Potential distribution and conservation of the *Colobosauroides carvalhoi* Soares and Caramaschi, 1998: a rare and endemic lizard of Northeast Brazil

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Abstract

Ecological niche modeling has contributed to the investigation of the geographical distribution and conservation of rare or little recorded species. Therefore, we studied the known and potential distributions of *Colobosauroides carvalhoi* Soares and Caramaschi 1998 and discuss the implications for its conservation. Data were obtained by manual collections made in quarterly samplings in three different regions, considering the regions with occurrence records and surrounding areas. The known distribution was determined by occurrence records and literature data, and potential distribution was estimated with an ecological niche model by the MaxEnt algorithm. Twenty-five specimens were collected exclusively in forest formations of Caatinga and Caatinga-Cerrado. Our data corroborated the relative rarity of *C. carvalhoi* and reflected the biogeographical history of the group, where it is restricted to forest formations with milder environmental conditions. The occurrence records indicated new records of *C. carvalhoi*, but the known distribution value is compatible with a restricted distribution. The ecological niche model estimated few areas with environmental suitability for the species and corroborated the restricted and relict distribution patterns. Finally, the known and potential distribution values were compatible with criteria for threatened species. These results suggest a worrisome scenario for *C. carvalhoi* conservation. However, the limited data about the species population do not allow the proper definition of its conservation status. Therefore, we suggest using potential distribution values with alternative criteria for redefining the conservation status of *C. carvalhoi* and the development of new studies that support a better assessment of its conservation aspects.

Keywords: Caatinga, MaxEnt, ecological niche model.

Distribuição potencial e conservação de *Colobosauroides carvalhoi* Soares and Caramaschi, 1998: um lagarto raro e endêmico do nordeste do Brasil

Resumo

A modelagem ecológica de nicho vem contribuindo para investigar a distribuição geográfica e conservação de espécies raras ou com poucos registros de ocorrência. Neste sentido, investigou-se a distribuição conhecida e potencial da espécie *Colobosauroides carvalhoi* Soares & Caramaschi, 1998, discutindo as implicações para a conservação da espécie. Os dados foram coletados por meio de coletas manuais realizadas em amostragens trimestrais realizadas em três regiões distintas, considerando as regiões com registros de ocorrência conhecidos e áreas adjacentes. A distribuição conhecida foi determinada a partir dos novos registros de ocorrência e dados da literatura e a distribuição potencial estimada por meio de um modelo ecológico de nicho com uso do algoritmo MaxEnt. Vinte e cinco exemplares da espécie *C. carvalhoi* foram coletados exclusivamente em formações arbóreas da Caatinga e áreas de interface entre a Caatinga e o Cerrado. Estes resultados corroboram a relativa raridade da espécie e refletem a história biogeográfica do grupo, relacionada a ambientes florestados e que apresentam condições ambientais mais amenas. Os registros de ocorrência de *C. carvalhoi* indicam novos registros, entretanto, o valor de distribuição conhecida foi compatível com valores de distribuição restrita. O modelo ecológico de nicho estimou poucas áreas adequadas à ocorrência da espécie, corroborando um padrão de distribuição restrita e relictual. Por fim, os valores de distribuição conhecida e potencial estimados são compatíveis com valores definidos para espécies ameaçadas. Estes resultados sugerem um cenário preocupante para a conservação de *C. carvalhoi*. Entretanto, a atual limitação de dados populacionais dificulta uma adequada avaliação de seu status de conservação. Portanto, sugerimos o uso dos valores de distribuição potencial como critério alternativo para avaliar seu status de conservação até que novos estudos possam subsidiar uma melhor avaliação da conservação da espécie.

Palavras-chave: Caatinga, MaxEnt, modelo ecológico de nicho.

1. Introduction

Knowledge about geographical distribution is essential to assess the conservation of species (Araújo and Williams, 2000; Guisan and Thuiller, 2005; Papes and Gaubert, 2007). Thus, geographical distribution is an important criterion for assessing the risk of extinction and species conservation status (IUCN, 2012). However, the limited data from species occurrence records make it difficult to investigate geographical distribution and conservation aspects (Araújo and Williams, 2000; Guisan and Thuiller, 2005; Winck et al., 2014; Sales et al., 2015).

Currently, the use of ecological niche models have been applied for diverse purposes (Araújo and Williams, 2000; Guisan and Thuiller, 2005; Giannini et al., 2012). Although the use of ecological niche models for species with few occurrence records or present-only datasets is a challenge (Giannini et al., 2012; Winck et al., 2014), in many cases, the ecological niche model is the best alternative for investigating the geographical distribution of such species (Attorre et al., 2012; Winck et al., 2014).

Different techniques in ecological niche modeling estimate the suitable areas for species occurrence on the basis of datasets of occurrence records and environmental variables (Guisan and Zimmermann, 2000; Guisan and Thuiller, 2005; Phillips et al., 2006; Giovanelle et al., 2010). Often, the maximum entropy algorithm (MaxEnt), compared to other algorithm models, shows a good performance for prediction of distribution with few occurrence records or presence-only occurrence datasets (Guisan and Zimmermann, 2000; Phillips et al., 2006; Costa et al., 2010).

Recent data has shown the occurrence of diverse and endemic lizards in the Caatinga domain (Rodrigues 2003; Cavalcanti et al., 2014; Delfim, 2012; Ribeiro et al., 2012; Garda et al., 2013). However, the geographical distribution, natural history and population information for these species are unsatisfactory, making conservation Caatinga lizards difficult (Rodrigues, 2003; Cavalcanti et al., 2014; Delfim, 2012; Sales et al., 2015).

The genus *Colobosauroides* belongs to the family Gymnophthalmidae and the tribe Ecpleopodinae (Pellegrino et al., 2001). The biogeographical history of this group is related to the presence of forest habitats with milder environmental conditions (Rodrigues, 2003; Rodrigues et al., 2013). Therefore, the existence of Ecpleopodinae species record restricted to the Caatinga domain corroborates the vanishing refuge theory (Vanzolini and Williams, 1981; Delfim, 2012). However, the diversification and radiation of these lizards in this region is currently not well understood (Pellegrino et al., 2001; Peloso et al., 2011; Rodrigues et al., 2013).

The genus *Colobosauroides* consists of two species, *C. cearensis* and *C. carvalhoi* (Cunha et al., 1991; Soares and Caramaschi, 1998). These species inhabit exclusively the northeastern part of Brazil and are recorded to be associated with relict forest formations in the Caatinga domain (Soares and Caramaschi, 1998; Rodrigues, 2003). Currently, studies suggest the hypothesis of a restricted and relict geographical distribution pattern for these lizard species (Rodrigues, 2003; Delfim, 2012; Rodrigues et al., 2013).

