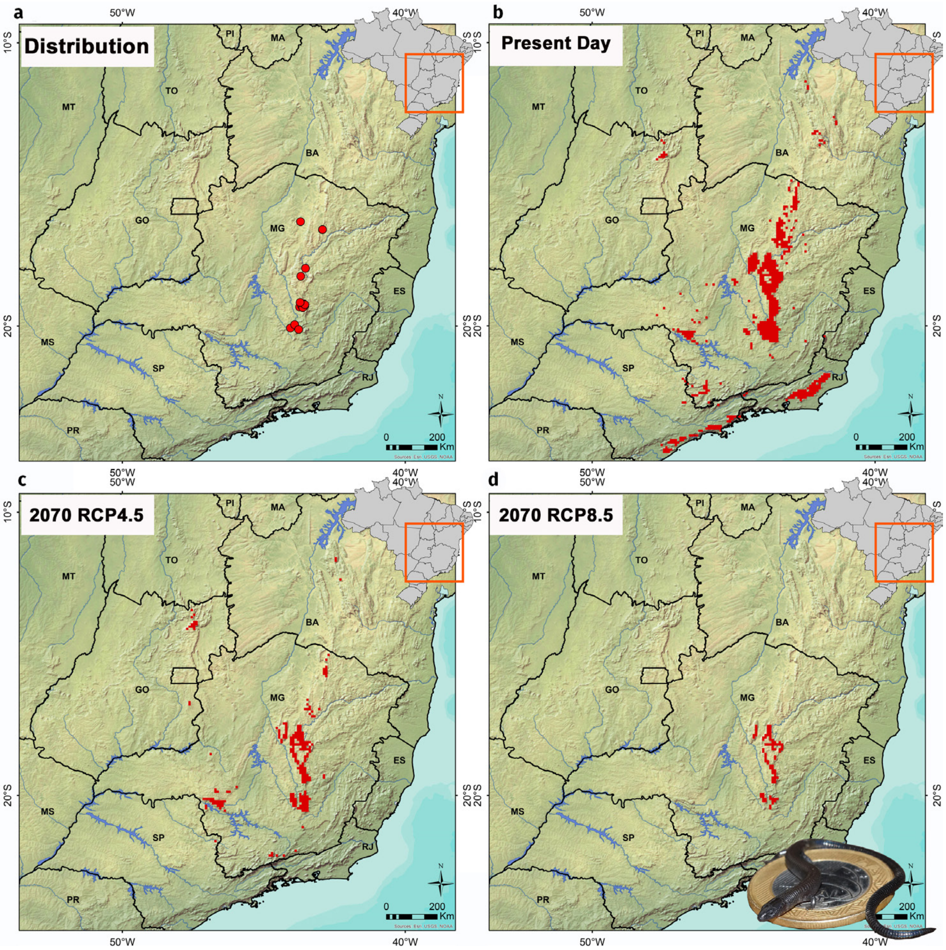

Figure 1. Projections of environmental suitability areas for the occurrence of *Rhachisaurus brachylepis*, where a) Literature and museum data of occurrence records of the species; b) environmental suitability areas projected for the present; c) environmental suitability areas projected for the year 2070 according to the scenario RCP 4.5; d) Projections of environmental suitability areas for the year 2070 according to the scenario RCP 8.5. Abbreviations: BA = Bahia; ES = Espírito Santo; GO = Goiás; MA = Maranhão; MG = Minas Gerais; MS = Mato Grosso do Sul; MT = Mato Grosso; PI = Piauí; PR = Paraná; RJ = Rio de Janeiro; SP = São Paulo; TO = Tocantins.

indicate ESA for 39 protected areas (Figure S2, Table SI).

For *T. montanus*, the models indicated an ESA of 88,058 km^2 (Fig. 2, Table I), especially in locations along SdE (Fig. 2b). Of this total, 13.9% are within protected areas. Other areas where the species has not yet been registered also showed ESAs. It's worth mentioning predicted areas with ESA along Serra do Mar in the eastern portion of Brazil, and elevated areas such as Parque Nacional da Chapada dos Veadeiros in the Central-western portion of Brazil. *Tropidurus montanus* was registered in 10 protected areas, but current models indicated ESAs for the occurrence of the species in at least 51 other protected areas (Figure S3, Table SII).

Future projections under the climate change scenario

Our 2070 projections for *R. brachylepis* (Table I), considering the RCP 4.5 carbon emission scenario, indicated a 59% reduction in ESA. Only 23 protected areas presented ESAs, representing 30.5% of the projections (Table I). Under the RCP 8.5 scenario, there was an 85% reduction in ESA in relation to the projections for the present and 33.8% of the ESA is within 12 protected areas.

For *T. montanus*, the 2070 projection under the RCP 4.5 scenario indicated a 39% reduction in ESA. Even so, 42 protected areas contained ESAs, comprising 19.4% of the total ESA projected by this scenario. The models under the RCP 8.5 scenario indicated an 80% reduction in ESA. In

Table I. Projections of the environmental suitability areas (km^2) of *Rhachisaurus brachylepis* and *Tropidurus montanus* for the current year and for the year 2070 in different scenarios of greenhouse gas emissions (RCP 4.5 and RCP 8.5). The values in parentheses represent the percentage of lost or gained area in the future in relation to the present.

	***Rachisaurus brachylepsis* (Dixon, 1974)**		***Tropidurus montanus* Rodrigues, 1987**	
	Brazil	**Protected areas**	**Brazil**	**Protected areas**
2020 - Present	46,888	8,949.4	88,058	12,274.2
2070 RCP 4.5	19,221 (-59%)	5,845.6 (-34.7%)	53,952 (-39%)	10,503.9 (-14.4%)
2070 RCP 8.5	6,970 (-85%)	2,354.7 (-73.7%)	17,573 (-80%)	3,694.7 (-69.9%)

this scenario, only 30 protected areas would possess ESAs, representing 21% of the total ESAs.

