# POTENTIAL DISTRIBUTION OF CAVE BATS AS A TOOL FOR LOCATING CAVES AREAS

## *DISTRIBUIÇÃO POTENCIAL DE MORCEGOS CAVERNÍCOLAS COMO FERRAMENTA PARA LOCALIZAÇÃO DE ÁREAS COM CAVERNAS*

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**Abstract**

The present study used the potential distribution of five species of cave bats (*Furipterus horrens, Natalus macrourus, Lonchorhina aurita, Pteronotus gymnonotus* and *Pteronotus parnellii*) as a tool to identify areas with potential for cave occurrence. First, the distribution potentials of bats, generated in the Maxent algorithm, were compared with the registered caves and with the potential occurrence map of caves in Brazil, confirming the distribution of species in sites with registration or potential presence of caves. Distribution models of the five species have overlapping areas; thus, it is suggested that when this overlap occurs with three or more of these species, the possibility of caves exists. Seventeen areas are thus indicated as having cave occurrence potential, distributed mainly in the states of Alagoas, Bahia, Federal District, Goiás, Pará, Pernambuco and Minas Gerais. The orientation provided here may contribute to researchers working in the exploration and registration of caves in Brazil and to the knowledge of cave bats.

**Key-Words:** chiroptera; species modeling distribution; maxent; speleological exploration; speleological heritage.

***Resumo***

*O presente estudo utilizou a distribuição potencial de cinco espécies de morcegos cavernícolas (Furipterus horrens, Natalus macrourus, Lonchorhina aurita, Pteronotus gymnonotus e Pteronotus parnellii) como ferramenta para identificar áreas com potencial para ocorrência de cavernas. Primeiramente, os potenciais de distribuição dos morcegos, gerados no algoritmo Maxent, foram comparados com as cavidades cadastradas e com o mapa de ocorrência potencial de cavernas no Brasil, confirmando a distribuição das espécies em locais com registro ou potencial presença de cavernas. Os modelos de distribuição das cinco espécies possuem áreas sobrepostas. Assim, sugere-se que quando esta sobreposição ocorre com três ou mais dessas espécies, existe grande possibilidade de existir cavernas no local. Dezessete áreas são indicadas como tendo potencial de ocorrência de cavernas, distribuídas principalmente nos estados de Alagoas, Bahia, Distrito Federal, Goiás, Pará, Pernambuco e Minas Gerais. A orientação aqui fornecida pode contribuir para pesquisadores que trabalham na exploração e registro de cavernas no Brasil e para o conhecimento sobre os morcegos cavernícolas.*

***Palavras-Chave****: chiroptera; modelagem de distribuição de espécies; maxent; exploração espeleológica; patrimônio espeleológico.*

## 1. INTRODUCTION

Bats are one of the few vertebrates to use caves as shelter in an efficient and permanent manner, performing an important role in supplying organic matter to the subterranean ecosystem (KUNZ, 1982; MARTINS; FERREIRA, 1999). Additionally, in Brazil, bats have been shown to be of fundamental importance to classify the caves according to their degree of relevance, as well as to determine the areas of influence of these subterranean spaces (BRAZIL, 2017). Such determinations have been decisive for the environmental decision-making agencies regarding environmental licensing processes in the country.

In Brazil, caves are legally protected, thus, there are rules and guidelines that govern their use and preservation (e.g. BRAZIL, 1990; 2008). However, to assist the public policy strategies for the conservation of caves, effectively locating and recording the largest possible number of caves is primarily necessary. Although there are more than 12,000 registered caves in the "Natural Subterranean Cave Geospatial Distribution Database " of the National Centre for Caves Research and Conservation – CECAV (CECAV, 2018), it is estimated that less than 5% of the Brazilian caves are known (PILÓ; AULER, 2011). Generation of basic knowledge, such as the simple registration of caves, significantly assists in the implementation of several public policies aimed at protecting natural resources and caves.