C. carvalhoi is characterized by an elongated body, short limbs and semifossorial habits (Soares and Caramaschi, 1998). However, after twenty years since its discovery, this species is still reported with rarity and has few occurrence records (Soares and Caramaschi, 1998; Rodrigues, 2003; Delfim, 2012). There are currently only two records of *C. carvalhoi*, in the municipally of Barreiras (locality type), northern Bahia and Serra da Capivara National Park, southeastern Piauí (Rodrigues, 2003).

The conservation status of *C. carvalhoi* is still not evaluated in the IUCN list of endangered species (IUCN, 2015) and categorized as Near Threatened (NT) in the Brazilian list of endangered species (ICMBio, 2014). However, the limited data about occurrence records, natural history and population data make proper evaluation of the conservation status of C. *carvalhoi* difficult.

Accordingly, we studied the geographical distribution of *C. carvalhoi* on the basis of their known and potential distributions. Our data present new occurrence records and known and potential distribution values, and we discuss the implications of the conservation status of *C. carvalhoi*.

2. Material and Methods

2.1. Study area

The Caatinga domain is located in Northeast Brazil and reported to include the largest seasonally dry tropical forests (SDTFs) (Prado, 2000; Werneck, 2011). SDTFs are discontinuously distributed through the Neotropical region, but it is supposed that in colder and drier periods of the Pleistocene, these formations showed a continuous distribution (Prado, 2000; Pennington et al., 2000; Werneck, 2011). Caatinga vegetation is characterized by a mosaic of dry forest vegetation as adaptations of the xeric environmental conditions of the semiarid climate (Prado, 2003; Albuquerque et al., 2012).

The study areas were Caatinga and Cerrado-Caatinga transition formations located in southeastern Piauí and northern Bahia. This region has five distinct vegetation formations: arboreal Caatinga (Lemos, 2004), scrub Caatinga (Lemos, 2004), enclaves of semi-deciduous forests (Emperaire, 1984), Cerrado-Caatinga transition formations (Prado, 2003) and Caatinga sand dunes (Rodrigues, 2003).

2.2. Collection and occurrence data

The data were collected between May 2012 and April 2014 through samplings at three distinct regions (Figure 1), all reported in the literature to be regions of occurrence of the species (Soares and Caramaschi, 1998; Rodrigues, 2003).

During field expeditions, the Serra da Capivara National Park, Serra das Confusões National Park, Ecological corridor Capivara-Confusões, surrounding areas of Piauí State and the discovery region of *C. carvalhoi* in the municipally of Barreiras, Bahia State, were investigated.

The areas were investigated for five consecutive days. To minimize possible sampling effects, samples were taken considering similar periods (dry and rainy) each year. The lizards were captured by manual collection during walks on 1-km random transects between 08:00 and 18:00. The observed specimens were captured during the investigation of litter or dead vegetation using garden rakes, and all captures and collection procedures were authorized by the Chico Mendes Institute of Nature Conservation (Nos. 21907-2 and 21907-3) and the Ethics Committee of Federal University of Vale do São Francisco. Six specimens of *C. carvalhoi* (CHSC010-CHSC016) were deposited in the Herpetological Collection of Serra da Capivara National Park of University of Vale do São Francisco, São Raimundo Nonato – Piauí.

2.3. Data analysis

The known distribution of *C. carvalhoi* was defined by range of occurrence with the minimum convex polygon (IUCN, 2012). This method is frequently used for determining a species' geographic distribution range for conservation purposes (IUCN, 2012). The potential distribution was defined by the ecological niche model with a maximum entropy algorithm - MaxEnt (Phillips et al., 2006; Phillips and Dudik, 2008). Ecological niche modeling estimates areas with suitable environmental for species occurrence (Araújo and Williams, 2000; Guisan and Thuiller, 2005; Elith et al., 2010). The MaxEnt algorithm shows a good

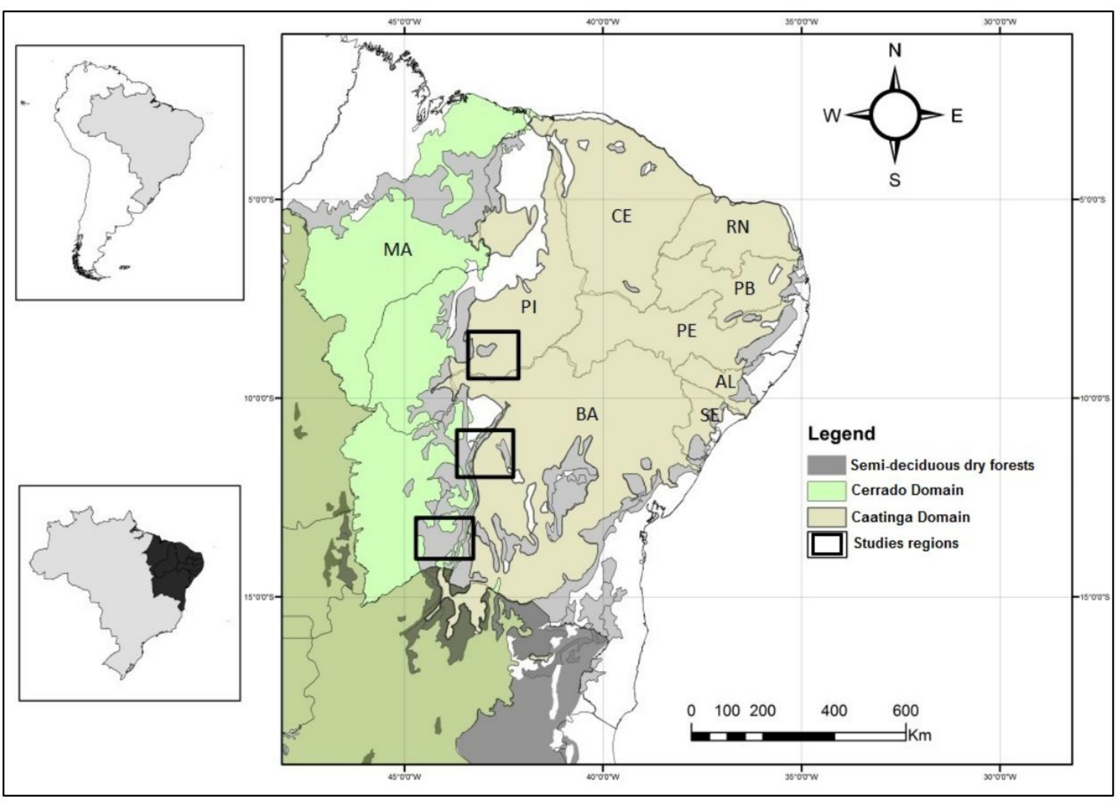

Figure 1. Map of studied regions (black squares) in which the occurrence of *Colobosauroides carvalhoi* was recorded in Northeast Brazil. Legend: MA: Maranhão; PI: Piauí; CE: Ceará; RN: Rio Grande do Norte; PB: Paraíba; PE: Pernambuco; BA: Bahia; AL: Alagoas and SE: Sergipe. 1: Serra das Confusões National Park and 2: Serra da Capivara National Park.