Protected areas that have occurrence points in the present (or records very close to their limits, <15 km) and that possess ESA, both for the present and for the two climatic scenarios projected for 2070, are concentrated only in the state of Minas Gerais, with six areas for *R. brachylepis* and seven for *T. montanus* (Table SIII).

Considering the intersection of areas predicted as climatically suitable for the present and for the two future scenarios of the distribution of *R. brachylepis*, we observed that these areas are located in the southern portion of SdE. Part of these climatically stable areas over time are concentrated within protected areas, and close to locations with current geographic records for the species (Fig. 3). Populations recorded at the northern limits of the species distribution will be outside the predicted climatically stable areas if our predictions are confirmed in the future.

The same pattern seems to occur for *T. montanus*, where climatically stable areas over time are concentrated in the southern portion of SdE. Populations registered north of the species' geographic distribution are the most vulnerable to future extinction due to a lack of climate suitability (Fig. 4).

In addition, our uncertainty analysis for *T. montanus* (Figure S4) and *R. brachylepis* (Figure S5) did not demonstrate interference from other methodological components, such as RCP, GCM, and methods in the species occurrence areas, which adds robustness to our results.

DISCUSSION

Mountainous areas are places of diversification, with biogeographical barriers and bridges, which is why they are so important for biodiversity (Perrigo et al. 2020). For both studied lizard species, the models built for the present indicated ESAs in locations where there are no records of occurrences, indicating the need for *in loco* investigations about the existence of still unknown populations for these species. On the other hand, projections of the present model of *R. brachylepis* do not include any ESA in the state of Pará, which reinforces the discussion presented by Gomides et al. (2020) that the record of the occurrence of the species in that state (Ribeiro-Junior & Amaral 2017) may have been a mistake, perhaps something similar to what happened with the species *Tantilla boipiranga* Sawaya & Sazima, 2003 (Mol et al. 2020). The analyses indicated that the two studied species will potentially be affected by climate change in the next years.

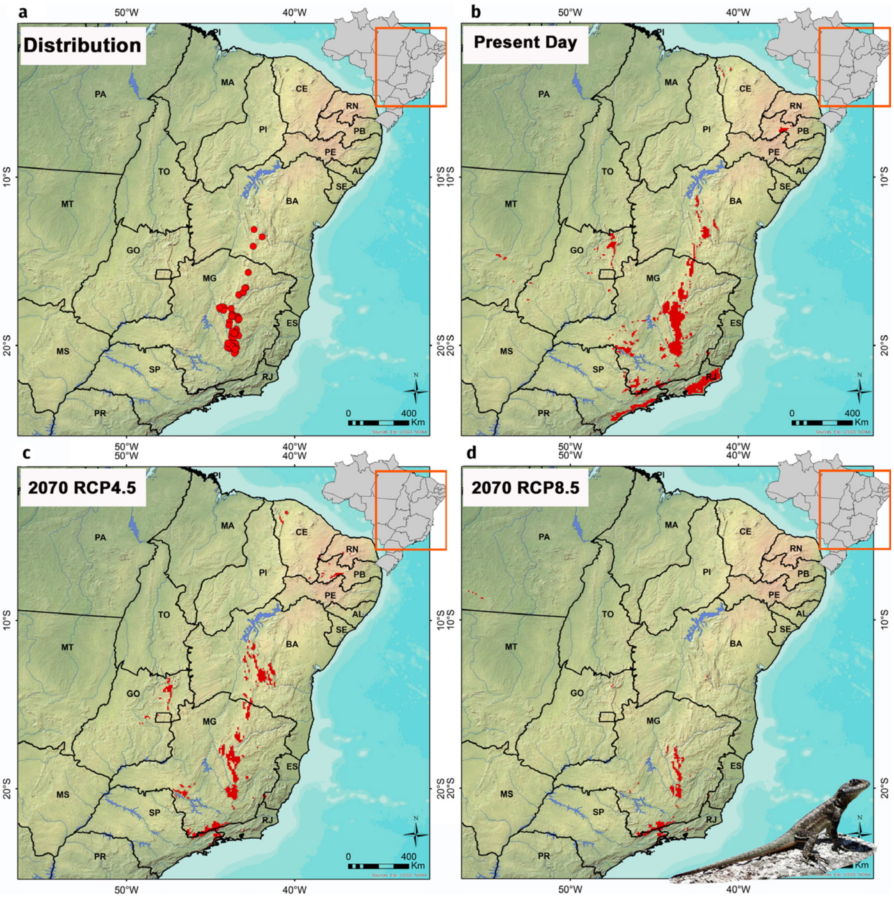

Figure 2. Projections of environmental suitability areas for the occurrence of *Tropidurus montanus*, where a) Literature and museum data of occurrence records of the species; b) environmental suitability areas projected for the present; c) environmental suitability areas projected for the year 2070 according to the scenario RCP 4.5; d) Projections of environmental suitability areas for the year 2070 according to the scenario RCP 8.5. Abbreviations: AL = Alagoas; BA = Bahia; CE = Ceará; ES = Espírito Santo; GO = Goiás; MA = Maranhão; MG = Minas Gerais; MS = Mato Grosso do Sul; MT = Mato Grosso; PA = Pará; PB = Paraíba; PE = Pernambuco; PI = Piauí; PR = Paraná; RN = Rio Grande do Norte; RJ = Rio de Janeiro; SE = Sergipe; SP = São Paulo; TO = Tocantins.

Our MOP analysis showed that our environmental variables had no negative effect on the projections of the models in the region where the species occur, which is desired (Owens et al. 2013). With the uncertainty analysis, we add robustness to our results demonstrating that in regions where species occur, there is little interference of methodological components, and that what most affects the suitability values in the regions of occurrence of the species is the temporal variation of climatic conditions (Figure S1), what is desired and recommended by the literature (Diniz-Filho et al. 2009, Terribile et al. 2012).

