

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
CENTRO DE CIÊNCIAS HUMANAS E NATURAIS
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS

**Impacto das mudanças climáticas em pequenos
mamíferos de dois hotspots de biodiversidade**

Bruno Henrique de Castro Evaldt

Dissertação de Mestrado

Vitória - ES

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Orientador: Yuri Luiz Reis Leite

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Se eu vi mais longe, foi por estar sobre ombros de gigantes.

- Isaac Newton

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Resumo

O termo mudanças climáticas se refere às mudanças sem precedentes no padrão climático em escalas globais e regionais em um curto período devido às atividades humanas. Uma das consequências esperadas desse fenômeno é a alteração na distribuição das espécies em todo o globo. Nosso objetivo foi analisar como as mudanças climáticas impactam a distribuição das espécies e como as características das espécies podem servir de parâmetro para o grau de impacto. Para isso, usamos o algoritmo de entropia máxima (Maxent) para modelar a distribuição no cenário presente e em quatro cenários futuros para 40 espécies de pequenos mamíferos não-voadores dos biomas Mata Atlântica e Cerrado. Encontramos que todos os cenários futuros têm uma diferença significativa em relação ao presente, com as espécies gradualmente perdendo mais área dependendo do cenário, desde o cenário mais otimista (RCP 2.6) até o mais pessimista (RCP 8.5). Espécies do Cerrado terão maior redução de área do que espécies da Mata Atlântica, e consequentemente, o Cerrado terá proporcionalmente mais espécies ameaçadas do que a Mata Atlântica. As espécies que ocorrem em ambos os biomas perderão proporcionalmente menos área do que as endêmicas do Cerrado, mas mais área do que as endêmicas da Mata Atlântica. A elevação média aumentará em todos os cenários analisados e as espécies que ocupam altitudes mais elevadas hoje perderão mais área no futuro. Não encontramos nenhuma relação entre a amplitude de nicho ou massa corporal e vulnerabilidade às mudanças climáticas, ou diferenças entre clados ou modos de locomoção. Assim, as espécies de pequenos mamíferos serão impactadas negativamente pelas mudanças climáticas, mas o grau do impacto depende da trajetória das concentrações de gases de efeito estufa. As características intrínsecas das espécies parecem ser menos importantes para prever a vulnerabilidade às mudanças climáticas do que as características extrínsecas, como onde ocorrem, tanto geograficamente quanto em termos de altitude.

Palavras-chave: modelagem de nicho ecológico; Rodentia, Didelphimorphia; conservação

Abstract

Climate change is the unprecedented change in the weather pattern across global and regional scales in a short period due to human activities, and it is expected that it will drive changes in the distribution of species across the globe. Our goal was to analyze how climate change impacts the distribution of species and how species characteristics can affect those changes. To do so, we used the maximum entropy (Maxent) algorithm to model the distribution in the present and four future scenarios for 40 species of non-volant small mammals from the Atlantic Forest and Cerrado biomes. We found that all future scenarios have a significant difference from the present, whereas species will gradually lose more area depending on the scenario, from the most optimistic Representative Concentration Pathway (RCP 2.6) to the most pessimistic (RCP 8.5). Species from the Cerrado will have greater area reduction than species from the Atlantic Forest, and as a consequence, the Cerrado will have proportionally more threatened species than the Atlantic Forest. Species that occur in both biomes will lose proportionally less area than those endemic to the Cerrado but more area than those endemic to the Atlantic Forest. Average elevation will increase in every scenario analyzed and species that occupy higher elevations today will lose more area in the future. We found no relationship between niche breadth or body mass and climate change vulnerability, or differences among clades or locomotion modes. Thus, small mammal species will be negatively impacted by climate change, but the degree of the impact depends on the trajectory of greenhouse gas concentrations. Intrinsic characteristics of the species seem to be less important to predict the vulnerability to climate change than extrinsic characteristics, such as where it occurs, both geographically and in terms of elevation.

Keywords: ecological niche modeling; Rodentia, Didelphimorphia; conservation

Introduction

The accelerated increase in greenhouse gas emissions and changes in land use from human activities in the past decades led to a more accentuated climate change than seen in previous periods of Earth's history, causing impacts both in natural and urban environments. Some of the expected consequences are a rise in global temperature and of the sea level, loss of biodiversity, change in rainfall regime, droughts, ocean acidification, and others (IPCC 2018). The climate is a determining factor in the geographic distribution of species that can respond to changes through phenological modifications, alterations in species abundance, expansion or reduction of distribution, and even complete extinction due to lack of habitat (Davis & Shaw 2001; Parmesan & Yohe 2003; Loarie *et al.* 2008; Vasconcelos *et al.* 2018).

Climate change is connected to the shift in the distribution of some species to climatically more adequate regions, such as previously colder regions that now match species' niches, for example. That shift can occur towards the poles through the expansion of the species' northern boundary (in the case of the Northern Hemisphere), or northern expansion and southern extinction because the southern portion of the distribution is not climatically adequate anymore (Parmesan *et al.* 1999; Thomas & Lennon 1999). The shift can also occur upward in the mountains and it is an important mechanism in tropical regions because the temperature variation in an altitudinal gradient can be more accentuated than in a latitudinal gradient (Brown 2001; Colwell *et al.* 2008; Moritz *et al.* 2008; Parolo & Rossi 2008). However, the area in a mountain range does not necessarily decrease monotonically with the elevation. In the southwest mountains of Brazil (Serra do Mar and Serra da Mantiqueira), for example, species may show a range expansion in the area of occurrence due to the shape of the mountain (Elsen & Tingley 2015). Different species have different ecological requirements and, therefore, the pattern of spatial distribution can vary between groups of living beings, especially in environments complex in terms of topography, microclimates, and biotic interactions (Brown 2001)

The Atlantic Forest is the second-largest rainforest in America, historically covering approximately 1.5 million km² and elevations that range from sea level to 2,900 m. It extends along the coast of Brazil from the states of Rio Grande do Norte to Rio Grande do Sul, and also inland into Misiones in Argentina and Paraguay. The Atlantic Forest has a variety of topographic and climatic characteristics that creates a

very heterogeneous environment with a high degree of endemism and species diversity. It is home to 72% of the Brazilian population and has been the most impacted biome in Brazil (Morellato & Haddad 2000; Ribeiro *et al.* 2011; SOS MATA ATLÂNTICA 2017). The Cerrado is a vast South American savannah, mostly in Brazil, that extends from the states of Maranhão to Paraná in Brazil, into Bolivia and Paraguay. It is the largest savanna in South America and the second-largest biome in Brazil, with approximately 2 million km² and elevations up to 1,800 m. It is also a highly heterogeneous biome with well-marked wet and dry seasons (Ratter *et al.* 1997; Sano *et al.* 2010).

Both biomes are biologically rich, but also threatened due to human activities, and are therefore considered biodiversity hotspots (Myers *et al.* 2000). In the Atlantic Forest, there are about 20,000 plant species and 1,361 vertebrate species, among which 8,000 and 567 are endemic, respectively. In the Cerrado, there are about 10,000 plant species and 1,268 vertebrate species, and 4,400 and 117 endemics, respectively (Myers *et al.* 2000). Considering only animals, the Atlantic Forest has 598 threatened species (428 endemics) and the Cerrado has 307 threatened species (123 endemics) (ICMBio 2016).

There are currently 6,399 extant mammal species in the world, with the Neotropics being the richest region with a total of 1,617 recognized species, and the region with the largest species density of 85.1 species/km² (Burgin *et al.* 2018). Estimates suggest that with global warming, an average of 9.4% of mammal species in any given location in the Americas will not be able to migrate to areas of better environmental suitability. And for 2.4% of species, migration will be limited mainly by the lack of habitat connecting the areas where they currently occur and areas that will be viable for the species in the future (Chen *et al.* 2011; Schloss *et al.* 2012).

Non-volant small mammals, here represented by rodents (Rodentia) and marsupials (Didelphimorphia) are highly diverse within mammals. Rodentia alone is the most diverse mammal group in the world (2,565 species) and also in Brazil (258 species) (Burgin *et al.* 2018; Quintela *et al.* 2020). Non-volant small mammals play many important ecological roles in species-specific fruit consumption; seed consumption and dispersal (Vieira *et al.* 2003; Pimentel & Tabarelli 2004); predation on insects, birds, and other mammals (Carvalho *et al.* 1999; Casella & Cáceres

2006; Pinotti *et al.* 2011); and as prey to birds and other mammals (Bueno & Motta-Junior 2006, 2008; Queirolo & Motta-Junior 2007; Scheibler & Christoff 2007).

Thus, a better understanding of the climate change impact on non-volant small mammals would be useful to predict the future of these species and how the effects on small mammals could impact ecosystems as a whole. Therefore, our goal was to use ecological niche modeling (ENM) to assess future changes in species' geographic distribution and to analyze how species with different characteristics could be affected by climate change.

Methodology

Environmental Data

We used the 19 WorldClim 1.4 bioclimatic variables at 2.5 arc-minutes spatial resolution, using the limits of the Atlantic Forest and Cerrado hotspots plus a 200 km buffer as the calibration area (Fig. 1) (Griffith *et al.* 1998; Hijmans *et al.* 2005). This resolution has good prediction and performance agreement compared to finer grain sizes available at WorldClim, while being computationally faster (Seo *et al.* 2009).