performance for predictions from few or presence-only datasets (Elith et al., 2010; Costa et al., 2010). The ecological niche model was performed using the MaxEnt software version 3.3.3k (Phillips et al., 2006; Elith et al., 2010).

To design the *C. carvalhoi* ecological niche model, we used a dataset of 25 environmental variables (Table 1) with a resolution of 1 km^2 (datum WGS 84) and limited to the Northeastern territory. The 23 continuous environmental variables were subjected to principal component analysis (PCA) and additionally, two categorical variables were added to estimate the ecological niche model predictions. The PCA analyze was recent used to select the most explanatory variables to created ecological niche models (Robertson et al., 2001; Pearson et al., 2007; Silva et al., 2014). These studies demonstrate that PCA is a good alternative for explanatory environmental variables and reduces collinearity issues common to environmental use of ecological niche models (Robertson et al., 2001; Jiménez-Valverde et al., 2011; Silva et al., 2014).

The bioclimatic variables (Bio1-Bio19) are from Worldclim.org, which uses climate interpolated data derived from temperature and rainfall obtained between the years 1950 and 2000 (Hijmans et al., 2005). Topographic variables (altitude and slope) were obtained from NASA's SRTM (Shuttle Radar Topography Mission) (Jarvis et al., 2008). Vegetation variables (percentage of tree cover and vegetation type) were obtained from the MODIS sensor (MODerate-resolution Imaging Spectroradiometer) aboard NASA's Terra satellite (Hansen et al., 2003) and from the Brazilian vegetation map (Veloso et al., 1991), respectively. The soil variable was obtained based on the Brazilian soil map (EMBRAPA, 1999). Finally, the hydrological variable (density of drainage network) was obtained from the SRTM (Lehner et al., 2006).

PCA was performed using the Past® statistical software (Hammer et al., 2001) and indicated the eight most explanatory variables related to *C. carvalhoi* (1-Bio4: temperature seasonality, 2-Bio8: mean temperature of the wettest quarter, 3-Bio12: Annual precipitation, 4-Bio18: Precipitation in the warmest quarter, 5-Bio19: precipitation in the coldest quarter, 6-Alt: altitude, 7-Den: density of drainage network, 8-Dec: slope). In addition, two variables (1-Soil: soil type and 2-Veg: vegetation type) were added.

For the preparation of the ecological niche model, eighteen occurrence records were selected to keep only one record per km^2, reducing possible collinearity effects (Hernandez et al., 2006). The software QGIS, version 2.4 was used for handling the dataset of environmental variables and raster matrices and potential preparation of distribution maps.

Model performance was determined by different statistical metrics (Elith et al., 2010). To evaluate the probability of the models being better than random ones, we conducted a simple binomial statistical test (z/t). This test is called

Table 1. Dataset of environmental variables used to design the ecological niche model of *Colobosauroides carvalhoi*.

Environmental variable	Variable size	Reference
1- Mean annual temperature	Bioclimatic	Hijmans et al. (2005)
2-Mean diurnal range	Bioclimatic	Hijmans et al. (2005)
3-Isothermality	Bioclimatic	Hijmans et al. (2005)
4-Temperature seasonality	Bioclimatic	Hijmans et al. (2005)
5-Max temperature of warmest month	Bioclimatic	Hijmans et al. (2005)
6-Min temperature of coldest month	Bioclimatic	Hijmans et al. (2005)
7- Annual temperature range	Bioclimatic	Hijmans et al. (2005)
8-Mean temperature of wettest quarter	Bioclimatic	Hijmans et al. (2005)
9-Mean temperature of driest quarter	Bioclimatic	Hijmans et al. (2005)
10-Mean temperature of warmest quarter	Bioclimatic	Hijmans et al. (2005)
11-Mean temperature of coldest quarter	Bioclimatic	Hijmans et al. (2005)
12-Annual precipitation	Bioclimatic	Hijmans et al. (2005)
13-Precipitation in wettest month	Bioclimatic	Hijmans et al. (2005)
14-Precipitation in driest month	Bioclimatic	Hijmans et al. (2005)
15-Precipitation seasonality	Bioclimatic	Hijmans et al. (2005)
16-Precipitation in wettest quarter	Bioclimatic	Hijmans et al. (2005)
17-Precipitation in driest quarter	Bioclimatic	Hijmans et al. (2005)
18-Precipitation in warmest quarter	Bioclimatic	Hijmans et al. (2005)
19-Precipitation in coldest quarter	Bioclimatic	Hijmans et al. (2005)
20-Altitude	Topography	Jarvis et al., (2008)
21-Slope	Topography	Jarvis et al. (2008)
22-Soil type	Soil	EMBRAPA (1999)
23-Percentage of tree cover	Vegetation	Hansen et al. (2003)
24-Vegetation type	Vegetation	Veloso et al. (1991)
25-Density of the drainage network	Hydrology	Lehner et al. (2006)

the p-value test and is a tool of MaxEnt, independent of the cutting test (Pearson et al., 2007). To evaluate the importance and the heuristic estimate of the relative contributions of variables of each predictor in the model generated, the jackknife test was applied (Fielding and Bell, 1997). The area under the curve (AUC), receiver operating characteristic (ROC) curve and omission error (OE) were available (Jiménez-Valverde and Lobo, 2007). The AUC provides a single measurement of the performance of the model, regardless of the choice of any prior decision limit (Phillips et al., 2006; Pearson et al., 2007). Despite being more used, recent studies are indicated that these metrics depend on the number of records, the algorithm used, and the type of data used (Jiménez-Valverde and Lobo, 2007). Therefore, in addition we calculate the True Skill Statistics (TSS). This metric is less affect by prevalence and is less prone to issues that affect the results of the commonly uses AUC (Aguirre-Gutiérrez et al., 2012). Finally, the potential distribution map was created by "5% of omission errors" to create the logistic model. This is appropriate for high precision of occurrence records data (Jiménez-Valverde and Lobo, 2007; Norris, 2014).