As hypothesized, forecasts for *T. montanus* indicate smaller proportional reductions in ESA in the future than for *R. brachylepis*. The ESA for *T. montanus* in the present and the future covers areas to the south, southeast, and west of the areas where the species has confirmed records. Despite the suitability of these areas, they are currently occupied by its congenerics species (Carvalho 2013). The habits and behaviors of species of the genus *Tropidurus* are phylogenetically conservative, which would explain the occupation of similar habitats (Filogonio et al. 2010, Carvalho 2013).

The two species studied here are found in typical phytophysiognomies of SdE, which can make it difficult for them to migrate and occupy new areas, although there are predictions of occurrence in other elevated areas of southeastern Brazil. Difficulty in migrating to other areas in a short period of time in order to avoid extinction has already been predicted for other groups (Román-Palacios & Wiens 2020), and raises an alert about the ability of the studied species to persist with the expected

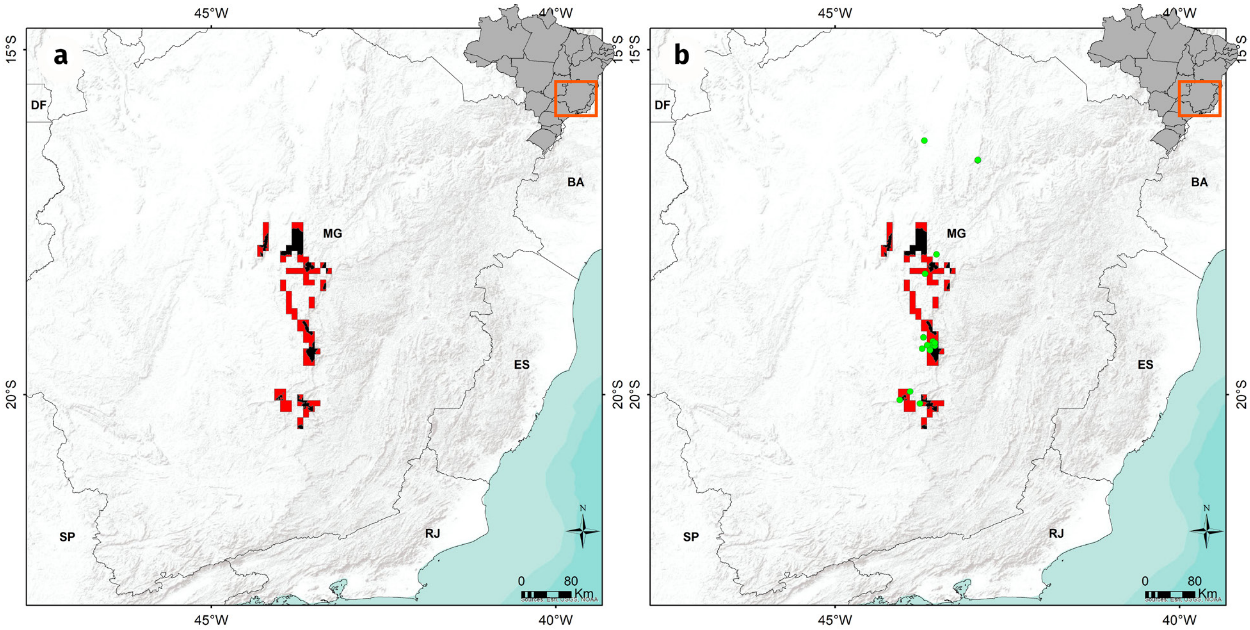

Figure 3. a) Projections of the intersection of environmental suitability areas for the occurrence of *Rhachisaurus brachylepis* for the present year, for the year 2070 according to the scenario RCP 4.5, and for the year 2070 according to the scenario RCP 8.5. The red zone indicates climatically stable areas in the three scenarios, and the black zones indicate climatically stable areas for the three scenarios that are within protected areas. b) Map with projections of climatically stable areas overlaid with the geographic occurrence of the species. Green dots indicate geographic records of the studied species. Abbreviations: BA = Bahia; DF = Federal District; ES = Espírito Santo; MG = Minas Gerais; RJ = Rio de Janeiro; SP = São Paulo.

climate change. In addition, the campos rupestres of SdE have a geological history and biogeographic affinities that are distinct from the altitudinal fields (campos de altitude) of elevated areas of eastern Brazil. Although during the last glacial maximum there may have been a connection allowing the migration of species between these areas, currently these ecological corridors are not suitable to high altitude species, mainly due to the fragmented matrix and different microclimatic conditions (Vasconcelos 2008). Protected areas, such as Parque Nacional da Chapada dos Veadeiros and Parque Nacional da Serra da Canastra, presented ESAs for both species, however, they have already been sampled with no record of either *R. brachylepis* or *T. montanus*, which suggests the existence of barriers and environmental filters that prevent migration and occupation by these species. On the other hand, ESAs for the present, but without confirmed records, may indicate insufficient sampling and thus the potential of housing still unknown populations. This seems to be the case for Parque Estadual da Serra do Cabral for *R. brachylepis* and Parque Nacional da Chapada Diamantina for *T. montanus*, among other examples of protected areas that have been under-sampled (Figures S2-S3).