To account for multicollinearity among predictors, we calculated the variance inflation factor (VIF) for all 19 current bioclimatic variables (climate data for 1960-1990) using the *usdm* 1.1-18 package in the R 3.6.3 environment (as for all analyses) and excluded those variables with VIF values greater than 10, resulting in nine selected variables (Chatterjee & Hadi 2006; Naimi *et al.* 2014; R Core Team 2020). Selected variables were: mean diurnal range (BIO02), isothermality (BIO03), mean temperature of the wettest quarter (BIO08), mean temperature of the driest quarter (BIO09), precipitation of wettest month (BIO13), precipitation of driest month (BIO14), precipitation seasonality (BIO15), precipitation of warmest quarter (BIO18), and precipitation of coldest quarter (BIO19), with the minimum VIF value of 1.42 and the maximum VIF value of 8.70.

We used the same set of variables for four Representative Concentration Pathways (RCP) for the year 2070 (average for 2061-2080), from the most optimistic to the most pessimistic scenario: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (van Vuuren *et al.* 2011). We chose the MIROC5 global climate model due to its low equilibrium climate sensitivity (2.72 °C) within one standard deviation from the

multi-model mean ($3.37\text{ }^{\circ}\text{C} \pm 0.83$), thus, being a more conservative approach (Watanabe *et al.* 2010; Andrews *et al.* 2012; Yoshimori *et al.* 2016).

Occurrence Data

Biodiversity data are biased in geographic space toward more accessible areas. This bias can lead to over-representation of better-sampled areas in the environmental space and model overfitting (Hijmans *et al.* 2000; Reddy & Dávalos 2003; Kadmon *et al.* 2004). And even though the development of online databases is making occurrence data more available than ever, small sample sizes in rare and harder to sample species can yield models with low predictive power and high variability between replicates (Hernandez *et al.* 2006; Anderson & Gonzalez 2011; van Proosdij *et al.* 2016). To overcome both problems, we did spatial filtering to reduce sampling bias by retaining one record per raster cell instead of using an arbitrary distance threshold and used only species with at least 15 records (Wisz *et al.* 2008; Anderson & Gonzalez 2011; Kramer-Schadt *et al.* 2013; Boria *et al.* 2014; van Proosdij *et al.* 2016). We also did not use species that occur outside the Atlantic Forest or the Cerrado, so the whole species distribution would be represented in our dataset.

We collected occurrence data from the literature that matched the criteria above, resulting in 2,641 records of 40 species of non-volant small mammals. For each species, we checked for records that are likely errors, such as range outliers, to account for possible geographic and taxonomic errors (Cerqueira 1985; Hoffmann *et al.* 2002; Gardner 2007; Paresque *et al.* 2007; Percequillo *et al.* 2008; Geise & Astúa 2009; Bezerra & de Oliveira 2010; Bonvicino *et al.* 2010; Asfora *et al.* 2011; Costa *et al.* 2011; Moreira & de Oliveira 2011; de la Sancha *et al.* 2012; Valdez & D'Elía 2013; Chiquito *et al.* 2014; Gonçalves & Oliveira 2014; Bezerra & Geise 2015; Loss *et al.* 2015; Patton *et al.* 2015; Christoff *et al.* 2016; Libardi & Percequillo 2016; Pardiñas *et al.* 2016; Peçanha *et al.* 2016; Bovendorp *et al.* 2017; Machado *et al.* 2018; Mendonça *et al.* 2018; Vanny *et al.* 2018; Gonzalez-Iltig *et al.* 2019). This way, we minimized the effects of taxonomic errors on models, which is positively correlated to the distance between species' niches (Costa *et al.* 2015).

Model Calibration and Evaluation

We used 10,000 background points within the calibration area and did k-fold cross-validation of occurrences with five random partitions, so each run had 80% of the occurrences for training and 20% for testing. This resulted in five models for each species, with every presence being used four times for training and once for validation (Phillips & Dudík 2008; Barbet-Massin *et al.* 2012; Hijmans *et al.* 2017).

We used the Maxent 3.4.0 (Phillips & Dudík 2008) algorithm for model calibration because it is a presence-only method with better performance compared to other modeling techniques or ensembling of multiple algorithms, even with small sample sizes (Giovanelli *et al.* 2010; van Proosdij *et al.* 2016; Kaky *et al.* 2020). The enmSdm 0.5.1.5 package implementation of Maxent selects the best model based on Akaike's information criterion across a range of features, regularization multiplier, and the number of coefficient combinations (Warren & Seifert 2011; Phillips *et al.* 2017; Smith 2020). For simpler, yet informative models, we only used a combination of hinge, linear or quadratic features, and regularization multiplier values that ranged from 1 to 4 (Phillips & Dudík 2008; Warren & Seifert 2011; Radosavljevic & Anderson 2014).

We used the continuous Boyce index (CBI) as the main performance metric because it is a presence-only method, not being affected by background extents like the area under the receiver operating characteristic curve (AUC), or specific threshold values like true skill statistic (TSS). We calculated AUC and TSS as a better than random measure. This way, we kept only models with CBI greater than 0.4, AUC greater than 0.5, and TSS greater than 0 (Allouche *et al.* 2006; Hirzel *et al.* 2006; Golicher *et al.* 2012; Leroy *et al.* 2018). We used the enmSdm package to calculate CBI, AUC, and TSS for each partition per species using the 20% of presences separated for testing, then computed the mean and standard deviation across all runs. The species' final model was calculated as the ensemble between the five runs weighted by the CBI of each run. The threshold values were calculated for each run as the 5th percentile suitability value from the presences (10th percentile resulted in unreasonable overestimation of species distributions in the current climate), and the CBI weighted mean threshold value was applied to the ensemble model for final binary transformation, that is, defining areas as either suitable or not suitable (Pearson *et al.* 2006; Urbina-Cardona & Loyola 2008). We trimmed the final

binary output using a 200 km buffer around the species' minimum convex polygon to account for limited dispersal capacity (Mendes *et al.* 2020).

Ecological Data

Using species' trimmed binary models for every scenario we calculated the log-transformed absolute area in km², computed the area ratio as the future absolute area (for each future scenario) divided by the current absolute area as an index of climate change impact, extracted minimum, median and maximum elevation. We obtained species' biomes occurrence, body mass (which we applied a log transformation), and locomotion (Paglia *et al.* 2012). When mass was given as an interval, we used the average value from the interval.

We used the future area ratio and the International Union for Conservation of Nature (IUCN) Red List A3 criteria (IUCN 2012) to assess species' future level of threat. The criteria definition is "population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years)", and it can be based on the decline in area of occupancy (AOO), which is defined as: "The area within its 'extent of occurrence' which is occupied by a taxon, excluding cases of vagrancy. The measure reflects the fact that a taxon will not usually occur throughout the area of its extent of occurrence, which may contain unsuitable or unoccupied habitats". A reduction of $\geq 30\%$ in the AOO would classify the species as vulnerable (VU), a reduction of $\geq 50\%$ would classify the species as endangered (EN), and a reduction of $\geq 80\%$ would classify the species as critically endangered (CR). The current status was extracted from the IUCN Red List website (IUCN 2020). One bias of this analysis is that criteria A is measured over the longest of 10 years or 3 generations, and the current and future scenarios used in the modeling process have an 80-year interval, so the results should be interpreted carefully.

To estimate niche breadth, we created a principal component analysis raster based on the 19 bioclimatic variables and took the first 3 axes, which represented 79.18% of the variation in climatic data. We extracted the values for every record per species and computed variance for each axis. Then we multiplied the three variances and used the log-transformed result as an index of niche breadth (Saupe *et al.* 2015; Gómez *et al.* 2016; Liu *et al.* 2020).

Species richness was calculated by summing all trimmed models, extracting all cell values, and then computing the mean value and standard deviation across all raster cells.

Statistical Analyses

We used the *rstatix* package to perform all statistical analyses. First, we tested normality using the Shapiro–Wilk test and then applied the appropriate tests to detect differences among groups. We used repeated-measures analysis of variance (ANOVA) or Friedman test for normal and non-normal distribution data, respectively, to test for significant differences in absolute area, minimum, median, and maximum elevation, and paired t-test or sign test to test for significant differences between groups. We used ANOVA or Kruskal-Wallis for normal and non-normal distribution data, respectively, and t-test or Dunn test as post-hoc analysis to test for significant differences between biomes, clades, and locomotion modes (Kassambara 2020). We removed *Nectomys squamipes* from the locomotion comparison because it was the only semi-aquatic species in our dataset.

We computed phylogenetic generalized linear model (PGLS) using the *caper* R package (Orme *et al.* 2018) with a species-level mammalian phylogenetic tree (Upham *et al.* 2019) to test for a relationship between future area ratio and median elevation, niche breadth, and body mass while taking into account the non-independence of the data points, i.e., the phylogenetic signal.

Results

The performance metrics for all species indicate good average performance in all species, with a minimum mean CBI value of 0.41. The median CBI value was 0.82 (± 0.15), the median AUC value and standard deviation were 0.94 (± 0.02), and the median TSS value was 0.67 (± 0.07) (Table S1).