Figure 2. A *Colobosauroides carvalhoi* specimen collected in semi-deciduous forested enclave of the National Park Serra das Confusões, Piauí State, Northeast Brazil.

3. Results

3.1. Collection and occurrence records

Twenty-six specimens of *C. carvalhoi* (Figure 2) were collected in the Serra da Capivara National Park (n=15), Serra das Confusões National Park (n=5), ecological corridor Capivara-Confusões protected areas (n=3) and other surrounding areas (n=3), always associated with an abundant presence of dead vegetation or litter.

The occurrence records of *C. carvalhoi* were associated with arboreal vegetation formations (Caatinga arboreal formations and enclaves of semi-deciduous forests). Caatinga arboreal formations are located along the banks of the Parnaíba and Piauí rivers in surrounding areas of the Serra da Capivara and Serra das Confusões National Parks. The enclaves of semi-deciduous forests are located exclusively in canyon valleys (Figure 3) in the protected areas Serra da Capivara National Park, Serra das Confusões National Park and ecological corridor Capivara-Confusões and other regions in Piauí State. These formations are locally called "Boqueirões" and are characterized by semi-deciduous forest vegetation associated with Cerrado and rainforest plant species.

C. carvalhoi was included in the 18 different occurrence records (Table 2). Of these, 16 were from sample data and two were compiled from bibliographic data. Our results indicated seven new occurrences of the species (São Braz do Piauí, João Costa, Brejo do Piauí, Caracol, Guaribas, Canto do Buriti and São João do Piauí), all located in southeastern Piauí.

3.2. Known and potential distributions

The known distribution range was calculated to be 4,500 km^2 in areas for occurrence records of *C. carvalhoi* in Bahia and Piauí states. However, the potential distribution (Figure 4) was found to be higher than the

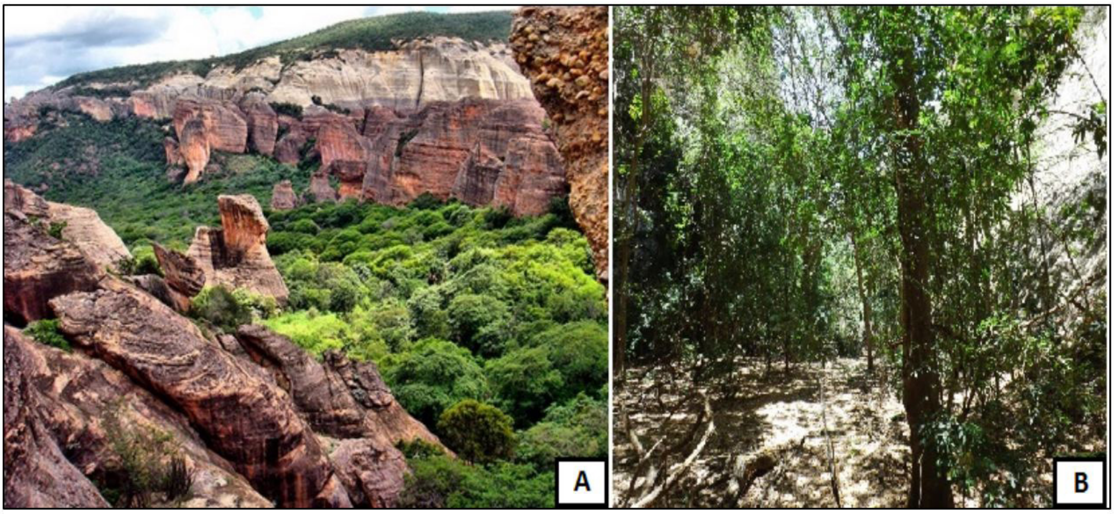

Figure 3. (A) Enclave of semi-deciduous arboreal vegetation of the National Park Serra da Capivara, Piauí State, Northeast Brazil; (B) Typical habitat of *Colobosauroides carvalhoi*.

Table 2. Localities where *Colobosauroides carvalhoi* was recorded with their respective geographical coordinates.

Locality	Municipality/State	Longitude (Decimal degrees)	Latitude (Decimal degrees)	Reference
1. Mata da Bica (localiy Type)	Barreiras/Bahia	-45.555563°	-12.039066°	Soares and Caramaschi (1998)
2. Serra da Capivara National Park	São Raimundo Nonato/ Piauí	-42.485664°	-8.774374°	Rodrigues (2003)
3. Serra da Capivara National Park (surround area)	São João do Piauí/Piauí	-42.315682°	-8.385175°	This study
4. Serra da Capivara National Park (surround area)	São João do Piauí/Piauí	-42.213596°	-8.519830°	This study
5. Serra da Capivara National Park	João Costa/Piauí	-42.355378°	-8.556757°	This study
6. Serra da Capivara National Park	João Costa/Piauí	-42.345335°	-8.600168°	This study
7. Serra da Capivara National Park	João Costa/Piauí	-42.508277°	-8.563028°	This study
8. Serra da Capivara National Park	Coronel José Dias/Piauí	-42.350120°	-8.650566°	This study
9. Serra da Capivara National Park	Coronel José Dias/Piauí	-42.355895°	-8.674292°	This study
10. Serra da Capivara National Park	Coronel José Dias/Piauí	-42.495554°	-8.781845°	This study
11. Serra da Capivara National Park	São Raimundo Nonato/ Piauí	-42.686379°	-8.864656°	This study
12. Ecological-Corridor	São Raimundo Nonato/ Piauí	-42.615404°	-8.855642°	This study
13. Ecological-Corridor	São Raimundo Nonato/ Piauí	-42.528608°	-9.051566°	This study
14. Ecological-Corridor	São Braz/Piauí	-43.021561°	-8.994292°	This study
15. Serra das Confusões National Park (surround area)	Brejo do Piauí/Piauí	-42.854231°	-8.545470°	This study
16. Serra das Confusões National Park	Caracol/Piauí	-43.569717°	-9.227508°	This study
17. Serra das Confusões National Park	Guaribas/Piauí	-43.739158°	-9.138405°	This study
18. Serra das Confusões National Park (surround area)	Canto do Burity/Piauí	-43.238305°	-8.410520°	This study

known distribution, that is 7,300 km^2 in suitable areas of species occurrence.