Discussions about future projections must consider the consequences that climate change will have on the environment, the tolerance of species to rising temperatures, and the ability of these ectothermic organisms to regulate their body temperature (Huey et al. 2009). With the drastic reduction of the ESA for the species in the future (see Table I), especially in the worst climate scenario (RCP 8.5), competition for resources could increase. With the prediction of alterations to native vegetation in the region where these species occur (see Bitencourt

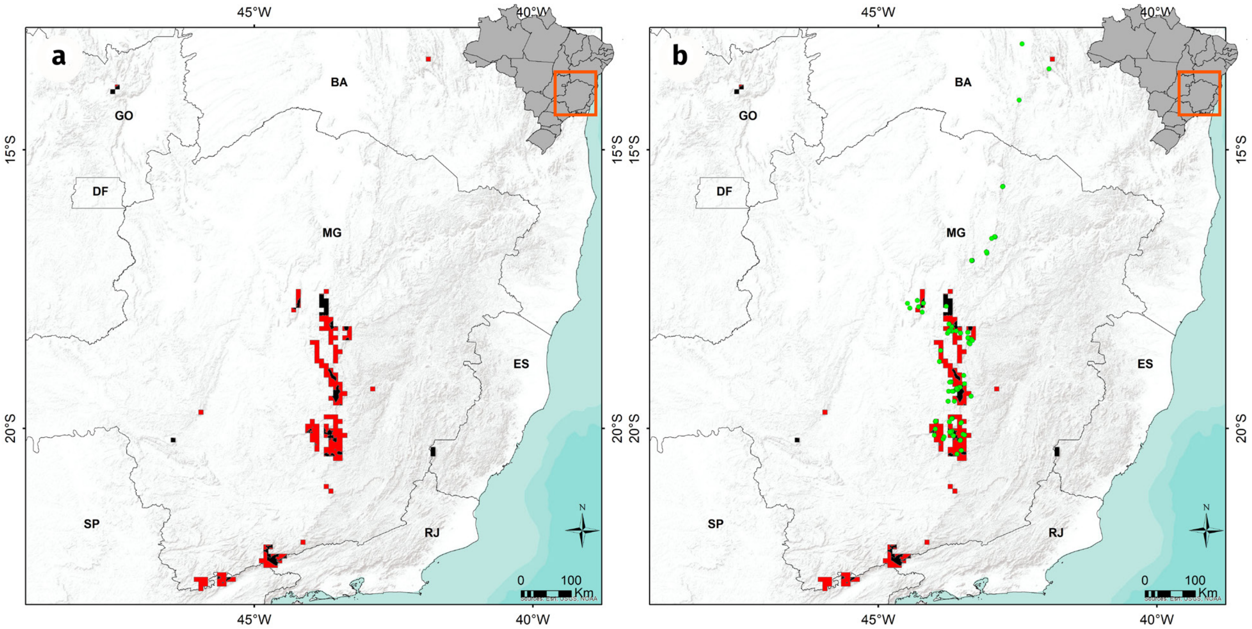

Figure 4. a) Projections of the intersection of environmental suitability areas for the occurrence of *Tropidurus montanus* for the present year, for the year 2070 according to scenario RCP 4.5, and for the year 2070 according to scenario RCP 8.5. The red zone indicates climatically stable areas in the three scenarios, and the black zones indicate climatically stable areas for the three scenarios that are within protected areas. b) Map with projections of climatically stable areas overlaid with the geographic occurrence of the species. Green dots indicate geographic records of the studied species. Abbreviations: BA = Bahia; DF = Federal District; ES = Espírito Santo; GO = Goiás; MG = Minas Gerais; RJ = Rio de Janeiro; SP = São Paulo.

et al. 2016), areas for shelter and protection will be modified, thereby affecting their thermoregulation behavior and, consequently, aspects of their physiology (Huey et al. 2009).

These changes may have even a greater impact on *R. brachylepis*, which depends on litter for shelter (Gomides et al. 2020). These thermoconformer lizards would suffer greater competition with, and predation by, lizard species adapted to open environments (Huey et al. 2009). Indeed, there is even a report of *T. montanus*, a heliophile species, preying upon *R. brachylepis* (Kiefer 1998). Temperatures beyond the optimum range can force these animals to stay sheltered for longer periods of time, which could induce stress and reduced physiological performance (Huey et al. 2009). For example, in warmer periods of the year, *T. montanus* decreases its activity at the hottest times of the day (Filogonio et al. 2010). Even for *T. montanus*, which actively thermoregulates in the environment in which it occurs, high temperatures can increase periods of inactivity during temperature peaks, affecting its foraging and the ability to occupy and maintain adequate places of permanence and reproduction. In addition, the predicted change in the local flora (Bitencourt et al. 2016) might hinder the typical behavior of species that use vegetation in thermoregulation by alternating between direct exposure to the sun and thermoregulation through solar light filtered in microhabitats (Filogonio et al. 2010).

Populations located in the north of the Minas Gerais state will be the most affected due to the lack of climate-suitable areas in future scenarios. Therefore, climatic stress can affect the physiology of these species. Changes in thermal niches can reduce the number of active hours for a species (Pontes-da-Silva et al.

2018), with effects on aspects of reproduction. For lizards of the genus *Tropidurus*, for example, local climatic conditions seem to influence minimum reproductive size (Gomides et al. 2013). Populations of *T. montanus* have a high turnover rate of individuals, with considerable mortality in the first six months of life (Galdino et al. 2017). Thus, a poor breeding season influenced by climatic excesses could trigger a local decline of the species.

Increased maximum annual temperatures are apparently the most important variable associated with local extinctions (Román-Palacios & Wiens 2020). The risks of losing species with an increase of 4.5° C are 8 to 10 times greater than those with an increase of 1.5° C (Warren et al. 2018). We are moving towards that, and at the end of the century the temperatures of the planet will have increased (Hannah et al. 2002), and in an accelerated way (Diffenbaugh & Field 2013). This temperature rise associated with the alteration of vegetation of SdE (Bitencourt et al. 2016), and the reduction of ESA can cause physiological and behavioral changes in the lizards and result in the extinction of populations, mainly in the northernmost portion of the distribution of these two species where are lack of climate suitability in the worst climate scenario in the future.