We found that the absolute area gradually decreased in all future scenarios, with median log scale absolute area values that ranged from 13.71 (± 0.86) in the current scenario to 13.16 (± 0.86) in RCP 8.5 (Fig. 2a, Table 1). There was a significant difference between the current climate and all future scenarios, and between all future scenarios, except for RCP 6.0 which was not statistically different

from any future scenario (Table S2). This decrease in species' area led to an overall decrease in mean species richness per pixel, with an average of 7.75 species (± 8.34) for the current climate, 5.09 species (± 7.79) for the RCP 2.6, 4.71 species (± 7.58) for the RCP 4.5, 4.40 species (± 7.71) for the RCP 6.0, and 4.03 (± 7.41) species for the RCP 8.5 scenario. The high standard deviation values are due to the low number of species in the buffer area. In all future scenarios, increasing species richness was more evident in the southern Atlantic Forest in Brazil, as indicated by the marginal plot in Figure 1. Decreasing species richness was widespread across the Cerrado and evident in the south of Bahia, north of Espírito Santo, south of São Paulo, north of Paraná, south of Mato Grosso do Sul in Brazil, and east of Paraguay (Fig. 1). We found the same results of decreasing absolute area values when analyzing only AF, only CR, or only AFCR species, with the current scenario statistically different from all future scenarios (Fig. 2b, Table S2).

Regarding the future area ratios (future area/current area), we found that future area ratios decreased in every scenario from RCP 2.6 to RCP 8.5, except for RCP 6.0 that had a higher median value than RCP 4.5 (Table 1). AF species had higher ratios and Cerrado species had the lowest values, with AFCR species showing an intermediate response (Fig. 2c). We found the same pattern when analyzing each biome separately. In all scenarios, there was a significant difference between AF and CR species and between AF and AFCR species except in RCP 4.5, but no significant difference between AFCR and CR (Table S3). Individual species' responses can be seen in supplementary figure 1.

The current level of threat of 37 species is Least Concern (LC) and 3 species are classified as Data Deficient (DD). The reduction of the future area relative to current climate conditions reflected negatively on the species' future level of threat, as the number of species in a more threatened category increases in every scenario, from RCP 2.6 to RCP 8.5 (Fig. 3). The same pattern can be observed when analyzing all species or when grouping species by biomes, with AF species status being proportionally less affected than AFCR and CR species (Fig. 3).

The median elevation of suitable areas increased in every scenario suggesting an increased preference for higher elevations, with the highest median value of 652 m (± 150.30 m) in RCP 4.5, not RCP 8.5 (Fig S2, Table 1). We found that median elevations of the current climate and RCP 2.6 are statistically different from RCP 4.5

and RCP 8.5, but not statistically different from RCP 6.0. RCP 6.0 is statistically different only from RCP 8.5 (Table S4). We found no significant difference between any scenario in minimum elevation or maximum elevations (Fig. S2).

There was no significant difference between clades (i.e. rodents and marsupials (Fig. S3, Table S5) or between any of the locomotion modes (Fig. S4, Table S6) in any scenario.

We found a significant negative relationship between current median elevation and response ratio for RCP 2.6 (p-value = 0.020, R-squared: 0.112, slope < -0.001), RCP 4.5 (p-value = 0.006, R-squared: 0.161, slope < -0.001) and RCP 8.5 (p-value = 0.041, R-squared: 0.082, slope < -0.001), but not significant for RCP 6.0 (p-value = 0.129, R-squared: 0.035, slope < -0.001) (Fig. 4a). We found no significant relationship between niche breadth (Fig. 4b) or body mass (Fig. 4c) and response ratio in any scenario.

Discussion

Our results of range contraction and reduction in species richness are compatible with other studies on Atlantic Forest amphibians, birds, snakes, and primates (Loyola *et al.* 2012, 2014; Vale *et al.* 2018; Lima *et al.* 2019; Lourenço-de-Moraes *et al.* 2019), as well as Cerrado mammals and plants (Hidasi-Neto *et al.* 2019; Velazco *et al.* 2019). One consequence of the reduction of the geographic distribution of the species is the change in the pattern of alpha diversity due to species loss, resulting in increased spatial heterogeneity (Lemes *et al.* 2014; Lima *et al.* 2019).

As expected, species will lose area in all future scenarios, with RCP 2.6 being the best-case scenario, RCP4.5 and RCP 6.0 having intermediary responses, and RCP 8.5 being the worst-case scenario. In the best-case scenario, species will lose on average 30% of their current distribution, reaching on average 39% loss in the worst-case scenario. RCP 4.5 and RCP 6.0 showed intermediate responses, with an average area decrease of 36% for RCP 4.5, and 33% for RCP 6.0. These percentages are highly biased by AF species which will lose proportionally less area than CR species, but represent 65% (n=26) of the species in our dataset, whereas the CR species represent only 10% (n=4), and AF-CR species represent 25% (n=10).

Both extreme scenarios seem to be unreasonable, given that RCP 2.6 would require extraordinary efforts by the governments to keep global warming below 2° C, whereas RCP 8.5 assumes a fivefold increase in coal usage as an energy source, an unlikely trajectory that should not be considered a priority for scientific research (van Vuuren *et al.* 2011; Rogelj *et al.* 2016; Ritchie & Dowlatabadi 2017; Hausfather & Peters 2020). RCP 6.0 seems to be a scenario where AF species experience a smaller range reduction when compared to AFCR and CR species. In RCP 6.0, CR species lose proportionally three times more area and AFCR species lose two times more area than AF species, while in RCP 8.5, CR species lose 2.3 times more and AFCR species lose 1.6 times more area than AF species. Although the difference among biomes is smaller in RCP 8.5 than in RCP 6.0, the mean ratios for all species are on average smaller in the RCP 8.5.

It is estimated that the Atlantic Forest reduction will be between 20% and 30% with the displacement of the forest to colder areas in the south (Colombo & Joly 2010). Cerrado species will lose between 40% and 60% of their distribution depending on the climate change scenario (Velazco *et al.* 2019). As currently colder areas such as the southern Atlantic Forest become warmer with climate change, species start to cluster in these regions as the new climate matches species' current niche. On the other hand, currently warm areas such as Cerrado and northern Atlantic Forest, being even warmer under climate change, species wouldn't be able to live in such regions with their current niche. This might explain the bigger difference between AF and CR species and explain why AFCR species show an intermediate response. AFCR species would lose most of their area in Cerrado but would still be able to maintain or expand their area in the Atlantic Forest.

In the future scenarios, species will face climatic conditions different from those in their current distributions, consequently, moving usually toward the poles to regions with environmental conditions more similar to their current niche. Eventually, species in some locations will not be able to track climate change, leading to a reduction in range sizes (Chen *et al.* 2011; Schloss *et al.* 2012; VanDerWal *et al.* 2013), as observed here. As range size decreases, so does the overlap among species distributions, leading to the decrease in the mean species richness as a consequence of local extinctions (Vale *et al.* 2018; Lima *et al.* 2019). *Juliomys ossitenuis* Costa, Pavan, Leite & Fagundes, 2007, an arboreal AF endemic rodent,

showed the largest relative area reduction in all scenarios but RCP 6.0, where CR species showed a bigger area reduction. *Brucepattersonius iheringi* (Thomas, 1896), a semifossorial AF endemic rodent that occurs in the southern Atlantic Forest where more species are expected to occur in the future, was the only species that showed an area increase, and only in RCP 6.0 with a future area ratio of 1.08, which is likely a particular case. In all other scenarios, there was an area reduction with ratios of 0.98 for RCP 2.6, 0.78 for RCP 4.5, and 0.78 for RCP 8.5 for *B. iheringi*.

Another factor to consider is that our model incorporates only climatic variables, not land-use change, a major factor in both hotspots. Approximately 28% of the Atlantic Forest remains today, although most of it is not protected and likely of secondary vegetation (Arroyo-Rodríguez *et al.* 2017; Rezende *et al.* 2018), and 47% of Cerrado's natural vegetation remains today (Beuchle *et al.* 2015). Considering only the fraction covered by native vegetation, 30% of the Atlantic Forest and only 6.5% of the Cerrado is within protected areas (Françoso *et al.* 2015; Rezende *et al.* 2018). The usage of current land-use or future land-use models as predictors to trim future projections in areas such as cities or pastures would certainly affect our results as less area would be available for species, but we have not found any South American land-use projections for the year 2070, only for Europe (Rounsevell *et al.* 2006; Holman *et al.* 2017)

The Serra do Mar mountain range in the Atlantic Forest is a species-rich area for birds, mammals, and amphibians, with a richness of endemic and small ranged species greater than Amazonia (Jenkins *et al.* 2015). Despite the high density of sampling in the Atlantic Forest, especially in the Serra do Mar region, it is still an area with a large number of data deficient species according to the IUCN (Jenkins *et al.* 2015). Not only will this area have stability in the number of species across all future scenarios, but it is also a region with many protected areas. This means that it could act as Anthropocene refugia, i.e., areas that will be climatically suitable in the future and have low levels of anthropogenic pressures, thus being a very important region for the maintenance of biodiversity (Jenkins *et al.* 2015; Morelli *et al.* 2016; Monsarrat *et al.* 2019). In the southern Atlantic Forest, where the expected gain of species is bigger, the vegetation cover varies between 30% and 60% but it has few fully protected areas (Jenkins *et al.* 2015; Rezende *et al.* 2018). This region should be of high interest for planning new protected areas because it has an intermediate

vegetation cover that could be rapidly improved, and climatic potential to harbor more mammals species in the future (our results) as well as amphibians (Lemes *et al.* 2014).

Endemic species with small ranges, like the ones found in the Atlantic Forest, are usually more threatened and at risk of extinction than widespread species, such as the ones in the Cerrado, which have higher absolute area values (Manne & Pimm 2001; Böhm *et al.* 2016). However, our analysis showed that a smaller proportion of AF species will become threatened than CR or AFCR species. In the RCP 8.5, for example, 62% of the AF species, 90% of AFCR species, and 100% of the CR species will become threatened. This highlights the importance of considering the implementation of new protected areas, especially in the Cerrado, and taking into account the species distribution range shift dynamics during the establishment of the new protected areas. An early implementation of new protected areas can be more effective in terms of species conservation, but also require less area than a delayed response, thus having a smaller socio-economic impact (Hannah *et al.* 2007; Araújo *et al.* 2011).