The potential distribution showed new areas with suitable environmental conditions for *C. carvalhoi* occurrence in Bahia and Piauí states and isolated areas in the states of Ceará, Rio Grande do Norte, Paraíba and Alagoas. However, no specimen was collected in the study areas in Bahia.

The ecological distribution model was statistically significant (p=0.002) and showed low omission errors (5%). The AUC_{model}=0.990±0.020 and TSS_{model}=0.965±0.03 suggesting that the model has a good performance in predicting suitable habitats for *C. carvalhoi*.

The environmental variables contributing to the ecological niche model of *C. carvalhoi* were (precipitation in the coldest quarter - 44.9%, slope - 20,9%, temperature seasonality - 16.1%, soil type - 7.8%, annual precipitation - 6.2%, altitude - 3.7%, density of drainage network - 0.3%, mean Temperature of the wettest quarter - 0.1% and vegetation type - 0.1%).

Finally, the known and potential distributions suggest that *C. carvalhoi* occurs in the Caatinga, Caatinga-Cerrado transitions, rainforest enclaves, Cerrado formations and semi-deciduous dry forests.

4. Discussion

4.1. Collection and occurrence records

The increase in studies of lizards has been expanding the natural history and geographical distribution of many species of the Caatinga region (Delfim, 2012; Rodrigues et al., 2013; Cavalcanti et al., 2014; Sales et al., 2015). However, despite new specimens collected and new occurrence records, the relative rarity and restricted occurrence sites of *C. carvalhoi* was corroborated (Rodrigues, 2003; Delfim, 2012). Similarly, the other *Colobosauroides* lizard species, *C. cearensis*, has been recorded in a small number of locations, but with relatively abundant occurrence records (Borges-Nojosa and Caramaschi, 2003; Rodrigues, 2003; Delfim, 2012).

C. carvalhoi is exclusively reported in forest formations of semi-deciduous dry forests, Arboreal Caatinga and Caatinga-Cerrado transition areas, reflecting the biogeographical history of this species (Borges-Nojosa and Caramaschi, 2003; Rodrigues, 2003; Delfim, 2012). The other ecpleopodi lizards of the Caatinga domain (*C. cearensis*, *Anotosaura collaris*, *A. vanzolinia*) have a similar pattern (Borges-Nojosa and Caramaschi, 2003; Rodrigues et al., 2013). However, *C. cearensis* has been recorded exclusively in Atlantic Forest enclaves (Borges-Nojosa

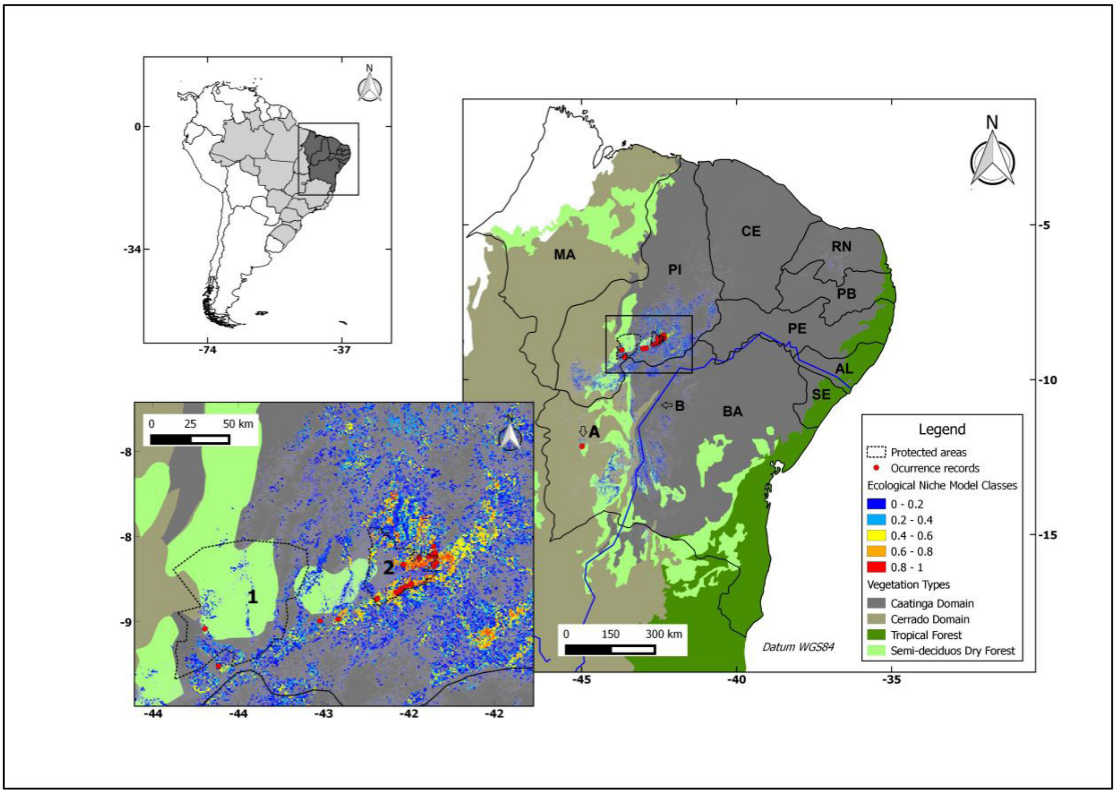

Figure 4. Known and potential distributions of *Colobosauroides carvalhoi* in Northeast Brazil. Legend: MA: Maranhão; PI: Piauí; CE: Ceará; RN: Rio Grande do Norte; PB: Paraíba; PE: Pernambuco; BA: Bahia; AL: Alagoas and SE: Sergipe. A = Locality type; B = São Francisco River. 1: Serra das Confusões National Park and 2: Serra da Capivara National Park.

and Caramaschi, 2003; Rodrigues et al., 2013), *A. collaris* is recorded exclusively in Caatinga arboreal formations (Rodrigues et al., 2013), and *A. vanzolinia* is recorded in Caatinga arboreal and Atlantic Forest enclaves in the Caatinga domain (Delfim, 2012).

