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Climatic changes effect on the threatened Muriquis (genus *Brachyteles* Spix, 1823) from the Atlantic Forest of South America

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ABSTRACT

The genus *Brachyteles* is composed by two species of the largest monkeys from South America, *Brachyteles hypoxanthus* and *B. arachnoides*, respectively, the northern muriqui and southern muriqui. Both species are endemic to the Atlantic Forest ecosystem and are critically endangered according to the red list of the International Union for Conservation of Nature (IUCN). Muriquis are important seed dispersers and, consequently, affect the conservation of several plants and animal species. Ecological niche models (ENMs) were implemented to assess the effect of global warming on potential distribution of muriquis in one of the most important biodiversity hotspots of the world. The models estimated between 24% and 27.2% of habitat loss for *B. hypoxanthus*, and 37.2% for *B. arachnoides* due to climatic changes until 2050. Thus, global warming can be an additional factor promoting reduction of potential distribution and increasing the effect of biogeographical barriers for *Brachyteles* species.

Keywords: Biodiversity hotspots; *Brachyteles*; Conservation; Global warming; Ecological niche models.

INTRODUÇÃO

Muriquis (*Brachyteles hypoxanthus* and *B. arachnoides*) are endemic monkeys from the Atlantic Forest of Brazil (INGBERMAN et al., 2016), one of the most threatened and important biodiversity hotspots in the world (MYERS et al., 2000; JENKINS et al., 2013). Both species are critically endangered according to the red list of the International Union for Conservation of Nature (IUCN) (FERRAZ et al., 2019; TALEBI et al., 2019). Muriquis perform important ecosystem services such as the dispersal of big seeds and, consequently, have significant influences for plant species diversity and food supplies to other animal species in the Atlantic Forest (BUENO et al., 2013; BUFALO et al., 2016).

The Atlantic Forest is characterized by high endemism, which indicates more relevance to conservation (MYERS et al., 2000; JENKINS et al., 2013). The trend of small geographical ranges on vertebrate species increases the threat of habitat loss (JENKINS et al., 2013), which also include the critically endangered *Brachyteles* genus, due to the genetic decay and demographic stochasticity, increasing the extinction risk for the populations

(BRITO et al., 2008). Viable populations of muriquis are mainly associated with environmental heterogeneity from undisturbed areas that provide available resources (STRIER, 2000). However, the devastation is evident on the Atlantic Forest, remaining around 12% of its forested cover, and protected areas covering a small amount of the remaining forests, in which 80% is composed by small fragments smaller than 50 ha (RIBEIRO et al., 2009; 2011). Besides the decrease in available habitats, the geographical distribution of muriquis could be also affected by climate and physical barriers such as rivers and mountains (INGBERMAN et al., 2016).

The global warming can also increase already existing threats on rare and endemic species from biodiversity hotspots which have specific ecological requirements (MALCOLM et al., 2006). Climatic changes might reduce available habitats and increase species vulnerability to future extinction which provides new perspectives on the comprehension of geographical distribution and to biodiversity conservation (WILLIAMS et al., 2008; FODEN et al., 2013). The ability to predict future potential distribution by Ecological Niche Models (ENMs) is a very useful tool to evaluate possible effects of different climatic changing scenarios (ELITH, LEATHWICK, 2009). The ENMs can identify suitable areas based on environmental variables for rare species such as the muriqui monkeys (INGBERMAN et al., 2016), and to assess how these species should be affected by the climatic changes. This approach can indicate important perspectives on our understanding about these species distribution and conservation (RAXWORTHY et al., 2003; PUSCHENDORF et al., 2009; LEMES et al., 2014). This study brings up the possible effect of global warming on the geographic distribution of muriqui species with the possible suitable habitat's reduction and the increasing of threats for the genus *Brachyteles* in the Brazilian Atlantic Forest.

OBJECTIVE

Evaluate the effect of global warming in the potential future geographic distribution of the threatened species of muriqui monkeys in the Atlantic Forest.