Data collected in the field on the body temperature of these species could improve our models (Pontes-da-Silva et al. 2018) and refine the forecast of climatic impacts. In fact, these data are important for understanding how differences in thermal characteristics between individuals from the same population or from different populations can help local adaptation and protect some populations from extinction (Pontes-da-Silva et al. 2018). This information would be very useful for planning future conservation areas.

Protected areas cover approximately 10% of SdE and are mainly concentrated in the campos rupestres (ca. 70%). Few protected areas seem to include the distribution of the studied lizard species (one for *R. brachylepis* and 10 for *T. montanus*), which is a global trend for reptiles. Only 3.5% of the global distribution area for reptiles is within protected areas, a figure below that for other groups of vertebrates such as mammals and birds (Roll et al. 2017). This is why it is so important to direct efforts to maintain and preserve fully protected areas indicated as climatically stable; that is, those with current records of species occurrence and with environmental suitability predicted by the two future scenarios (see Table SIII). The distribution areas of the two species located further north seem to be the most affected by climate forecasts (Figs. 3-4), as well as predicted for endemic birds that occur in this region (Hoffmann et al. 2020). The areas predicted to be climatically stable over time are concentrated mainly in the southern portion of the distribution of these two species. Therefore, investment in the creation and maintenance of protected areas, mainly in the southern portion of SdE, is a priority. However, areas in the southern Espinhaço range face high mining exploitation pressure, and consequently, the loss of natural areas (Pena et al. 2017).

The present work identifies areas where current research efforts should be directed to find new populations since both species are likely to be affected by the effects of climate change in the future. Both climatic scenarios investigated predict losses of ESA for the region where these species are currently distributed. Few protected areas can contribute to their preservation, especially for *R. brachylepis*, which is currently protected by only one integral protection area. The successful implementation of the Paris Agreement would lead to a substantial benefit for the conservation of the two species treated in this work, as well as for global biodiversity (Warren et al. 2018).

Acknowledgments

We would like to thank P. Eisenlohr for his immense contribution of ideas, help with methodology, and generous sharing of knowledge. We thank the anonymous reviewers and Leandro Abade for providing useful comments and suggestions on the manuscript. We appreciate the efforts of museums and their curators, as well as of the field collectors and institutions that made our study possible. We thank Erik Wild for reviewing the English language. SCG thanks the support of the Campos-Gomides' family, especially LCG, and TMM thanks the support of the Mota-Machado' family in the most critical moments during the COVID-19 pandemic.

REFERENCES

ALLOUCHE O, TSOAR A & KADMON R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). J Appl Ecol 43: 1223-1232.

BARBET-MASSIN M, JIGUET F, ALBERT CH & THUILLER W. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? Method Ecol Evol 3: 327-338.

BITENCOURT C, RAPINI A, DAMASCENA LS & JUNIOR PDM. 2016. The worrying future of the endemic flora of a tropical mountain range under climate change. Flora 218: 1-10.

CALDAS A. 2014. Species traits of relevance for climate vulnerability and the prediction of phenological responses to climate change. J Lepid Soc 68: 197-202.

CARVALHO A. 2013. On the distribution and conservation of the South American lizard genus *Tropidurus* Wied-Neuwied, 1825 (Squamata: Tropiduridae). Zootaxa 3640: 42-56.

COBOS ME, PETERSON AT, BARVE N & OSORIO-OLVERA, L. 2019. kuenm: an R package for detailed development of ecological niche models using Maxent. PeerJ 7: e6281.

DIFFENBAUGH NS & FIELD CB. 2013. Changes in ecologically critical terrestrial climate conditions. Science 341: 486-492.

DINIZ-FILHO JAF, BINI LM, RANGEL TF, LOYOLA RD, HOF C, NOGUÉS-BRAVO D & ARAÚJO MB. 2009. Partitioning and mapping uncertainties in ensembles of forecasts of species turnover under climate change. Ecography 32: 897-906.

DIXON JR. 1974. Systematic review of the lizard genus *Anotosaura* (Teiidae). Herpetologica 30: 13-18.

DORMANN CF, ELITH J, BACHER S, BUCHMANN C, CARL G, CARRÉ G, MARQUÉZ JRG, GRUBER B, LAFOURCADE B & LEITÃO P. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36: 27-46.

FILOGONIO R, DEL LAMA FS, MACHADO LL, DRUMOND M, ZANON I, MEZZETTI NA & GALDINO CA. 2010. Daily activity and microhabitat use of sympatric lizards from Serra do Cipó, southeastern Brazil. Iheringia Ser Zool 100: 336-340.

FREEMAN BG, SCHOLER MN, RUIZ-GUTIERREZ V & FITZPATRICK JW. 2018. Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. Proc Natl Acad Sci USA 115: 11982-11987.

GALDINO CA, VENTURA SP, LISBOA CC & YOUNG RJ. 2017. Social spacing of the montane lizard *Tropidurus montanus*. Herpetol J 27: 333-338.

GOICOECHEA N, FROST DR, DE LA RIVA I, PELLEGRINO KC, SITES JR J, RODRIGUES MT & PADIAL JM. 2016. Molecular systematics of teioid lizards (Teioidea/Gymnophthalmoidea: Squamata) based on the analysis of 48 loci under tree-alignment and similarity-alignment. Cladistics 32: 624-671.

GOMIDES SC, JUNIOR MT, LEAL F, THOMASSEN H, CASSIMIRO J, RECODER RS, DE ARRUDA PINTO HB, RODRIGUES MT & LEITE FSF. 2020. Redescription and Geographical Distribution of a Rare Microteiid Lizard: *Rhachisaurus brachylepis* (Dixon, 1974) (Squamata: Gymnophthalmidae). S Am J Herpetol 2020: 20-29.