4.2. Known and potential distributions

The known and potential distribution values of *C. carvalhoi* were compatible with restricted distribution (IUCN, 2012). The potential distribution suggests a disjoint distribution pattern of these lizards (Rodrigues, 2003). The restricted and disjoint patterns of *C. Carvalho*i and other Eplepodinae lizards of the Caatinga domain were associated with these forest formations with mesic environmental conditions (Rodrigues, 2003; Rodrigues et al., 2013). The distribution of these lizards corroborates the "vanishing refuge hypothesis" (Vanzolini and Williams, 1981; Delfim, 2012; Rodrigues et al., 2013). Currently, the mesic formations are disjointly distributed in the Caatinga domain (Rodrigues, 2003; Prado, 2003; Werneck, 2011). However, sharing the biota in interface areas of the Caatinga-Cerrado associated with expansion and retraction events of dry forests may be related to the current distribution pattern of C. *carvalhoi* (Werneck and Colli, 2006). Therefore, molecular studies are necessary to understand the diversification and distribution aspects of *C. carvalhoi*.

The environmental variables related to potential distribution of *C. carvalhoi* (precipitation in the coldest quarter, slope, temperature seasonality and annual precipitation) corroborate its association with mesic environmental areas. However, although reported as important, the environmental variables (vegetation type, altitude and density of drainage network) related to forest vegetation formations were not good contributions to the niche model and need further investigation.

5. Implications for conservation

The known and potential distribution ranges of *C. carvalhoi* were compatible with threatened distribution values (IUCN, 2012). The first (<5,000 km^2) is reported for endangered species and the second (<10,000 km^2) for vulnerable species (IUCN, 2014). Despite, the importance to geographical distribution to evaluate the conservation status (IUCN, 2012), population data are important for proper assessment of the risk of extinction (IUCN, 2014). However, the currently limited data on *C. carvalhoi* (Rodrigues, 2003; Delfim, 2012) possibly helped to define its conservation status.

Currently, new information and techniques, such as ecological niche model, contribute to conservation purpose (Jiménez-Valverde et al., 2011). Thus, the relative rarity, restricted and disjoint distribution patterns and limited population data of *C. carvalhoi* indicate a worrisome scenario for species conservation.

Finally, we suggest that the known and potential distribution values and relative rarity of *C. carvalhoi* enable the reevaluation of the conservation status of *C. carvalhoi* to "Near Threatened - NT" from "Endangered - ED"; however, further studies focusing on the population data are necessary for better evaluation of its conservation and development of management and conservation strategies.

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References

AGUIRRE-GUTIÉRREZ, J., CARVALHEIRO, L.G., POLCE, C., LOON, E.E.V., RAES, N. and REEMER, M., 2012. Fit-for-purpose: species distribution model performance depends on evaluation criteria: dutch hoverflies as a case study. *PLoS One*, vol. 8, no. 5, pp. 1-11. http://dx.doi.org/10.1371/journal.pone.0063708. PMid:23691089.

ALBUQUERQUE, U.P., ARAUJO, E.L., EL-DEIR, A.C.A., LIMA, A.L.A., SOUTO, A., BEZERRA, B.M., FERRAZ, E.M.N., FREIRE, E.M.X., SAMPAIO, E.V., DE-SA, B., LAS-CASAS, F.M.G., MOURA, G.J.B., PEREIRA, G.A., MELO, J.G., RAMOS, M.A., RODAL, M.J.N., SCHIEL, N., LYRA-NEVES, R.M., ALVES, R.R.N., AZEVEDO-JUNIOR, S.M., TELINO-JUNIOR, W.R. and SEVERI, W., 2012. Caatinga revisited: ecology and conservation of an important seasonal dry forest. *The Scientific World Journal*, vol. 2012, no. 205182, pp. 1-18. PMid:22919296. http://dx.doi.org/10.1100/2012/205182.

ARAÚJO, M.M. and WILLIAMS, P.H., 2000. Selecting areas for species persistence using occurrence data. *Biological Conservation*, vol. 6, no. 3, pp. 331-345. http://dx.doi.org/10.1016/S0006-3207(00)00074-4.

ATTORRE, F., DE-SANCTIS, M., FARCOMENI, A., GUILLET, A., SCEPI, E., VITALE, M., PELLA, F. and FASOLA, M., 2012. The use of spatial ecological modelling as a tool for improving the assessment of geographic range size of threatened species. *Journal of Nature Conservation*, vol. 21, no. 1, pp. 48-55. http://dx.doi.org/10.1016/j.jnc.2012.10.001.

BORGES-NOJOSA, D.M. and CARAMASCHI, U., 2003. Composição e análise comparativa da diversidade e das afinidades biogeográficas dos lagartos e anfisbenídeos (Squamata) dos Brejos Nordestinos. In: I.R. LEAL, M. TABARELLI and J.M.C. SILVA, eds. *Ecologia e Conservação da Caatinga*. Recife: Universidade Federal de Pernambuco, pp. 463-512.

CAVALCANTI, L.B.Q., COSTA, T.B., COLLI, G.R., COSTA, G.C., FRANÇA, F.G.R., MESQUITA, D.O., PALMEIRA, C.N.S., PELEGRIN, N., SOARES, A.H.B., TUCKER, D.B. and GARDA, A.A., 2014. Herpetofauna of protected areas in the Caatinga II: Serra da Capivara National Park, Piauí, Brazil. *Check List*, vol. 10, no. 1, pp. 18-27. http://dx.doi.org/10.15560/10.1.18.

COSTA, G.C., NOGUEIRA, C., MACHADO, R.B. and COLLI, G.R., 2010. Sampling bias and the use of ecological niche modelling in conservation planning: a field evaluation in a biodiversity hotspot. *Biodiversity and Conservation*, vol. 19, no. 3, pp. 883-899. http://dx.doi.org/10.1007/s10531-009-9746-8.

CUNHA, O.K., LIMA-VERDE, J.S. and LIMA, A.C.M., 1991. Novo gênero e espécie de lagarto do Estado do Ceará (Lacertilia: Teiidae). *Boletim Museu Emílio Goeldi*, vol. 7, pp. 163-176.

DELFIM, F.R., 2012. *Riqueza e padrões de distribuição dos lagartos do Domínio Morfoclimático da Caatinga*. João Pessoa: Universidade Federal da Paraíba, 242 p. Tese de Doutorado em Zoologia.

ELITH, J., KEARNEY, M. and PHILLIPS, S.J., 2010. The art of modeling ranges hifting species. *Methods in Ecology and Evolution*, vol. 1, no. 4, pp. 330-342. http://dx.doi.org/10.1111/j.2041-210X.2010.00036.x.