One unexplored possibility is to analyze how untrimmed binary models would affect the species' future distributions. Assisted migration can be a useful tool to prevent species extinctions in the wild when they are unable to disperse and might be the only option for some species to survive (Butt *et al.* 2021). Some factors important to consider are the species' probability of extinction due to climate change, translocation technical feasibility, species' ecological roles, and socioeconomic costs in the target habitat (Hunter 2007; Hoegh-Guldberg *et al.* 2008). The translocation can be done within the range of a widespread species, i.e. reintroduction of a species where it has been locally extinct, or outside its range to replace an ecological equivalent species that has been extinct (Hunter 2007; Hoegh-Guldberg *et al.* 2008; Thomas 2011). Instead of focusing on single species translocations, another option is to focus on creating landscape connectivity so a large number of species would be able to migrate naturally. This approach, however, would have a low impact on species with low vagility or species with specific habitat conditions, which wouldn't be able to disperse and thus, would likely go extinct (Mawdsley *et al.* 2009).

Occurrence records of neotropical species are often scarce, known absences are even more uncommon, so much is unknown about the distribution of the

neotropical species (Hortal *et al.* 2015). The use of ENM algorithms that incorporate absences is not possible for most species and the use of occurrence-only species distribution modeling techniques, such as Maxent, maybe the only option. But it can be a limitation as well because our knowledge of the limits of species' niches is based only on occurrences, therefore, we do not know if a species would not survive in the projected climate change scenarios due to the lack of known absences or physiological experiments on Neotropical species. We can only infer the likelihood of a species occurrence in a given area in the future based on its current distribution, which is affected by other factors such as biological interactions, dispersion limitations, or land use, and we also fail to consider the role phenotypic plasticity may play in the adaptation to new environments in ecological time scales (Ghalambor *et al.* 2007; Soberón & Nakamura 2009).

There was a significant statistical difference in elevation only between the median elevation of the most distinct climatic scenarios. The lack of statistical difference between any scenario in the minimum and the maximum elevation is surprising, as climate conditions can greatly vary in an elevational gradient but the raster resolution might not have been fine enough to capture those differences, so a finer resolution might be necessary, although it may not be viable considering the extent of our calibration area. The relationship between the current median altitude and the future area ratio is expected because the species will try to track climate change by migrating to other regions or moving upwards in mountains and retracting from lower elevations (Moritz *et al.* 2008; Chen *et al.* 2009, 2011). The area available in the Atlantic Forest and Cerrado mountain ranges peak at mid-range elevations, then dramatically decrease at higher elevations (Elsen & Tingley 2015). This pattern might benefit species from low elevations as area increases up to mid-elevations, but might be detrimental after these species reach mid-elevations, and also to those species which already occupy mid and high elevations, as the area starts to decrease up to a point where species or populations cannot coexist, leading to some species or communities extinctions.

We expected a significant relationship between niche and future area ratios because species with smaller niches live in more specific conditions, which they might not be able to track as the climate changes, while species with wider niches would be able to live in a variety of conditions, being less affected by changes in

climate. However, species climatic niches do not evolve faster in species with wider niches than in species with restricted niches. Divergence time may be more important to define the rates of evolution, so a younger clade may evolve more rapidly in a short time, adapting to climate change, whereas older lineages would conserve their niche due to conservatism, thus, being more vulnerable to climate change (Jezkova & Wiens 2016; Liu *et al.* 2020). Although our results did not show it, we expected body mass to be a good predictor of species vulnerability to climate change, where bigger species would be more vulnerable than smaller species. The decrease of body mass related to climate change is a well-known phenomenon across mammals and birds, which has been observed empirically, and that likely will affect species in the future. (Smith *et al.* 1998; Martin *et al.* 2018; Prokosch *et al.* 2019).

Conclusions

Climate change will negatively impact small mammals species in both biodiversity hotspots, even in the most optimistic scenario, affecting their geographic and elevational distribution ranges, with implications on the species' future level of threat. The actions we take as a society might mitigate those impacts, as the impacts may vary depending on greenhouse gas concentrations trajectory, but there will be significant differences relative to the current scenario nonetheless. The biome where species live and the elevation range they occupy are better predictors of species vulnerability to climate change, that is, species that live in the Cerrado or higher elevations are at a greater risk than Atlantic Forest and lowland species, respectively. Intrinsic characteristics such as body mass, clade, or locomotion modes are not as good predictors. Integrating land-use models is key to better understand how species respond to climate change in a human-dominated world, and to use this knowledge to plan conservation actions.

Figures

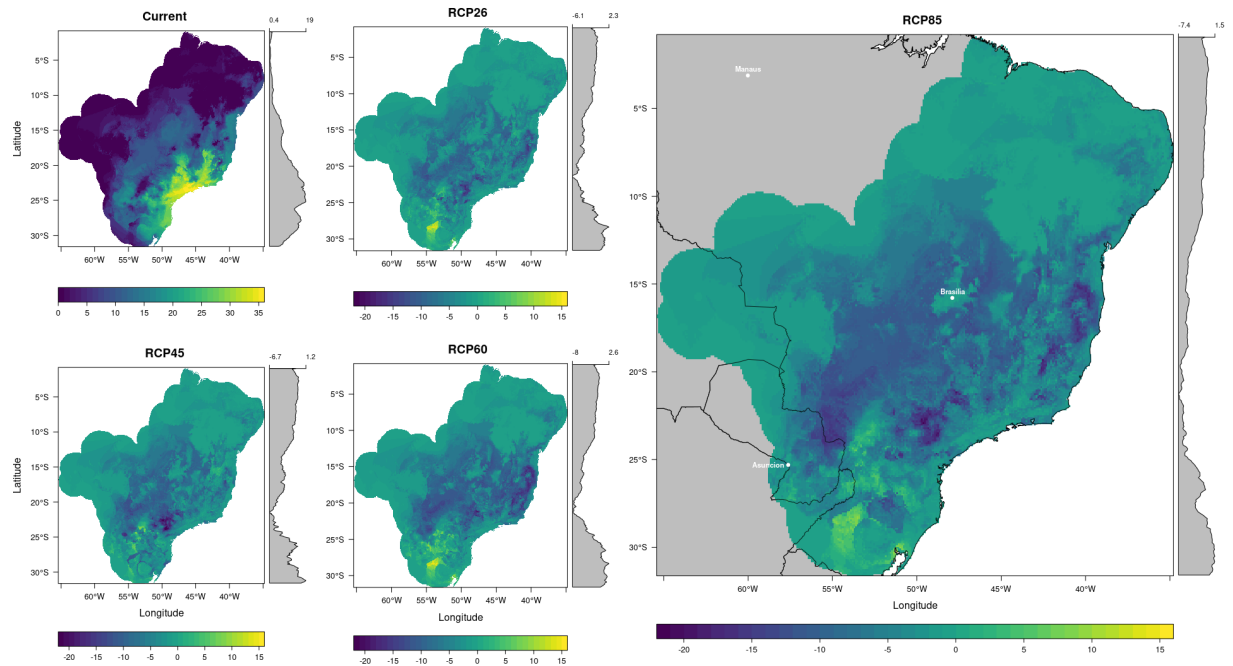


Figure 1: The first panel (Current) shows species richness in the current climate, the scale shows the absolute number of species, and the marginal plot to the right shows the mean number of species by latitude. The remaining panels (RCP 2.6 - RCP 8.5) show the difference between each scenario and current climate species richness, the scale shows the gain (yellow) or loss (blue) of the number of species relative to the current climate, and the marginal plot shows mean difference relative to the current climate by latitude.