GOMIDES SC, MACHADO TM, EVANGELISTA-VALE JC, MARTINS-OLIVEIRA AT, PIRES-OLIVEIRA JC, MULLER A, BARROS DA ROSA L, LUCAS SANTOS-SILVA D & EISENLOHR PV. 2021. Assessing species reintroduction sites based on future climate suitability for food resources. Conserv Biol 35: 1821-1832. https://doi.org/10.1002/cobi.13796.

GOMIDES SC, RIBEIRO LB, PETERS VM & SOUSA BM. 2013. Feeding and reproduction ecology of the lizard *Tropidurus torquatus* (Squamata: Tropiduridae) in a rock outcrop area in southeastern Brazil. Rev Chil Hist Nat 86: 137-151.

HANNAH L, MIDGLEY GF, LOVEJOY T, BOND WJ, BUSH M, LOVETT JC, SCOTT D & WOODWARD FI. 2002. Conservation of biodiversity in a changing climate. Conserv Biol 16: 264-268.

HIJMANS RJ & VAN ETTEN J. 2012. raster: Geographic analysis and modelling with raster data. R package version 2.0-12.

HOFFMANN D, VASCONCELOS MF & FERNANDES GW. 2020. The fate of endemic birds of eastern Brazilian mountaintops in the face of climate change. Perspect Ecol Conserv 18: 257-266.

HUEY RB, DEUTSCH CA, TEWKSBURY JJ, VITT LJ, HERTZ PE, ÁLVAREZ PÉREZ HJ & GARLAND JR T. 2009. Why tropical forest lizards are vulnerable to climate warming. P Roy Soc B-Biol Sci 276: 1939-1948.

HUEY RB, KEARNEY MR, KROCKENBERGER A, HOLTUM JA, JESS M & WILLIAMS SE. 2012. Predicting organismal vulnerability to climate warming: roles of behaviour, physiology and adaptation. Philos T R Soc B 367: 1665-1679.

KARGER DN, CONRAD O, BÖHNER J, KAWOHL T, KREFT H, SORIA-AUZA RW, ZIMMERMANN NE, LINDER HP & KESSLER M. 2017. Data Descriptor: climatologies at high resolution for the earth's land surface areas. Sci Data 4. https://doi.org/10.1038/sdata.2017.122.

KIEFER MC. 1998. *Anotosaura brachylepis* (ncn). Predation Herpetol Rev 29: 41.

MIOLA DTB, RAMOS VDV & SILVEIRA FAO. 2020. A brief history of research in campo rupestre: identifying research priorities and revisiting the geographical distribution of an ancient, widespread Neotropical biome. Biolol J Lennean Soc 133(2): 464-480.

MOL RM, TUNES PH & FRANÇA ATRC. 2020. Distribution extension of the black-headed snake *Tantilla boipiranga* Sawaya & Sazima, 2003 in the state of Minas Gerais, Brazil. Oecologia Aust 24: 948.

NAIR US, LAWTON RO, WELCH RM & PIELKE SR RA. 2003. Impact of land use on Costa Rican tropical montane cloud forests: Sensitivity of cumulus cloud field characteristics to lowland deforestation. J Geophys Res-Atmos 108: 4-13.

OWENS HL, CAMPBELL LP, DORNAK LL, SAUPE EE, BARVE N, SOBERÓN J, INGENLOFF K, LIRA-NORIEGA A, HENSZ CM MYERS & CE PETERSON AT. 2013. Constraints on interpretation of ecological niche models by limited environmental ranges on calibration areas. Ecol Modell 263: 10-18.

PARMESAN C. 2006. Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37: 637-669.

PEARSON RG, RAXWORTHY CJ, NAKAMURA M & TOWNSEND PA. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. J Biogeogr 34: 102-117.

PENA JCC, GOULART F, FERNANDES GW, HOFFMANN D, LEITE FSF, SANTOS NB, SOARES-FILHO B, SOBRAL-SOUZA T, VANCINE MH & RODRIGUES M. 2017. Impacts of mining activities on the potential geographic distribution of eastern Brazil mountaintop endemic species. Perspect Ecol Conserv 15(3): 172-178.

PERRIGO A, HOORN C & ANTONELLI A. 2020. Why mountains matter for biodiversity. J Biogeogr 47: 315-325.

PIRES-OLIVEIRA JC, JOSÉ-SILVA L, ROCHA DSB & EISENLOHR PV. 2019. Concepts and methods in environmental suitability modelling, an important tool for forest conservation. In: EISENLOHR PV (Ed), Forest Conservation: Methods, Management and Challenges, 1st ed. New York: Nova Publishers LTDA, p. 269-290.

PONTES-DA-SILVA E, MAGNUSSON WE, SINERVO B, CAETANO GH, MILES DB, COLLI GR, DIELE-VIEGAS LM, FENKER J, SANTOS JC & WERNECK FP. 2018. Extinction risks forced by climatic change and intraspecific variation in the thermal physiology of a tropical lizard. J Therm Biol 73: 50-60.

R CORE TEAM. 2019. R: a Language and Environment for Statistical Computing R Foundation for Statistical Computing, Vienna, Austria (2017) Retrieved from https://www.R-project.org/.

RAXWORTHY CJ, PEARSON RG, RABIBISOA N, RAKOTONDRAZAFY AM, RAMANAMANJATO JB, RASELIMANANA AP, WU S, NUSSBAUM RA & STONE DA. 2008. Extinction vulnerability of tropical montane endemism from warming and upslope displacement: a preliminary appraisal for the highest massif in Madagascar. Glob Change Biol 14: 1703-1720.

RIAHI K, RAO S, KREY V, CHO C, CHIRKOV V, FISCHER G, KINDERMANN G, NAKICENOVIC N & RAFAJ P. 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Clim Change 109: 33.

RIBEIRO-JUNIOR MA & AMARAL S. 2017. Catalogue of distribution of lizards (Reptilia: Squamata) from the Brazilian Amazonia. IV. Alopoglossidae, Gymnophthalmidae. Zootaxa 4269: 151-196.