EMPERAIRE, L., 1984. A região da Serra da Capivara (Sudeste do Piauí) e sua vegetação. *Brasil Florestal*, vol. 14, no. 60, pp. 5-22.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA, 1999. *Sistema Brasileiro de Classificação de Solos*. Rio de Janeiro: Centro Nacional de Pesquisa de Solos. 412 p.

FIELDING, A.H. and BELL, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation*, vol. 24, no. 1, pp. 38-49. http://dx.doi.org/10.1017/S0376892997000088.

GARDA, A.A., COSTA, T.B., SILVA, C.R.S., MESQUITA, D.O., FARIA, R.G., CONCEIÇÃO, B.M., SILVA, I.R.S., FERREIRA, A.S., ROCHA, S.M., PALMEIRA, C.N.S., RODRIGUES, R., FERRARI, S.F. and TORQUATO, S., 2013. Herpetofauna of protected areas in the Caatinga I: Raso da Catarina Ecological Station (Bahia, Brazil). *Check List*, vol. 9, no. 2, pp. 405-414. http://dx.doi.org/10.15560/9.2.405.

GIANNINI, T.C., SIQUEIRA, M.F., ACOSTA, A.L., BARRETO, F.C.C., SARAIVA, A.M. and ALVES-DOS-SANTOS, S., 2012. Desafios atuais da modelagem preditiva de distribuição de espécies. *Rodriguésia*, vol. 63, no. 3, pp. 733-749. http://dx.doi.org/10.1590/S2175-78602012000300017.

GIOVANELLE, J.G.R., SIQUEIRA, M.F., HADDAD, C.F.B. and ALEXANDRINO, J., 2010. Modelling a spatially restricted distribution in the Neotropics: How the size of calibration area affects the performance of five presence-only methods. *Ecological Modelling*, vol. 221, no. 2, pp. 215-224. http://dx.doi.org/10.1016/j.ecolmodel.2009.10.009.

GUISAN, A. and THUILLER, W., 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters*, vol. 8, no. 8, pp. 993-1009. http://dx.doi.org/10.1111/j.1461-0248.2005.00792.x.

GUISAN, A. and ZIMMERMANN, N.E., 2000. Predictive habitat distribution models in ecology. *Ecological Modelling*, vol. 135, no. 2-3, pp. 147-186. http://dx.doi.org/10.1016/S0304-3800(00)00354-9.

HAMMER, O., HARPER, D.A.T. and RYAN, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, vol. 4, no. 1, pp. 1-9.

HANSEN, M.C., DEFRIES, R.S., TOWNSHEND, J.R.G., CARROLL, M., DIMICELI, C. and SOHLBERG, R.A., 2003. Global percent tree cover at a spatial resolution of 500 meters: first results of the MODIS vegetation continuous fields algorithm. *Earth Interactions*, vol. 7, no. 10, pp. 1-15. http://dx.doi.org/10.1175/1087-3562(2003)007<0001:GPTCAA>2.0.CO;2.

HERNANDEZ, P.A., GRAHAM, C.H., MASTER, L.L. and ALBERT, D.L., 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography*, vol. 29, no. 5, pp. 773-785. http://dx.doi.org/10.1111/j.0906-7590.2006.04700.x.

HIJMANS, R.J., CAMERON, S.E., PARRA, J.L., JONES, P.G. and JARVIS, A., 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, vol. 25, no. 15, pp. 1965-1978. http://dx.doi.org/10.1002/joc.1276.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE – ICMBio, 2014 [viewed 30 June 2015]. *Lista Brasileira de espécies com dados insuficientes*. Brasilia. Available from: ww.icmbio.gov.br/portal/biodiversidade/fauna-brasileira/lista-de-especies-dados-insuficientes.html.

JARVIS, A., REUTER, H.I., NELSON, A. and GUEVARA, E., 2008. *Hole-filled SRTM for the globe: version 4*.

JIMÉNEZ-VALVERDE, A., LOBO, J.M. 2007. Threshold criteria for conversion of probability of species presence to either-or presence-absence. *Acta Oecologica*, no. 31, pp. 361-369.

JIMÉNEZ-VALVERDE, A., PETERSON, A.T., SOBÉRON, J., OVERTON, J.M., ARAGÓN, P. and LOBO, J.M., 2011. Use of niche models in invasive species risk assessments. *Biological Invasions*, vol. 13, no. 12, pp. 2785-2797. http://dx.doi.org/10.1007/s10530-011-9963-4.

LEHNER, B., VERDINI, K. and JARVIS, A., 2006 [viewed 15 May 2015]. *HydroSheds: technical documentation: versão1*. 27 p. Available from: http://gisdata.usgs.net/HydroSHEDS/ downloads/HydroSHEDS_TechDoc_v10.pdf.

LEMOS, J.R., 2004. Composição florística do Parque Nacional Serra da Capivara, Piauí, Brasil. *Rodriguésia*, vol. 55, pp. 55-66.

NORRIS, D., 2014. Model thresholds are more important than presence location type: understanding the distribution of lowland tapir (*Tapirus terrestris*) in a continuous Atlantic forest of southeast Brazil. *Tropical Conservation Science*, vol. 7, no. 3, pp. 529-547. http://dx.doi.org/10.1177/194008291400700311.

PAPES, M. and GAUBERT, P., 2007. Modelling ecological niches from low numbers of occurrences: assessment of the conservation status of poorly known viverrids (Mammalia, Carnivora) across two continents. *Diversity & Distributions*, vol. 13, no. 6, pp. 890-902. http://dx.doi.org/10.1111/j.1472-4642.2007.00392.x.

PEARSON, R.G., RAXWORTHY, C.J., NAKAMURA, M. and PETERSON, A.T., 2007. Predicting species' distributions from small numbers of occurence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography*, vol. 34, pp. 102-117. http://dx.doi.org/10.1111/j.1365-2699.2006.01594.x.

PELLEGRINO, K.C.M., RODRIGUES, M.T., YONENAGA-YASSUDA, Y. and SITES JUNIOR, J.W., 2001. A molecular perspective on the evolution of microteiid lizards (Squamata, Gymnophthalmidae), and a new classification for the family. *Zoological Journal of the Linnean Society*, vol. 74, no. 3, pp. 315-338. http://dx.doi.org/10.1111/j.1095-8312.2001.tb01395.x.