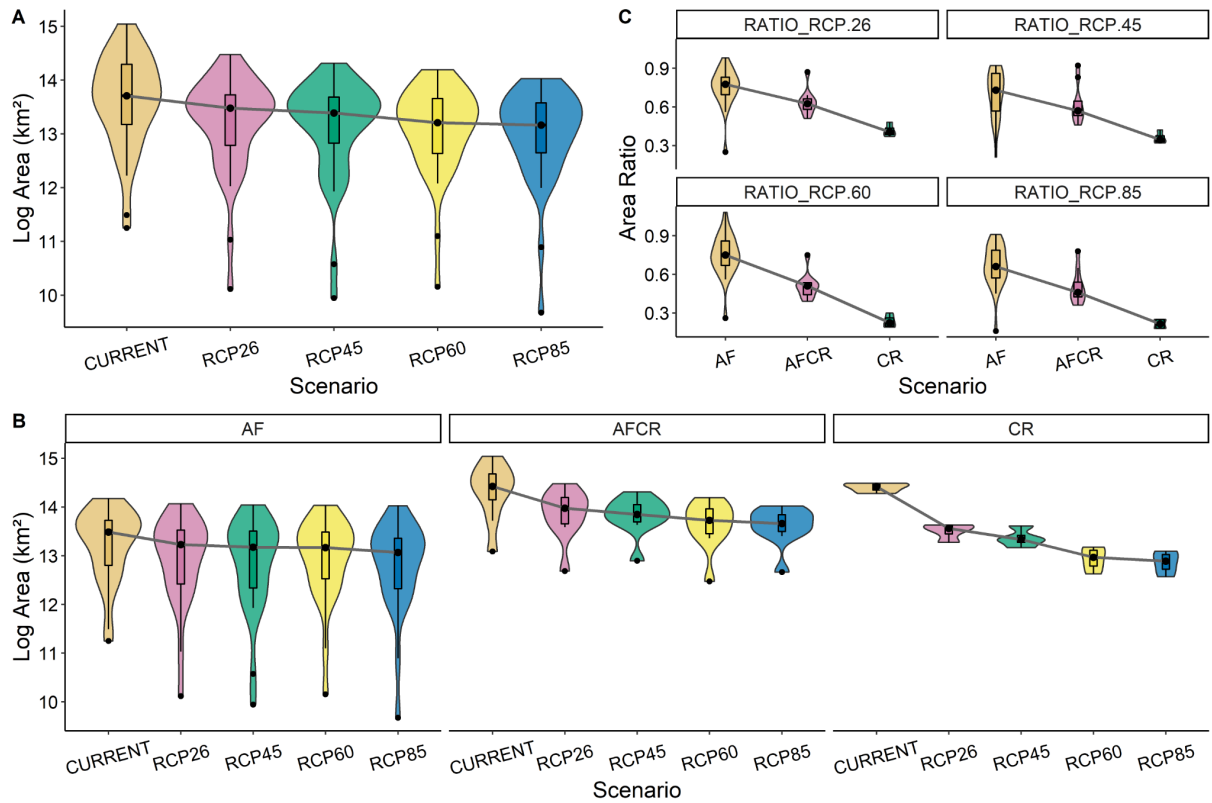


Figure 2: Boxplot and violin plot of the A) Log scale of area (km²) for all species in the five scenarios analyzed B) Log scale of area (km²) in the five scenarios analyzed, grouped by species' biome, Atlantic Forest only species (AF), Atlantic Forest and Cerrado species (AF-CR), and Cerrado only species (CR) C) Future area ratio relative to Current distribution grouped by the RCP scenario.

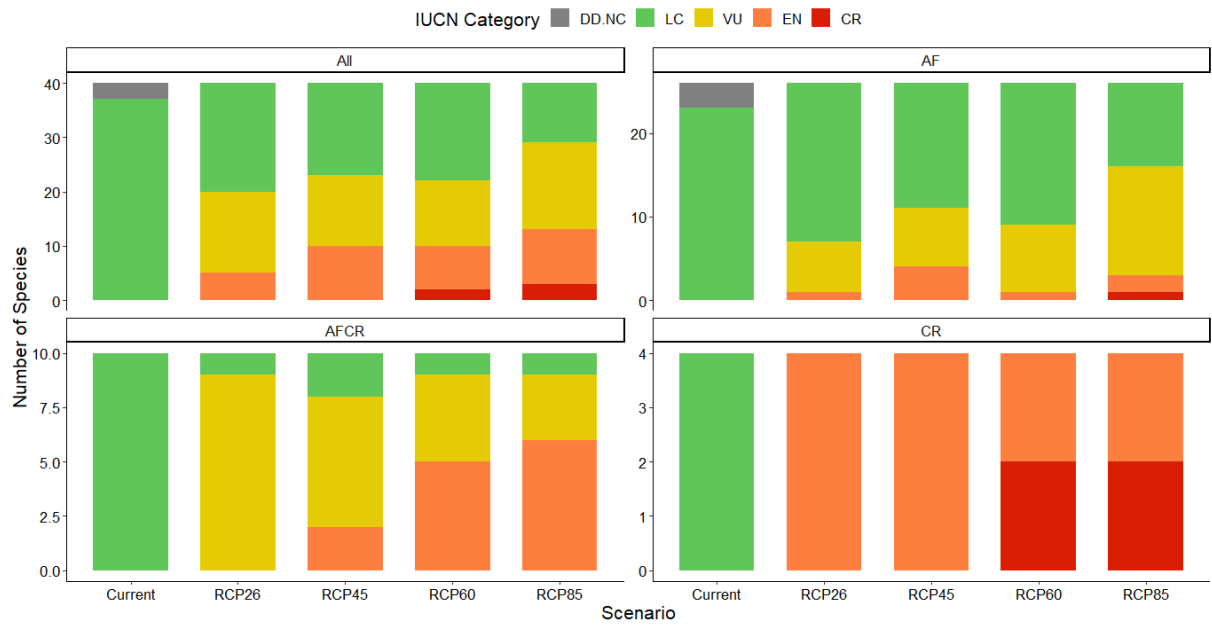


Figure 3: The first panel shows the number of species on each IUCN level of threat for all species in each scenario. Other Panels show the number of species on each IUCN level of threat in each scenario grouped by biome, as indicated by subtitles. Gray is for Data Deficient, green is for Least Concern, yellow for Vulnerable, orange is for Endangered, and red for Critically Endangered

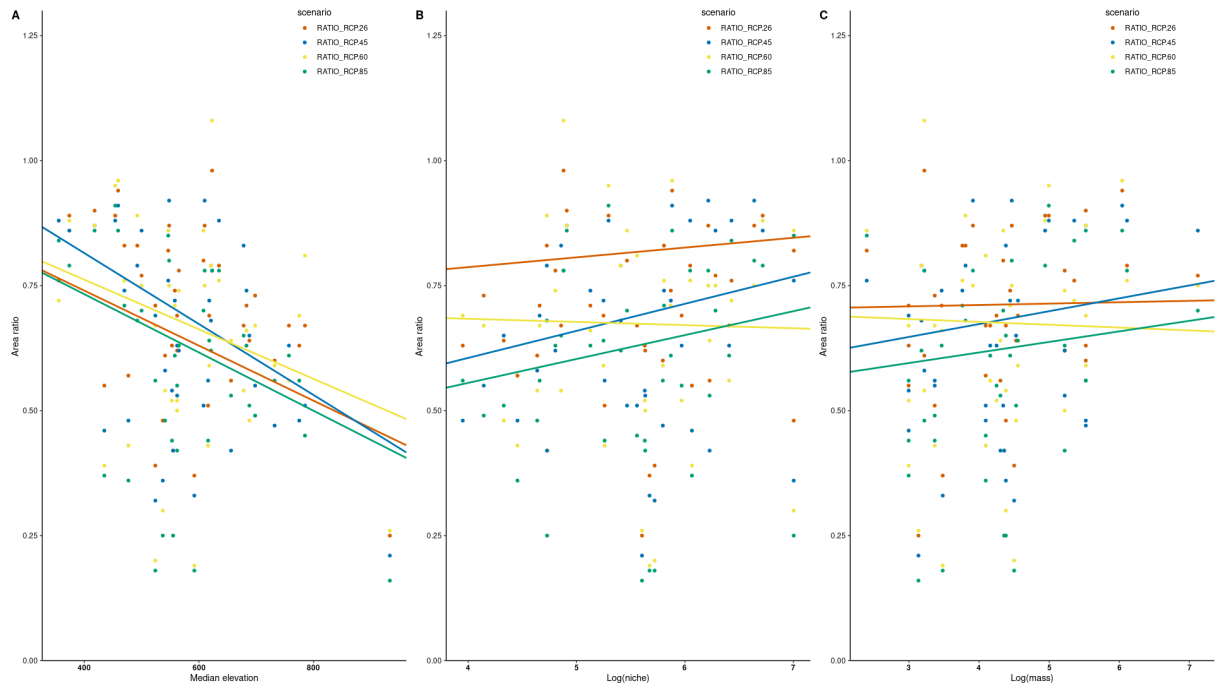


Figure 4: Phylogenetic generalized linear models showing the relationship between future area ratio and A) median elevation B) Log scale of the niche breadth C) Log scale of the body mass. Orange dots and lines represent the RCP 2.6 scenario, blue represents the RCP 4.5 scenario, yellow represents the RCP 6.0 scenario, and green represents the RCP 8.5 scenario.

Tables

Table 1: Absolute log scale area values, future area ratios, and median elevations of each scenario for all species. The number in parenthesis represents the standard deviation.

Scenario	Absolute Area	Future Area Ratio	Median elevation
CURRENT	13.71 (± 0.86)	1	562 m (± 118.03 m)
RCP 2.6	13.48 (± 0.87)	0.70 (± 0.17)	623 m (± 136.13 m)
RCP 4.5	13.39 (± 0.92)	0.64 (± 0.19)	652 m (± 150.30 m)
RCP 6.0	13.21 (± 0.80)	0.67 (± 0.22)	629 m (± 142.91 m)
RCP 8.5	13.16 (± 0.86)	0.61 (± 0.20)	649 m (± 158.56 m)

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Supplementary Material

Supplementary Results

Considering only Atlantic Forest (AF) species, the absolute area decreases in all future scenarios. Median log scale absolute area values and standard deviation were 13.49 (± 0.75) for the current climate, 13.23 (± 0.90) for RCP 2.6, 13.18 (± 0.98) for RCP 4.5, 13.17 (± 0.87) for RCP 6.0, and 13.07 (± 0.94) for RCP 8.5 (Fig. 2b). There was a significant difference between the current climate and all future scenarios, between RCP 2.6 and RCP 8.5, and between RCP 6.0 and RCP 8.5 (Table S2).

For species that occur both in the Atlantic Forest and the Cerrado (AFCR), the absolute area decreases in all future scenarios. Median log scale absolute area values were 14.42 (± 0.58) for the current climate, 13.98 (± 0.50) for RCP 2.6, 13.85 (± 0.39) for RCP 4.5, 13.73 (± 0.49) for RCP 6.0, and 13.66 (± 0.39) for RCP 8.5 (Fig. 2b). There was a significant difference between the current climate and all future scenarios between RCP 2.6 and RCP 6.0, RCP 2.6 and RCP 8.5, and RCP 4.5 and RCP 8.5 (Table S2).