MATHERIAL AND METHODS

The occurrence data of both species, *Brachyteles hypoxanthus* (N = 43) and *B. arachnoides* (N = 34), was compiled from Ingberman et al. (2016). The dataset is a list of locality points from field work, published studies and museum's collections, corresponding by one record for each 115 km^2, the minimum size for supporting a viable population of *Brachyteles* species (INGBERMAN *et al.* 2016). The predictor variables were downloaded from CHELSA database (www.chelsa-climate.org/), which corresponds to a high resolution climatological models dataset including the South American Atlantic Forest domain (KARGER et al., 2017). The future projections were implemented from mean distributions between three climatic data sources (CISRO-Mk3-6-0; CCSM4 and MIROC5) on the climatology for 2050 from Coupled Model Intercomparison Project Phase 5 (CMIP5). The future climatic scenarios were selected regarding the Representative Concentration Pathways (RCPs), one optimistic and one pessimistic, respectively, with 2.6 RCPs W/m^2 and 8.5 RCPs W/m^2. All variables were defined with 2.5 ArcMin resolution, following Ingberman et al. (2016).

The most important variables for the climatic niche estimation of each species (Table 1) were selected according to Ingberman et al. (2016). The variables were masked by the Atlantic Forest domain (*sensu* OLSON et al., 2001), considering only Atlantic Forest as potential habitats for the predictions. The correlation between these variables was tested with the Variance Inflation Factor (VIF; ZUUR et al., 2010) in the 'usdm' R package (NAIMI, 2017). The variables with collinearity problems (VIF > 10) were excluded. In this way, independent groups of variables were determined for each species without collinearity problems between the predictors. Thus, the geographical distribution patterns of muriqui species corresponded to averaging projections from: generalized linear models (GLM), generalized additive models (GAM), boosted regression trees (BRT) and randomForest algorithm (RF) (see PETERSON et al., 2011; BARBET-MASSIN et al., 2012) implemented in 'dismo', 'gam', 'gbm' and 'randomForest' R packages (SOUTHWORTH, 2015; HIJMANS et al., 2016; BREIMAN, CUTLER, 2018; HASTIE, 2018).

Table 1: Selected climatic variables for mapping *Brachyteles* species (see also INGBERMAN et al., 2016). The asterisk marks the variables used herein for each species modelling, after the VIF analyses.

Brachyteles hypoxanthus	*Brachyteles arachnoides*
Annual precipitation	Annual mean temperature*
Isotermality*	Annual precipitation*
Mean diurnal range	Isotermality*
Precipitation of driest month*	Mean diurnal range
Precipitation of wettest month*	Precipitation of driest month*
Temperature seasonality*	Temperature annual range
	Temperature seasonality*

The models were calibrated with 80% of geographic records and evaluated by 20% of the remaining data (INGBERMAN et al., 2016). Pseudo-absences were generated by random sampling within a spatially buffered (~300km) convex hull around the locality points, for each species (Figure 1). The model fitting was replicated in two groups regarding the number of pseudo-absences, one sampling four times and another sampling eight times the number of occurrences as pseudo-absences, with four random replications per group (ZIZKA et al., 2020). The Area Under the Curve (AUC) of the Receiver Operation Characteristic (ROC) was used for models' evaluation (ELITH et al., 2006; BARBET-MASSIN et al., 2012). The best fitted model for each algorithm, with highest AUC value, was selected for each algorithm. After that, the average model was defined for each species (HIJMANS, ELITH, 2015). Then, the binary distributions was calculated using equal sensitivity and specificity as threshold (ZIZKA et al., 2020), and provided the geographical ranges measurement across the temporal series for current, and both optimistic and pessimistic future scenarios. Thus, the surfaces were superposed to show where the habitat loss can occur across the predictions. All analyses were performed in R software (R Core Team, 2020).