RODRIGUES MT. 1987. Sistemática, ecologia e zoogeografia dos *Tropidurus* do grupo torquatus ao sul do Rio Amazonas (Sauria, Iguanidae). Arq Zool 31: 105-230.

ROLL U, FELDMAN A, NOVOSOLOV M, ALLISON A, BAUER AM, BERNARD R, BÖHM M, CASTRO-HERRERA F, CHIRIO L & COLLEN B. 2017. The global distribution of tetrapods reveals a need for targeted reptile conservation. Nat Ecol Evol 1: 1677-1682.

ROMÁN-PALACIOS C & WIENS JJ. 2020. Recent responses to climate change reveal the drivers of species extinction and survival. PNAS 117: 4211-4217.

SILVEIRA FA, NEGREIROS D, BARBOSA NP, BUISSON E, CARMO FF, CARSTENSEN DW, CONCEIÇÃO AA, CORNELISSEN TG, ECHTERNACHT L & FERNANDES GW. 2016. Ecology and evolution of plant diversity in the endangered campo rupestre: a neglected conservation priority. Plant Soil 403: 129-152.

SINERVO B, MENDEZ-DE-LA-CRUZ F, MILES DB, HEULIN B, BASTIAANS E, VILLAGRÁN-SANTA CRUZ M, LARA-RESENDIZ R, MARTÍNEZ-MÉNDEZ N, CALDERÓN-ESPINOSA ML & MEZA-LÁZARO RN. 2010. Erosion of lizard diversity by climate change and altered thermal niches. Science 328: 894-899.

TERRIBILE LC ET AL. 2012. Areas of climate stability of species ranges in the Brazilian Cerrado: disentangling uncertainties through time. Nat Conserv 10: 152-159.

THUILLER W, GEORGES D, ENGLER R, BREINER F, GEORGES MD & THUILLER CW. 2016. Package 'biomod2.' Species distribution modelling within an ensemble forecasting framework. https://CRAN.R-project.org/package=biomod2.

VASCONCELOS MD. 2008. Mountaintop endemism in eastern Brazil: why some bird species from campos rupestres of the Espinhaço Range are not endemic to the Cerrado region. Rev Bras Ornitol 16: 348-362.

WARREN R, PRICE J, GRAHAM E, FORSTENHAEUSLER N & VANDERWAL J. 2018. The projected effect on insects, vertebrates, and plants of limiting global o 1.5 °C rather than 2 °C. Science 360: 791-795.

ZHANG L, LIU S, SUN P, WANG T, WANG G, ZHANG X & WANG L. 2015. Consensus forecasting of species distributions: The effects of niche model performance and niche properties. PLoS ONE 10: 1-18.

ZUQUIM G, COSTA FRC, TUOMISTO H, MOULATLET GM & FIGUEIREDO FOG. 2020. The importance of soils in predicting the future of plant habitat suitability in a tropical forest. Plant Soil 450: 151-170.

ZWIENER VP, LIRA-NORIEGA A, GRADY CJ, PADIAL AA & VITULE JR. 2018. Climate change as a driver of biotic homogenization of woody plants in the Atlantic Forest. Glob Ecol Biogeogr 27: 298-309.

APPENDIX

Appendix 1. List of literature and online database used to compile species occurrences.

CARVALHO ALG. 2013. On the distribution and conservation of the South American lizard genus *Tropidurus* Wied-Neuwied, 1825 (Squamata: Tropiduridae). Zootaxa 3640: 42-56. http://dx.doi.org/10.11646/zootaxa.3640.1.3.

CARVALHO ALG, SENA MAS, PELOSO PLV, MACHADO FA, MONTESINOS R, SILVA HR, CAMPBELL G & RODRIGUES MT. 2016. A New *Tropidurus* (Tropiduridae) from the Semiarid Brazilian Caatinga: Evidence for Conflicting Signals between Mitochondrial and Nuclear Loci Affecting the Phylogenetic Reconstruction of South American Collared Lizards. Am Mus Novit 3852: 1-68. https://doi.org/10.1206/3852.1.

CRIA - CENTRO DE REFERÊNCIA E INFORMAÇÃO AMBIENTAL. 2020. Specieslink. http://www.splink.org.br/index (accessed 6 May 2020).

DIXON JR. 1974. Systematic review of the lizard genus *Anotosaura* (Teiidae). Herpetologica 30: 13-18. https://www.jstor.org/stable/3891405.

FILOGONIO R, DEL LAMA FS, MACHADO LL, DRUMOND M, ZANON I, MEZZETTI NA & GALDINO CAB. 2010. Daily activity and microhabitat use of sympatric lizards from Serra do Cipó, southeastern Brazil. Iheringia 100: 336-340. https://doi.org/10.1590/S0073-47212010000400008.

GALDINO CAB, VENTURA SPR, LISBOA CC & YOUNG RJ. 2017. Social spacing of the montane lizard *Tropidurus montanus*. Herpetol J 27: 333-338. https://www.thebhs.org/publications/the-herpetological-journal/volume-27-number-4-october-2017/1052-04-social-spacing-of-the-montane-lizard-i-tropidurus-montanus-i.

GBIF - GLOBAL BIODIVERSITY INFORMATION FACILITY. 2020. *Tropidurus montanus* Rodrigues, 1987. https://doi.org/10.15468/dl.zb82g8 (accessed 6 May 2020).

GBIF - GLOBAL BIODIVERSITY INFORMATION FACILITY. 2020. *Rhachisaurus brachylepis* (Dixon, 1974). https://doi.org/10.15468/dl.q6eysq (accessed 6 May 2020).