Considering only Cerrado (CR) species, the absolute area decreases in all future scenarios. Median log scale absolute area values were 14.42 (± 0.10) for the current climate, 13.56 (± 0.16) for RCP 2.6, 13.33 (± 0.18) for RCP 4.5, 12.97 (± 0.25) for RCP 6.0, and 12.89 (± 0.24) for RCP 8.5 (Fig. 2b). There was a significant difference between the current climate and all future scenarios between RCP 2.6 and RCP 6.0, RCP 2.6 and RCP 8.5, and RCP 4.5 and RCP 8.5 (Table S2).

The median RCP 2.6 ratio was 0.70 (± 0.17) for all species, 0.78 (± 0.15), 0.63 (± 0.10), and 0.41 (± 0.05) for AF, AFCR, and CR species, respectively (Fig. 2c). There was a significant difference between AF and the other groups, but not between AFCR and CR species (Table S3). The median RCP 4.5 ratio was 0.64 (± 0.19) for all species, 0.73 (± 0.18), 0.57 (± 0.15), and 0.35 (± 0.05) for AF, AFCR and CR species, respectively (Fig. 2c). There was a significant difference only between AF and CR species (Table S3). RCP 6.0 median ratio was 0.67 (± 0.22) for all species, 0.75 (± 0.16), 0.51 (± 0.10), 0.23 (± 0.10) for AF, AFCR and CR species, respectively (Fig. 2c). There was a significant difference between AF and the other groups, but not between AFCR and CR species (Table S3). RCP 8.5 median ratio was 0.61 (\pm

0.20) for all species, 0.66 (± 0.16), 0.46 (± 0.13), and 0.22 (± 0.04) for AF, AF-CR and CR species, respectively (Fig. 2c). There was a significant difference between AF and the other groups, but not between AF-CR and CR species (Table S3).

We found no significant difference between any scenario in minimum elevation, with median values of 0 m (± 36.71 m), 0 m (± 85.76 m), 0 (± 105.07 m), 0 m (± 93.59 m), and 0 m (± 120.59 m) for current, RCP26, RCP45, RCP60, and RCP85, respectively.

We found no significant difference between any scenario in maximum elevation, with median values of 2351 m (± 214.49 m), 2351 m (± 222.84 m), 2351 m (± 230.00 m), 2351 (± 222.06 m), and 2351 m (± 214.12 m) for current, RCP26, RCP45, RCP60, and RCP85, respectively.

We found no significant relationship between niche breadth and response ratio in RCP26 (p-value: 0.419, R-squared: -0.009, slope < 0.001), RCP45 (p-value: 0.116, R-squared: 0.039, slope < 0.001), RCP60 (p-value: 0.896, R-squared: -0.026, slope < 0.001) or RCP85 (p-value: 0.198, R-squared: 0.018, slope < 0.001) (Fig. 4b).

We found no significant relationship between body mass and response ratio in RCP26 (p-value: 0.954, R-squared: -0.026, slope: 0.003), RCP45 (p-value: 0.630, R-squared: -0.02, slope: 0.026), RCP60 (p-value: 0.093, R-squared: -0.026, slope: -0.006) or RCP85 (p-value: 0.715, R-squared: -0.023, slope: 0.021) (Fig. 4c).

Rodents' median ratios were 0.71 (± 0.13), 0.76 (± 0.18), 0.66 (± 0.19) and 0.65 (± 0.18) for current climate, RCP26, RCP45, RCP60 and RCP85, respectively. Marsupials median ratios were 0.69 (± 0.18), 0.63 (± 0.19), 0.67 (± 0.23) and 0.56 (± 0.21) for current climate, RCP26, RCP45, RCP60 and RCP85, respectively.

There was no significant difference between any of the locomotion modes in any scenario. RCP26 ratios were 0.71 (± 0.19), 0.77 (± 0.11), 0.67 (± 0.15) and 0.74 (± 0.19) for arboreal, scansorial, terrestrial and semifossorial species, respectively. RCP45 ratios were 0.63 (± 0.23), 0.86 (± 0.13), 0.56 (± 0.17) and 0.67 (± 0.15) for arboreal, scansorial, terrestrial and semifossorial species, respectively. RCP60 ratios were 0.69 (± 0.22), 0.75 (± 0.17), 0.64 (± 0.21) and 0.67 (± 0.29) for arboreal, scansorial, terrestrial and semifossorial species, respectively. RCP85 ratios were 0.62 (± 0.22), 0.70 (± 0.16), 0.51 (± 0.19) and 0.64 (± 0.20) for arboreal, scansorial, terrestrial and semifossorial species, respectively.

Supplementary Figures

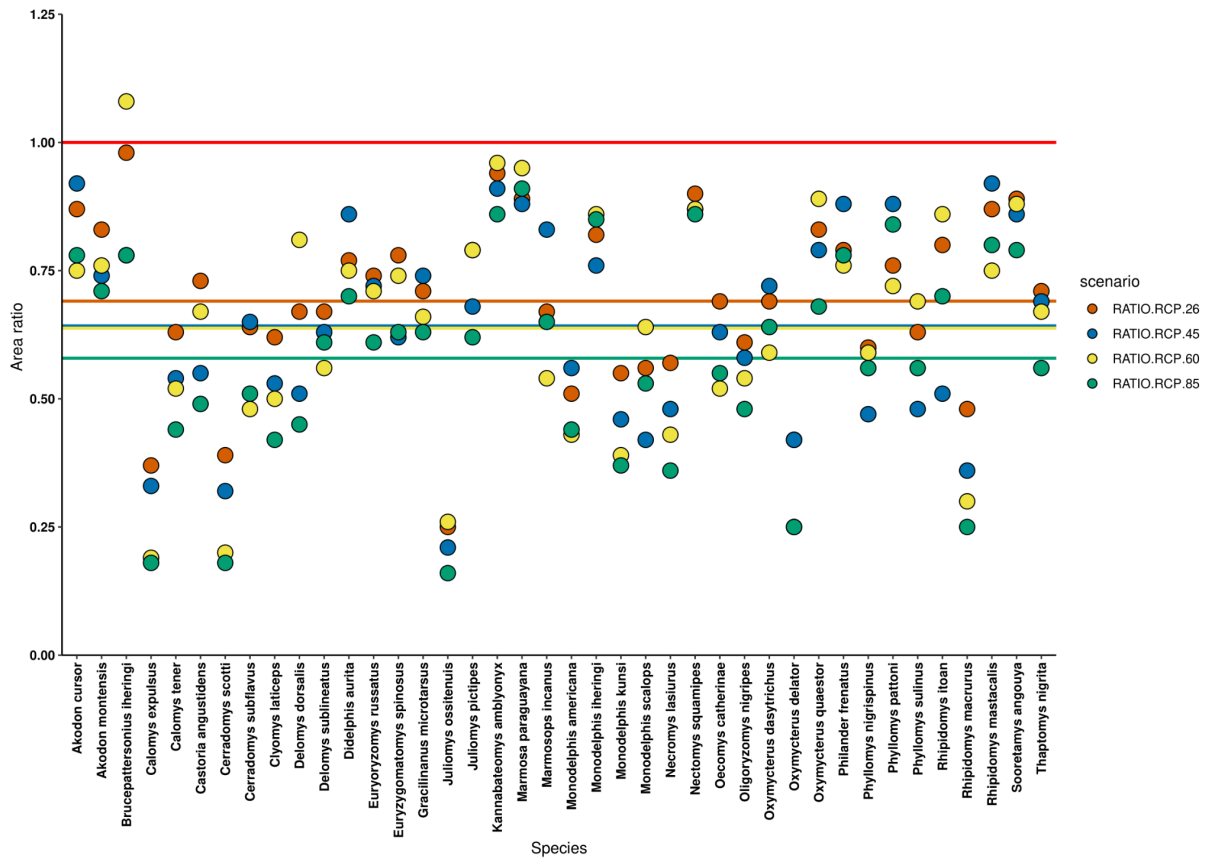


Fig S1: Individual species' responses to climate change. Redline represents the Current climate baseline, orange dots represent the RCP 2.6 scenario ratio, blue dots represent the RCP 4.5 scenario ratio, yellow dots represent the RCP 6.0 scenario ratio, and green dots represent the RCP 8.5 scenario ratio.