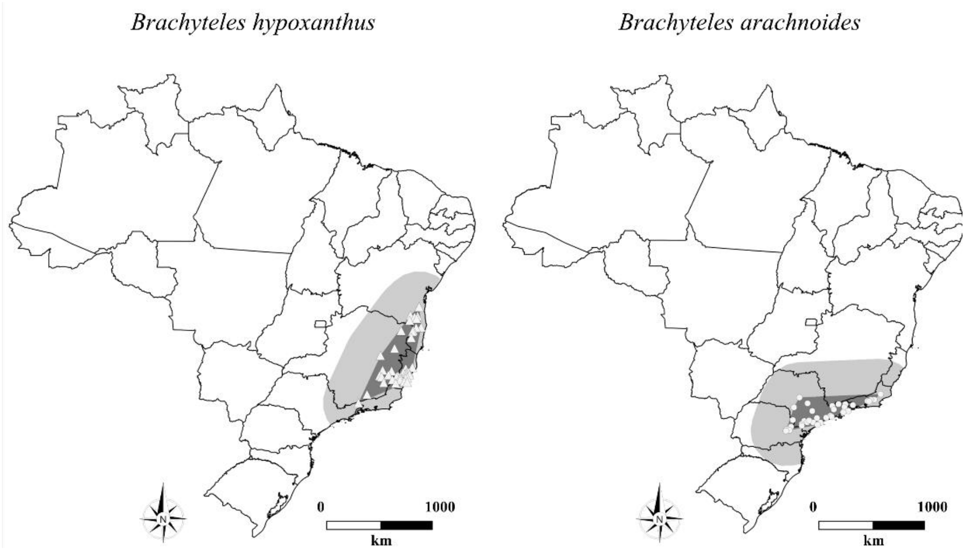

Figure 1: The left side shows the occurrence data for *Brachyteles hypoxanthus* (white triangles) and the right side shows the occurrence data for *B. arachnoides* (white circles) in the Brazilian territory. The grey buffers surrounding the convex hulls (darker grey) show the limits of modelling background areas for each species.

RESULTS

The VIF analysis showed high correlation between mean diurnal range and annual precipitation in the *Brachyteles hypoxanthus* variables' set. And, between mean diurnal range and temperature annual range in the *B. arachnoides* variables' set. Thus, the remaining variables were used to implement the ENMs (Table 1). The selected models had excellent evaluation with AUC values varying from 0.70 to 0.90 for *B. hypoxanthus*, and from 0.96 to 0.98 for *B. arachnoides*. The models predicted around 341,840 km² of current potential distribution for *Brachyteles hypoxanthus* and 82,856 km² for *B. arachnoides*. Both species presented the estimation of habitat loss across the climatic change scenarios with 259,592 km² (24% of habitat loss) in the optimistic future and 248,652 km² (27.2% of habitat loss) in the pessimistic future for *B. hypoxanthus* (figure 2). While both the optimistic and pessimistic future projections of *B. arachnoides* presented 52,032 km² (37.2% of habitat loss) (Figure 2).