PELOSO, P.L.V., PELLEGRINO, K.C.M., RODRIGUES, M.T. and ÁVILA-PIRES, T.C.S., 2011. Description and phylogenetic relationships of a new genus and species of lizard (Squamata, Gymnophthalmidae) from the Amazonian rainforest of Northern Brazil. *American Museum Novitates*, vol. 3713, no. 3713, pp. 1-24. http://dx.doi.org/10.1206/3713.2.

PENNINGTON, R.T., PRADO, D.E. and PENDRY, C.A., 2000. Neotropical seasonally dry forests and quaternary vegetation change. *Journal of Biogeography*, vol. 27, no. 2, pp. 261-273. http://dx.doi.org/10.1046/j.1365-2699.2000.00397.x.

PHILLIPS, S.J. and DUDIK, M., 2008. Modelling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, vol. 31, no. 2, pp. 161-175. http://dx.doi.org/10.1111/j.0906-7590.2008.5203.x.

PHILLIPS, S.J., ANDERSON, R.P. and SCHAPIRE, R.E., 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, vol. 190, no. 3-4, pp. 231-259. http://dx.doi.org/10.1016/j.ecolmodel.2005.03.026.

PRADO, D.E., 2000. Seasonally dry forests of tropical South America: from forgotten ecosystems to a phylogeographic unit. *Edinburgh Journal of Botany*, vol. 57, no. 3, pp. 437-461. http://dx.doi.org/10.1017/S096042860000041X.

PRADO, D.E., 2003. As caatingas da América do Sul. In: I.R. LEAL, M. TABARELLI and J.M.C. SILVA, eds. *Ecologia e conservação da Caatinga*. Recife: Universidade Federal de Pernambuco, pp. 3-73.

RIBEIRO, S.C., ROBERTO, I.J., SALES, D.L., ÁVILA, W. and ALMEIDA, W.O., 2012. Amphibians and reptiles from the Arapipe bioregion, northeastern Brazil. *Salamandra (Frankfurt)*, vol. 48, no. 3, pp. 133-146.

ROBERTSON, M.P., CAITHNESS, N. and VILLET, M.H.A., 2001. A PCA-based modeling technique for predicting environmental suitability for organisms from presence records. *Diversity & Distributions*, vol. 7, no. 1-2, pp. 15-27. http://dx.doi.org/10.1046/j.1472-4642.2001.00094.x.

RODRIGUES, M.T., 2003. Herpetofauna da Caatinga. In: I. R. LEAL, M. TABARELLI and J. M. C. SILVA, eds. *Ecologia e Conservação da Caatinga*. Recife: Universidade Federal de Pernambuco, pp. 181-236.

RODRIGUES, M.T., TEIXEIRA JUNIOR, M., VECHIO, F.D., AMARO, R.C., NISA, C., GUERRERO, A.C., DAMASCENO, R., ROSCITO, J.G., NUNES, P.M. and RECODER, R.S., 2013. Rediscovery of the earless microteiid lizard *Anotosaura collaris* Amaral, 1933 (Squamata: Gymnophthalmidae): a redescription complemented by osteological, hemipenial, molecular, karyological, physiological and ecological data. *Zootaxa*, vol. 31, no. 3, pp. 345-370. PMid:25277577. http://dx.doi.org/10.11646/zootaxa.3731.3.5.

SALES, R.F.D., ANDRADE, M.J.M., JORGE, J.S., KOLODIUK, M.F., RIBEIRO, M.M. and FREIRE, E.M.X., 2015. Geographic distribution model for *Mabuya agmosticha* (Squamata: Scincidae) in northeastern Brazil. *Zoologia*, vol. 32, no. 1, pp. 71-76. http://dx.doi.org/10.1590/S1984-46702015000100011.

SILVA, D.P., GONZALES, V.H., MELO, G.A.R., LUCIA, M., ALVAREZ, L.J. and MARCO JUNIOR, P., 2014. Seeking the flowers for the bees: integrating biotic interactions intoniche models to assess the distribution of the exotic bee species *Lithurgus huberi* in South America. *Ecological Modelling*, vol. 273, pp. 200-209. http://dx.doi.org/10.1016/j.ecolmodel.2013.11.016.

SOARES, M. and CARAMASCHI, U., 1998. Espécie nova de *Colobosauroides* Cunha, Lima-Verde and Lima, 1991 do estado da Bahia, Brasil (Squamata, Sauria, Gymnophthalmidae). *Boletim do Museu Nacional, Série Zoologia*, vol. 388, pp. 1-8.

THE IUCN RED LIST OF THREATENED SPECIES – IUCN, 2012. *IUCN Red List categories and criteria: version 3.1*. Cambridge. 32 p.

THE IUCN RED LIST OF THREATENED SPECIES – IUCN, 2014 [viewed 15 January 2016]. *Guidelines for using the IUCN Red List categories and criteria: version 11*. Cambridge. Available from: www.iucnredlist.org/documents/RedListGuidelines.pdf.

THE IUCN RED LIST OF THREATENED SPECIES – IUCN, 2015 [viewed 30 June 2015]. *IUCN Red List of Threatened Species*. Cambridge. Available from: www.iucnredlist.org.

VANZOLINI, P.E. and WILLIAMS, E.E., 1981. The vanishing refuge: a mechanism for ecogeographic speciation. *Papéis Avulsos de Zoologia*, vol. 34, no. 23, pp. 251-255.

VELOSO, H.P., RANGEL-FILHO, A.L.R. and LIMA, J.C.A., 1991. *Classificação da vegetação brasileira, adaptada a um sistema Universal*. Rio de Janeiro: IBGE. 123 p.

WERNECK, P.F. and COLLI, G.R., 2006. The lizard assemblage from seasonally dry tropical forest enclaves in the Cerrado biome, Brazil, and its association with the Pleistoceninc Arc. *Journal of Biogeography*, vol. 33, no. 11, pp. 1983-1992. http://dx.doi.org/10.1111/j.1365-2699.2006.01553.x.

WERNECK, P.F., 2011. The diversification of eastern South American open vegetation biomes: historical biogeography and perspectives. *Quaternary Science Reviews*, vol. 30, no. 13-14, pp. 1630-1648. http://dx.doi.org/10.1016/j.quascirev.2011.03.009.

WINCK, G.R., ALMEIDA-SANTOS, P. and ROCHA, C.F.D., 2014. Potential distribution of the endangered endemic lizard *Liolaemus lutzae* Mertens, 1938 (Liolaemidae): are there other suitable areas for a geographically restricted species? *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 74, no. 2, pp. 338-348. PMid:25166318. http://dx.doi.org/10.1590/1519-6984.18612.