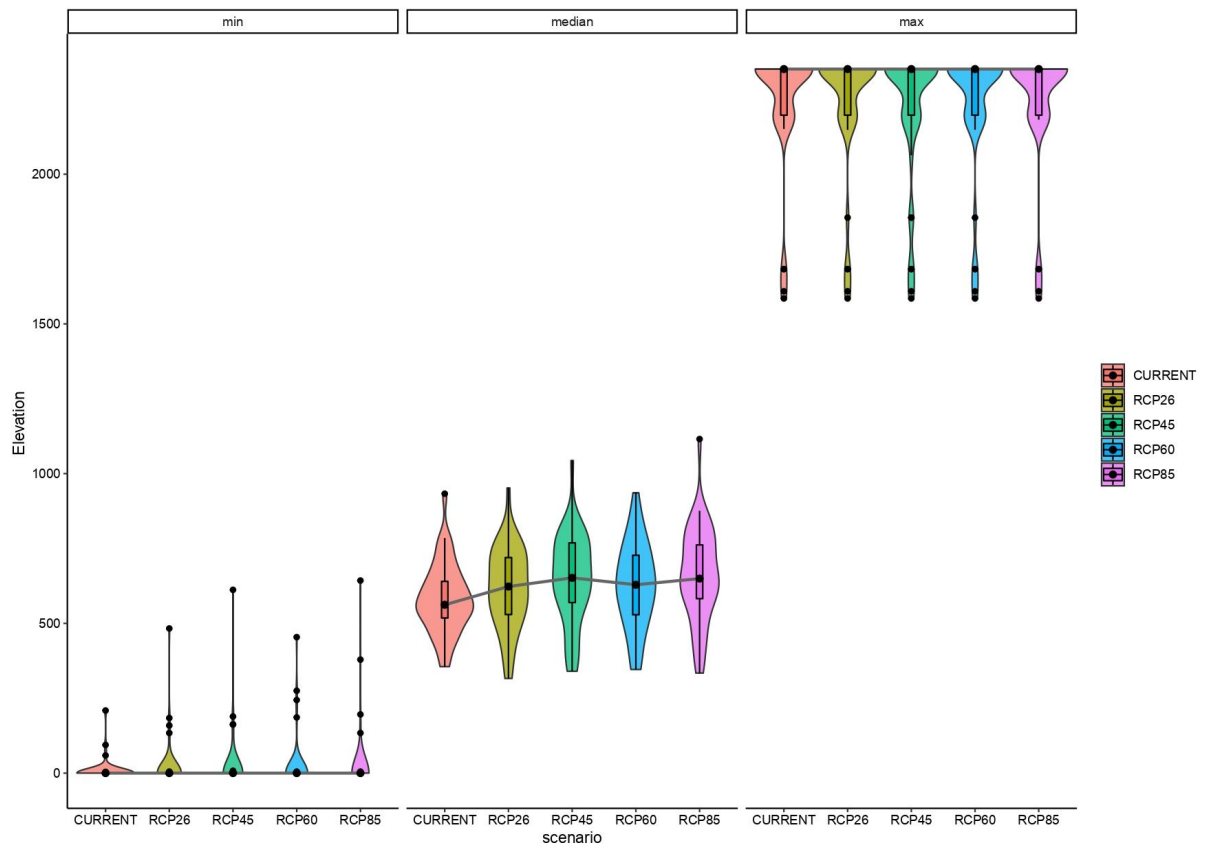


Figure S2) Boxplot and violin plot of the minimum, median and maximum elevation for each scenario analyzed

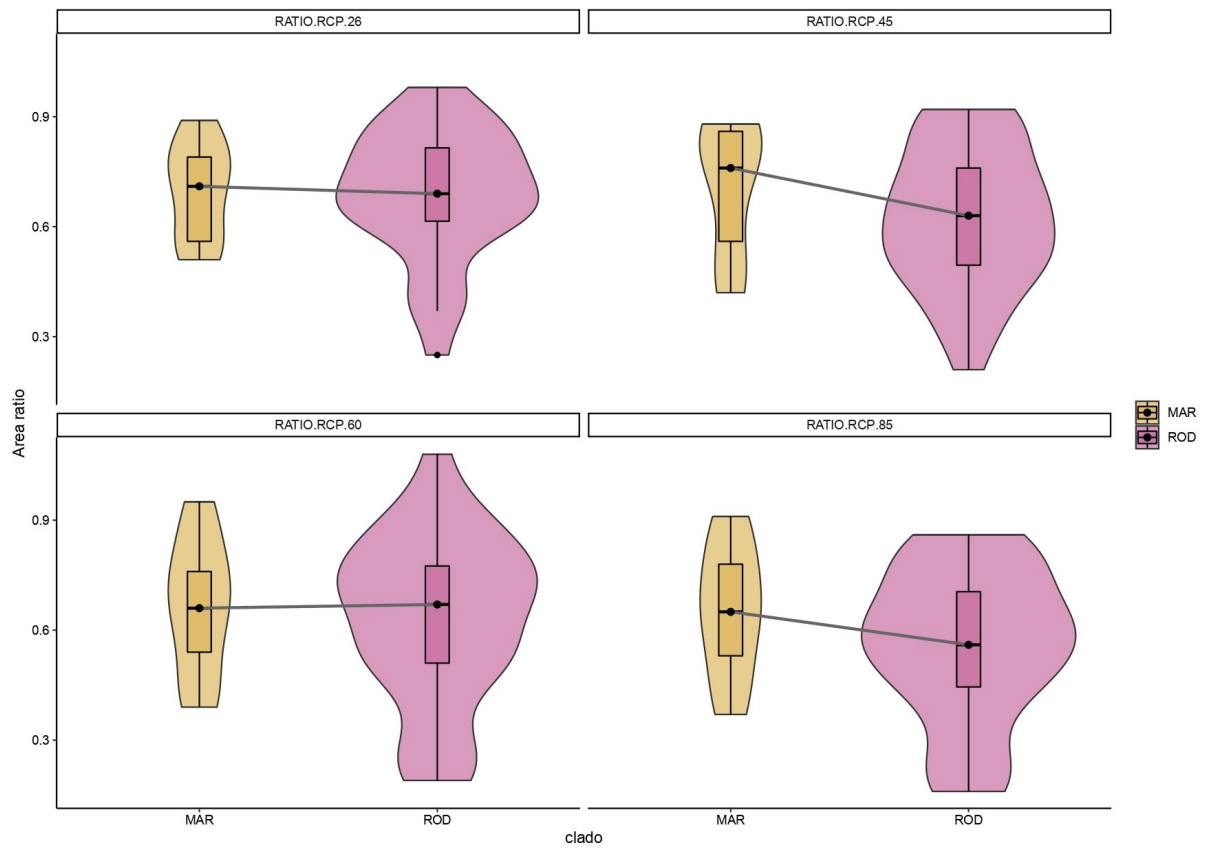


Figure S3) Boxplot and violin plot of the future area ratio for each clade, marsupials (MAR), and rodents (ROD), grouped by future climate scenario.

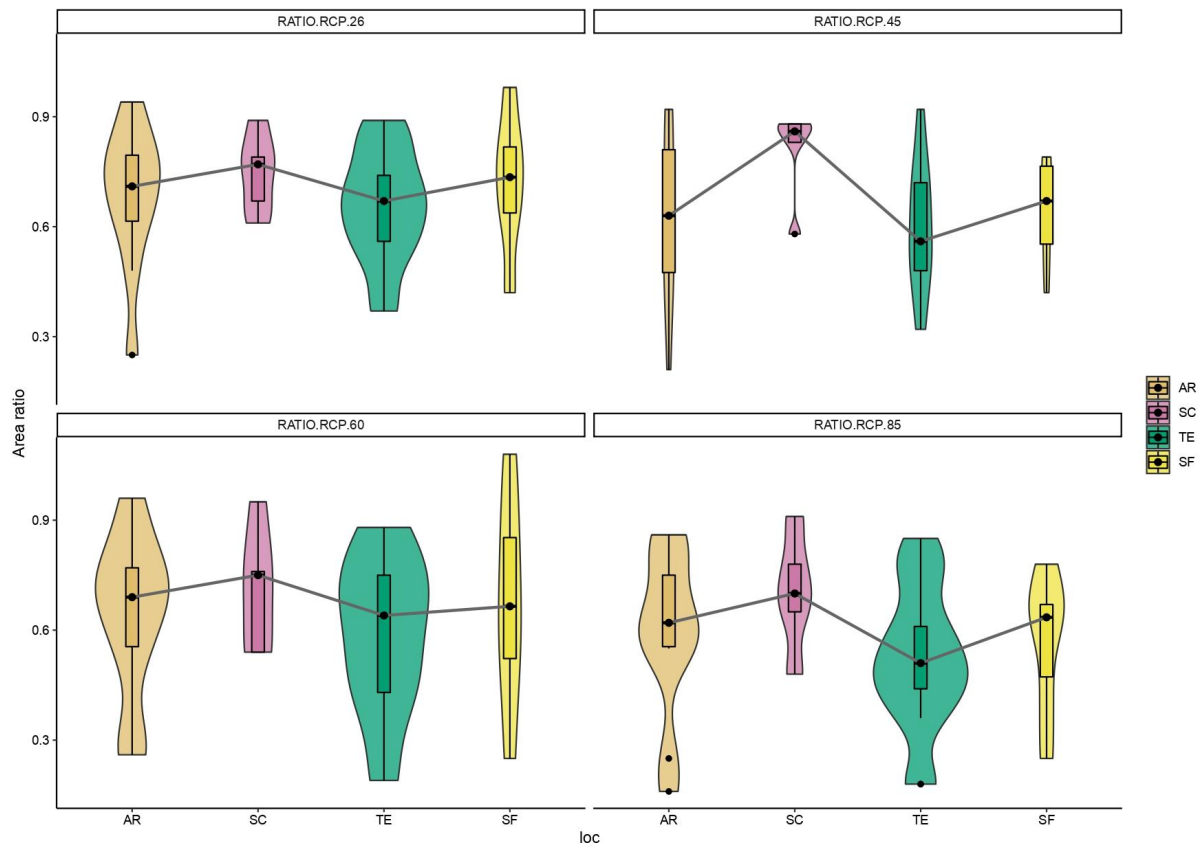


Figure S4: Boxplot and violin plot of the future area ratio for each locomotion group, arboreal (AR), scansorial (SC), terrestrial (TE), and semifossorial (SF), grouped by future climate scenario.

Supplementary Tables

Table S1: Species name, number of records, and evaluation metrics mean values (standard deviation between parenthesis). Metrics are: Continuous Boyce Index (CBI), Area Under The Receiver Operating Characteristic Curve (AUC), and True Skill Statistic (TSS).