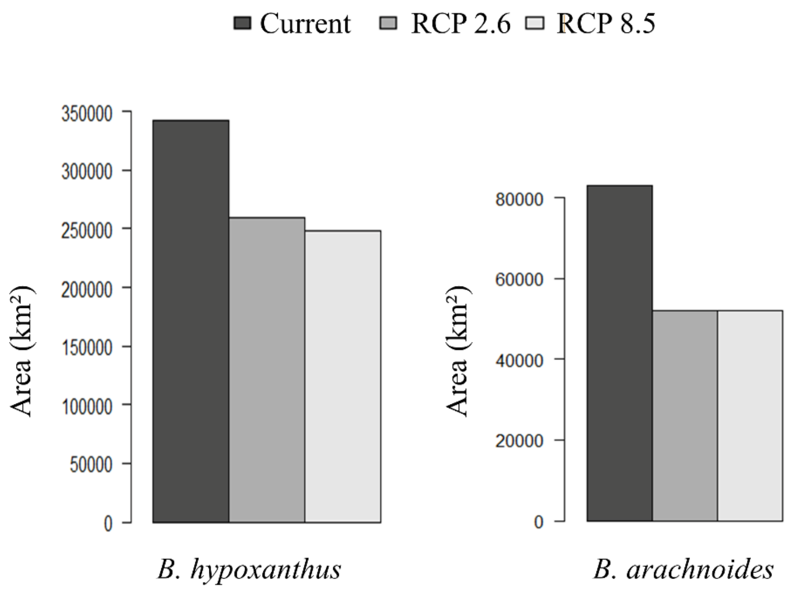

Figure 2: Bar plots of potential distribution area, varying along all ecological niche models for current and future predictions until 2050, on both optimistic and pessimistic scenarios presented on grey shades. On left side, the measurements for *Brachyteles hypoxanthus*, respectively, 341,840 km² of current potential distribution area (darker bar), 259,592 km² on optimistic prediction (RCP 2.6; grey bar), and 248,652 km² on pessimistic scenario (RCP 8.5; light grey bar). On right side, the measurements for *B. arachnoides*, respectively, 82,856 km² of current potential distribution area (darker bar), 52,032 km² on optimistic prediction (RCP 2.6; grey bar), and 52,032 km² on pessimistic scenario (RCP 8.5; light grey bar).

Brachyteles hypoxanthus presented potential distribution in the states of Bahia, Minas Gerais, Espírito Santo, Rio de Janeiro, and São Paulo. The superposed surfaces, for current and future predictions, showed the major habitat loss on a corridor splitting occurrence areas from the state of Minas Gerais and the coastal forests in the states of Espírito Santo and south of Bahia, excluding also potential habitats on future projections in the state of São Paulo. *Brachyteles arachnoides* presented potential distribution in the state of Espírito Santo, Rio de Janeiro, and São Paulo. The habitat loss was estimated for the central region of the state of Rio de Janeiro and in almost all potential geographical range in the state of Espírito Santo. Furthermore, for this species, was also predicted future habitat loss between the Serra do Mar and Mantiqueira Mountain ranges in the state of São Paulo (Figure 3).

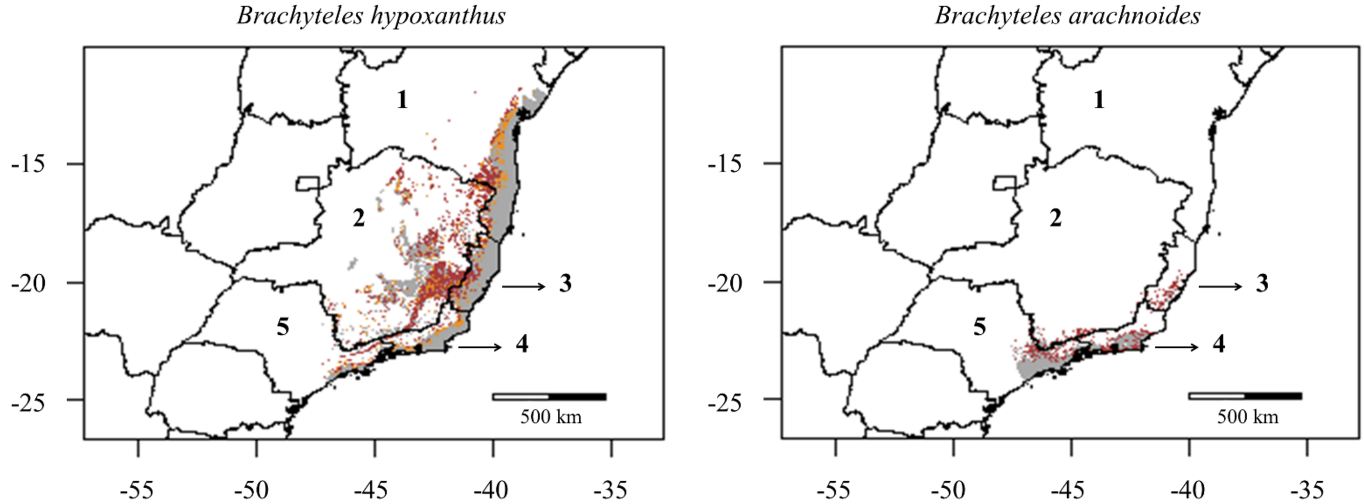

Figure 3: Ecological niche models of the *Brachyteles* genus along the states of Bahia (1), Minas Gerais (2), Espírito Santo (3), Rio de Janeiro (4), and São Paulo (5). Grey region represents the prevalent habitat predicted by current and future scenarios. Red regions are the habitat loss estimated in 2050 by the optimistic scenario (RCP 2.6), and the orange scores are the prediction of habitat loss in 2050 from the pessimistic scenario (RCP 8.5). *Brachyteles arachnoides* has the same habitat loss for both future estimations, represented by the red area.