GOMIDES SC, TEIXEIRA JUNIOR M, LEAL F, THOMASSEN H, CASSIMIRO J, RECODER RS, PINTO HBA, RODRIGUES MT & LEITE FSF. 2020. Redescription and Geographical Distribution of a Rare Microteiid Lizard: *Rhachisaurus brachylepis* (Squamata: Gymnophthalmidae). S Am J Herpetol 15: 20-29. https://doi.org/10.2994/SAJH-D-17-00078.1.

KASAHARA S, PELLEGRINO KCM, YONENAGA-YASSUDA Y & RODRIGUES MT. 1996. Comparative cytogenetic studies of eleven species of the *Tropidurus torquatus* group (Sauria; Tropiduridae), with banding patterns. Hereditas 125: 37-46. https://doi.org/10.1111/j.1601-5223.1996.00037.x.

KIEFER MC. 1998. *Anotosaura brachylepis* (NCN). Predation. Herpetol Rev 29: 41.

KIEFER MC & SAZIMA I. 2002. *Tropidurus montanus* (NCN). Cannibalism. Herpetol Rev 33: 136.

MACHADO LL, GALDINO CAB & SOUSA BM. 2007. Defensive behavior of the lizard *Tropidurus montanus* (TROPIDURIDAE): efects of sex, body size and social context. S Am J Herpetol 2: 136-140. https://doi.org/10.2994/1808-9798(2007)2[136:DBOTLT]2.0.CO;2.

RODRIGUES MT. 1987. Sistemática, ecologia e zoogeografia dos *Tropidurus* do grupo torquatus ao sul do Rio

Amazonas (Sauria, Iguanidae). Arq Zool 31: 105-230. https://doi.org/10.11606/issn.2176-7793.v31i3p105-230.

RODRIGUES MT. 1988. Distribution of lizards of the genus *Tropidurus* in Brazil (Sauria, Iguanidae), In: VANZOLINI PE & HEYER WR (Eds), Proceedings of a workshop on Neotropical distribution patterns. Rio de Janeiro: Academia Brasileira de Ciências, p. 305-315.

SOARES M. 2000. Estudo do esqueleto cefálico de *Anotosaura* Amaral (1933), *Bachia* Gray, 1845 e *Heterodactylus* Spix, 1845 (Squamata, Teiioidea, Gymnophthalmidae). Bol Mus Nac Zool 426: 1-20.

VÁCLAV A, ANJOS L, QUEIRÓZ M, NASCIMENTO L & GALDINO C. 2017. Nematode infection patterns in a Neotropical lizard species from an insular mountain habitat in Brazil. J Helminthol 91: 578-582. https://doi:10.1017/S0022149X16000754.

VAN SLUYS M, MENDES HMA, ASSIS VB & KIEFER MC. 2002. Reproduction of *Tropidurus montanus* Rodrigues, 1987 (Tropiduridae), a lizard from a seasonal habitat of southeastern Brazil, and a comparison with other *Tropidurus* species. J Herpetol 12: 89-97. https://www.thebhs.org/publications/the-herpetological-journal/volume-12-number-3-july-2002/1682-01-reproduction-of-tropidurus-montanus-rodrigues-1987-tropiduridae-a-lizard-from-a-seasonal-habitat-of-south-eastern-brazil-and-a-comparison-with-other.

VANZOLINI PE. 1976. Two notes on *Anotosaura* (Sauria, Teiidae). Pap Avulsos Zool 30: 119-122.

VENTURA SPR, PASSOS DC, MACHADO LL, HORTA G & GALDINO CAB. 2017. Escape tactics by a neotropical montane lizard: a comparison of flight responses against natural and non-natural predators. Acta Ethol 20: 9-15. https://doi.org/10.1007/s10211-016-0242-3.

YONENAGA-YASSUDA Y, KASAHARA S, CHU TH & RODRIGUES MT. 1988. High-resolution RBG-banding pattern in the genus *Tropidurus* (Sauria, Iguanidae). Cytogenet Genome Res 48: 68-71. https://doi.org/10.1159/000132592.

SUPPLEMENTARY MATERIAL

Tables SI-SIII
Figures S1-S5.

How to cite
GOMIDES SC, PIRES-OLIVEIRA JC & MACHADO TM. 2023. Threats from climate change for lizard species of a Neotropical mountain range. An Acad Bras Cienc 95: e20210519. DOI: 10.1590/0001-3765202320210519.

Manuscript received on April 6, 2021;
accepted for publication on October 7, 2022

SAMUEL C. GOMIDES[1]
https://orcid.org/0000-0002-8454-5862

JOÃO CARLOS PIRES-OLIVEIRA[2]
https://orcid.org/0000-0002-8151-8156

TALITA M. MACHADO[3]
https://orcid.org/0000-0003-4082-3899

[1]Programa de Pós-Graduação em Biodiversidade,
Universidade Federal do Oeste do Pará, Rodovia PA-439,
nº 257, Santíssimo, 68270-000 Oriximiná, PA, Brazil

[2]Programa de Ecologia e Conservação, Universidade do
estado de Mato Grosso, Campus de Nova Xavantina,
Av. Prof. Dr. Renato Figueiro Varella, s/n, Olaria, Caixa
Postal 08, 78690-000 Nova Xavantina, MT, Brazil

[3]Universidade Federal de Minas Gerais, Instituto de
Ciências Biológicas, Departamento de Botânica, Av.
Presidente Antônio Carlos, 6627, Pampulha, Caixa
Postal 486, 31270-901 Belo Horizonte, MG, Brazil

Correspondence to: **Samuel C. Gomides**
E-mail: samuelbio@hotmail.com

Author contributions

S.C.G. and T.M.M. conceived the ideas; S.C.G. collected and processed species occurrence, S.C.G., J.C.P.O., and T.M.M. processed climate data and constructed species distribution models. The analyses, interpretation of results, and writing of the manuscript were conducted collaboratively by all authors.