Species	N Records	CBI	AUC	TSS
<i>Akodon cursor</i>	109	0.83 (0.12)	0.94 (0.01)	0.64 (0.06)
<i>Akodon montensis</i>	86	0.69 (0.15)	0.91 (0.04)	0.72 (0.07)
<i>Brucepattersonius iheringi</i>	24	0.67 (0.21)	0.98 (0.01)	0.86 (0.11)
<i>Calomys expulsus</i>	45	0.94 (0.03)	0.90 (0.03)	0.55 (0.06)
<i>Calomys tener</i>	82	0.75 (0.02)	0.86 (0.07)	0.43 (0.10)
<i>Castoria angustidens</i>	48	0.84 (0.13)	0.95 (0.02)	0.74 (0.07)
<i>Cerradomys scotti</i>	46	0.88 (0.03)	0.91 (0.07)	0.48 (0.10)
<i>Cerradomys subflavus</i>	29	0.89 (0.09)	0.84 (0.12)	0.41 (0.23)
<i>Clyomys laticeps</i>	37	0.93 (0.07)	0.86 (0.03)	0.36 (0.08)
<i>Delomys dorsalis</i>	50	0.8 (0.12)	0.97 (0.01)	0.82 (0.10)
<i>Delomys sublineatus</i>	47	0.66 (0.19)	0.98 (0.01)	0.80 (0.05)
<i>Didelphis aurita</i>	79	0.90 (0.04)	0.94 (0.03)	0.73 (0.07)
<i>Euryoryzomys russatus</i>	90	0.78 (0.15)	0.96 (0.02)	0.73 (0.08)
<i>Euryzygomatomys spinosus</i>	33	0.74 (0.22)	0.89 (0.03)	0.65 (0.11)
<i>Gracilinanus microtarsus</i>	49	0.80 (0.20)	0.91 (0.04)	0.68 (0.11)
<i>Juliomys ossitenuis</i>	22	0.63 (0.13)	0.99 (0.01)	0.89 (0.12)
<i>Juliomys pictipes</i>	60	0.91 (0.08)	0.95 (0.01)	0.78 (0.06)
<i>Kannabateomys amblyonyx</i>	59	0.85 (0.11)	0.94 (0.04)	0.76 (0.10)
<i>Marmosa paraguayana</i>	47	0.80 (0.16)	0.95 (0.01)	0.70 (0.09)
<i>Marmosops incanus</i>	60	0.87 (0.06)	0.96 (0.03)	0.82 (0.06)
<i>Monodelphis americana</i>	123	0.83 (0.05)	0.91 (0.02)	0.60 (0.04)
<i>Monodelphis iheringi</i>	51	0.67 (0.04)	0.98 (0.01)	0.87 (0.08)
<i>Monodelphis kunsii</i>	45	0.82 (0.16)	0.81 (0.01)	0.38 (0.04)
<i>Monodelphis scalops</i>	43	0.93 (0.05)	0.95 (0.02)	0.75 (0.06)
<i>Necomys lasiurus</i>	190	0.83 (0.05)	0.80 (0.01)	0.25 (0.04)
<i>Necomys squamipes</i>	155	0.91 (0.03)	0.92 (0.01)	0.64 (0.04)
<i>Oecomys catherinae</i>	58	0.94 (0.02)	0.89 (0.04)	0.54 (0.12)
<i>Oligoryzomys nigripes</i>	189	0.84 (0.13)	0.89 (0.02)	0.50 (0.04)
<i>Oxymycterus dasytrichus</i>	55	0.89 (0.05)	0.94 (0.03)	0.78 (0.06)
<i>Oxymycterus delator</i>	33	0.87 (0.09)	0.84 (0.06)	0.39 (0.09)
<i>Oxymycterus quaestor</i>	61	0.78 (0.14)	0.96 (0.01)	0.83 (0.07)

**Table S1
(cont.)**

Table S1 (cont.)

Species	N Records	CBI	AUC	TSS
<i>Philander frenatus</i>	48	0.82 (0.18)	0.95 (0.02)	0.79 (0.06)
<i>Phyllomys nigrispinus</i>	24	0.72 (0.14)	0.96 (0.05)	0.78 (0.15)
<i>Phyllomys pattoni</i>	36	0.74 (0.16)	0.97 (0.03)	0.79 (0.1)
<i>Phyllomys sulinus</i>	16	0.85 (0.12)	0.97 (0.04)	0.87 (0.1)
<i>Rhipidomys itoan</i>	19	0.79 (0.15)	0.98 (0.02)	0.93 (0.13)
<i>Rhipidomys macrurus</i>	58	0.91 (0.12)	0.88 (0.05)	0.42 (0.08)
<i>Rhipidomys mastacalis</i>	70	0.90 (0.05)	0.93 (0.03)	0.70 (0.10)
<i>Sooretamys angouya</i>	194	0.87 (0.07)	0.95 (0.01)	0.79 (0.04)
<i>Thaptomys nigrita</i>	71	0.81 (0.17)	0.93 (0.02)	0.70 (0.07)
Total/Mean (SD)	2641	0.82 (0.15)	0.94 (0.02)	0.67 (0.07)

Table S2: P-values (below diagonal) and statistical significance (above diagonal) of the absolute area values analyses between climate scenarios for all species, AF species only, AFCR species only, and CR species only.

		CURRENT	RCP26	RCP45	RCP60	RCP85
All Species	CURRENT		****	****	****	****
	RCP26	1.82E-11		*	ns	****
	RCP45	1.82E-11	0.022		ns	***
	RCP60	7.46E-10	0.064	1		ns
	RCP85	1.82E-11	1.95E-07	0.00E+00	6.40E-02	
Atlantic Forest Endemics (AF)	CURRENT		****	****	****	****
	RCP26	2.98E-07		ns	ns	***
	RCP45	2.98E-07	9.40E-02		ns	ns
	RCP60	8.05E-06	1	1		*
	RCP85	2.98E-07	0.001	0.29	0.025	
Atlantic Forest and Cerrado (AFCR)	CURRENT		****	***	****	****
	RCP26	3.55E-05		ns	****	**
	RCP45	0	1		**	****
	RCP60	6.70E-06	1.82E-05	0.01		ns
	RCP85	6.02E-05	0.002	1.33E-06		1
Cerrado Endemics (CR)	CURRENT		**	**	**	**
	RCP26	5.00E-03		ns	*	**
	RCP45	0.004	0.901		ns	*
	RCP60	0.008	0.015	0.148		ns
	RCP85	0.004	0.009	0.025		1

Table S3: P-values and statistical significance of the area ratio analyses between biomes in each scenario.

	Group 1	Group 2	Adjusted p-value	Significance
RCP 2.6	AF	AFCR	0.034	*
	AF	CR	0.001	**
	AFCR	CR	0.340	ns
RCP 4.5	AF	AFCR	0.745	ns
	AF	CR	0.004	**
	AFCR	CR	0.086	ns
RCP 6.0	AF	AFCR	0.002	**
	AF	CR	0.000	***
	AFCR	CR	0.586	ns
RCP 8.5	AF	AFCR	0.023	*
	AF	CR	0.001	**
	AFCR	CR	0.386	ns

Table S4: P-values (below diagonal) and statistical significance (above diagonal) of the minimum, median and maximum elevation between climate scenarios.

		CURRENT	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Minimum	CURRENT		ns	ns	ns	ns
	RCP 2.6	0.156		ns	ns	ns
	RCP 4.5	0.156	1		ns	ns
	RCP 6.0	0.078	1	1		ns
	RCP 8.5	0.313	1	1	1	
Median	CURRENT		ns	***	ns	***
	RCP 2.6	0.293		****	ns	****
	RCP 4.5	0.001	4.28E-05		ns	ns
	RCP 6.0	0.124	0.436	0.161		***
	RCP 8.5	0.000	2.18E-06	0.200	0.001	
Maximum	CURRENT		ns	ns	ns	ns
	RCP 2.6	1		ns	ns	ns
	RCP 4.5	1	1		ns	ns
	RCP 6.0	1	1	1		ns
	RCP 8.5	1	1	1	1	

Table S5: P-values and statistical significance of the area ratio analyses between clades in each scenario.

	Group 1	Group 2	Adjusted p-value	Significance
RCP26	MAR	ROD	0.901	ns
RCP45	MAR	ROD	0.232	ns
RCP60	MAR	ROD	0.683	ns
RCP85	MAR	ROD	0.232	ns

Table S6: P-values and statistical significance of the area ratio analyses between locomotion modes in each scenario.

RCP 2.6				
	AR	SC	TE	SF
AR		ns	ns	ns
SC		1	ns	ns
TE		1	1	ns
SF		1	1	1
RCP 4.5				
	AR	SC	TE	SF
AR		ns	ns	ns
SC		0.476	ns	ns
TE		1	0.176	ns
SF		1	0.860	1
RCP 6.0				
	AR	SC	TE	SF
AR		ns	ns	ns
SC		1	ns	ns
TE		1	1	ns
SF		1	1	1
RCP 8.5				
	AR	SC	TE	SF
AR		ns	ns	ns
SC		1	ns	ns
TE		1	0.418	ns
SF		1	1	1


Bruno Henrique de Castro Evaldt

“Impacto das mudanças climáticas em pequenos mamíferos de dois hotspots de biodiversidade”

Dissertação apresentada ao Programa de Pós-Graduação em Ciências Biológicas do Centro de Ciências Humanas e Naturais, da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do Grau de Mestre em Biologia Animal.

Aprovada em 31 de agosto de 2021.

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