DISCUSSION

Both species of muriqui monkeys presented evidence of habitat loss due to future climatic changes. *Brachyteles arachnoides* had higher estimation of habitat loss on global warming projections than *B. hypoxanthus*. However, *B. hypoxanthus* had an increase of habitat reduction in the pessimistic scenario, while *B. arachnoides* had relative stability in the habitat loss between the optimistic and pessimistic scenarios. Thus, the ENMs projected negative effects for the *Brachyteles* genus due to climatic changes.

The higher negative effect of climatic changes for *Brachyteles arachnoides* corroborates with the highest vulnerability of species with smaller geographical ranges (PURVIS et al., 2000; HARRIS, PIMM, 2008; PIMM et al., 2014) which tend to have specialized environmental requirements, presenting higher sensitivity to global warming (VILELA et al., 2018). The future projections also estimate the habitat loss between the mountain ranges of Serra do Mar and Serra da Mantiqueira, probably increasing the effect of the biogeographical barrier of Paraíba do Sul River (see INGBERMAN et al., 2016). The major prevalence of *Brachyteles arachnoides* occurs on Ombrophilous Dense Forests, mainly on Serra do Mar mountain range, which corroborates with the trends of persistence in undisturbed areas (STRIER, 2000; BOUBLI et al., 2010). The Serra do Mar mountain range is the bigger continuum of protected areas remaining in the Atlantic Forest (RIBEIRO et al., 2009; 2011), with great importance for the conservation of *B. arachnoides* (INGBERMAN et al., 2016), also considering future predictions regarding climatic changes.

The climatic changes could lead to a vicariance between eastern and western areas for *Brachyteles hypoxanthus*, promoting the isolation between the central region of Minas Gerais and the coastal forests from Bahia, Espírito Santo and Rio de Janeiro. This effect could be enlarged by riverine biogeographical barriers of Itanhém River in the south of Bahia, and the Doce River between Minas Gerais and Espírito Santo (INGBERMAN et al., 2016). In this way, global warming could expand biogeographical barriers and reduce the probability of gene flow across the dispersion between these areas, aggravating the recorded demographic and genetic problems to *B. hypoxanthus* (BRITO et al., 2008). Besides that, the climatic changes could prevent the dispersion and the reestablishment of viable populations in the State of Bahia, where the species was probably extinct (FERRAZ et al., 2019).

The ENMs approaches can provide an important anticipation of the magnitude from potential effects of global warming to the biodiversity in the Neotropical regions (ANCIÃES, PETERSON, 2006). *Brachyteles hypoxanthus* and *B. arachnoides* have evidences of population reduction at least 80% over the past 60 years, declining around 90% of occupancy area, mainly due to habitat loss (FERRAZ et al., 2019; TALEBI et al., 2019). The results herein reinforced the evidence of the trend to increase the threat for both species in the face of future climatic change scenarios. The climatic changes could also accentuate vicariances associated with the presence of biogeographical barriers as rivers, isolating habitats from the State of Bahia and Minas Gerais to *B. hypoxanthus* and limiting the dispersion between the mountainous ranges of Serra do Mar and Serra da Mantiqueira to *B. arachnoides*, on future projections.

The potential reduction of species geographical ranges represents one of the major challenges for biodiversity conservation (HUNTLEY et al., 2008). Management options include to maintain the network of suitable habitats, facilitating migration, and connecting heterogeneous habitats, especially between mountainous regions (LEVINSKY et al., 2007). In the case of muriquis, the population reduction can also affect other species due to the ecosystem function of seed dispersal for a great quantity of plant species, and, consequently, influences on food supplies for several animal species in the threatened Atlantic Forest (BUENO et al., 2013). These species of large monkeys have a great importance for the Atlantic Forest conservation, and the climatic changes should be more one threat for these critically endangered species.

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