Some bat species preferentially shelter in caves, among which we can mention: *Lonchorhina aurita* (LASSIEUR; WILSON, 1989; TAVARES et al., 2010); *Natalus macrourus*, (TADDEI; UIEDA, 2001; ESBÉRARD et al., 2005); *Furipterus horrens* (UIEDA et al., 1980; ESBÉRARD et al., 2005); *Pteronotus parnellii* (HERD, 1983; EISENBERG; REDFORD, 1999); and *Pteronotus gymnonotus* (VIZOTTO et al., 1980). Thus, the distribution of these species includes key information for locating caves.

To predict the geographic distribution of species, ecological niche modeling is a tool that has been recently used to generate species distribution models (GUISAN; THUILLER, 2005; LATIMER et al., 2006). In practice, the species distribution model reflects the fundamental niche based on the accomplished niche (presence data), predicting where there are suitable conditions for the occurrence of the species and their "potential distribution" (GUISAN; THUILLER, 2005; LATIMER et al., 2006).

From this perspective, our goal was to present a novel methodological approach which uses the overlay of cave bat potential distribution to identify areas with cave occurrence potential.

## 2. MATERIALS AND METHODS

### 2.1. Study Area and Target Species

The study area includes the entire Brazilian territory (~ 8,515,767.049 km$^2$) (IBGE, 2010). The records of target species occurrence are divided into 20 federal units (AM, AP, BA, CE, DF, GO, MA, MG, MS, MT, PA, PB, PE, PI, RJ, RN, RR, SE , SP and TO) and information about environmental variables, registered caves and the cave occurrence potential map cover the whole country.

Five species of bats that mostly use caves as shelters were selected as target species: *Furipterus horrens* (F. Cuvier, 1828); *Natalus macrourus* (Gervais, 1856); *Lonchorhina aurita* Tomes, 1863; *Pteronotus gymnonotus* Natterer, 1843 and *Pteronotus parnellii* (Gray, 1843). The latter species has recently undergone taxonomic revision (PAVAN; MARROIG, 2016; DE THOISY, et al., 2014; PAVAN, 2014), which may represent a complex of at least four species.

### 2.2. Potential Distribution Modeling

The potential distribution of the species was prepared by the method of maximum entropy, using the Maxent algorithm (version 3.3.2), which considers a multivariate set of environmental data and species occurrence points, to generate a map of the probability of species occurrence within the range from zero to 100% (PHILLIPS et al., 2006; ELITH et al., 2011). We adopted the default configuration of Maxent, with the *remove duplicate presence records* function, so that only one record of the species for each grid (~1 km²) was considered, improving the performance of the generated models (PHILLIPS et al., 2006; PHILLIPS; DUDIK, 2008).

### 2.3. Occurrence data of target species

Although the algorithm used (Maxent) has a good performance, even with a small number of records (PEARSON et al., 2007), Hernandez et al. (2008) analyzed distribution models of 16 species (eight birds and eight mammals) with different amount of occurrence points, and found better results for species with more occurrence points. Thus, to enable a comparison with greater accuracy among each target species model, we standardized the occurrence points for each species at 30. However, for *P. gymnonotus* only 25 points were used, due to the low number of records. The points of occurrence are from research conducted by the authors (32 new records for the five species) and that in the literature (Table 1).

The 32 new records are from surveys conducted in the last 10 years in 13 Brazilian states (MA, BA, CE, DF, GO, MG, MS, MT, PE, PI, RN, SE and TO). Bats were sampled through captures using mist nets and harp traps.

**Table 1**. The table below contains the occurrence points used in the species potential distribution modeling: La – *Lonchorhina aurita*; Fh – *Furipterus horrens*; Nm – *Natalus macrourus*; Pg – *Pteronotus gymnonotus*; and Pp – *Pteronotus parnellii*.

| Region | State | Local | Latitude | Longitude | La | Fh | Nm | Pg | Pp | Ref |
|---|---|---|---|---|---|---|---|---|---|---|
| Buíque | PE | G. Gato | -8.853573 | -37.255525 | X | | | | | 1 |
| D. Pastora | SE | G. Pedra Branca | -10.777141 | -37.145346 | X | | | | | 1 |
| F. Guerra | RN | G. Três Lagos | -5.593288 | -37.687155 | X | | | | | 1 |
| Goianésia | GO | L. Fuzil | -15.475846 | -49.010234 | X | | X | | | 1 |
| Sonora | MS | G. Sumidouro | -17.612910 | -54.835138 | X | | | | | 1 |
| Unaí | MG | G. Res. Malhadinha | -16.212234 | -47.265565 | X | | | | | 1 |
| Uruaçú | GO | G. Bibiana | -13.517139 | -48.117125 | X | X | X | | | 1 |
| C. Formoso | BA | T. Morrinho | -10.209096 | -40.918145 | | X | | | | 1 |
| C. Formoso | BA | T. Tiquara | -10.452656 | -40.536515 | | X | | | | 1 |
| C. Formoso | BA | T. Grotão | -10.216200 | -40.972900 | | X | | | | 1 |
| C. Formoso | BA | T. Gonçalo | -10.510567 | -40.894684 | | X | X | | | 1 |
| C. J. Dias | PI | G. Inferno | -8.781859 | -42.483352 | | X | | | | 1 |
| Damianópolis | GO | G Rib. Dos Porcos | -14.518237 | -46.142492 | | X | X | | | 1 |
| Dianópolis | TO | G. Alagada | -11.874704 | -46.768996 | | X | | | X | 1 |
| Dianópolis | TO | PCH Boa Sorte | -11.657242 | -46.705878 | | X | | | | 1 |
| Itacaranbi | MG | G. Olhos d'Água | -15.117120 | -44.167069 | | X | | | | 1 |
| Buíque | PE | G Meu Rei | -8.580199 | -37.267204 | | | X | X | | 1 |
| Cuiabá | MT | G. Aroe Jari | -15.613833 | -55.499272 | | | X | | | 1 |
| Sonora | MS | PCH PPE | -17.592954 | -54.825510 | | | X | X | | 1 |
| P. Preta | RN | G. Guano | -5.139540 | -35.908600 | | | X | | | 1 |
| Serranópolis | GO | G. Diogo | -18.279095 | -52.024600 | | | X | | | 1 |
| Araripe | CE | G. Brejinho | -7.230723 | -39.996902 | | | | X | X | 1 |
| Arinos | MG | G. Salobo | -15.487972 | -46.221677 | | | | X | | 1 |
| Cotriguaçú | MT | A. dos Morcegos | -8.559583 | -58.535306 | | | | X | X | 1 |
| F. Guerra | RN | G. Urubu | -5.572946 | -37.652542 | | | | X | | 1 |
| Juruena | AM | Parna Juruena | -7.272404 | -58.202193 | | X | | X | | 1 |
| Laranjeiras | SE | G. Urubu | -10.706541 | -37.117046 | | | | X | | 1 |
| Ourolândia | BA | T. dos Ossos | -10.930442 | -41.057562 | | | | X | X | 1 |
| Sonora | MS | PCH PPE | -17.612999 | -54.835369 | | | | X | X | 1 |
| Dianópolis | TO | Faz. Cannaã | -11.874700 | -46.768987 | | | | | X | 1 |
| Sonora | MS | PCH PPE | -17.610415 | -54.832353 | | | | | X | 1 |
| Sonora | MS | PCH PPE | -17.630336 | -54.863365 | | | | | X | 1 |
| Iporanga | SP | G. Jeremias | -24.640000 | -48.703200 | | X | | | | 2 |
| Iporanga | SP | G. Areia de Cima | -24.583809 | -48.700458 | X | | X | | | 2 |
| Iporanga | SP | G. Santana | -24.533470 | -48.702152 | | | X | | | 2 |
| Alter do Chao | PA | Rio Tapajos | -2.5 | -54.95 | | | | X | X | 3 |
| Paraiso | MS | Faz. Mimoso | -19.040833 | -52.874166 | | | X | | | 4 |
| Costa Rica | MS | Faz. Pouso Frio | -18.665278 | -52.892778 | X | | | | X | 4 |
| P. Bernardo | GO | T. Gameleira | -15.483747 | -48.050428 | X | X | | | | 5 |
| P. Bernardo | GO | G. das Orquídeas | -15.483747 | -48.067128 | | X | | | | 5 |
| Brasília | DF | G. Saúva | -15.546900 | -47.866900 | | | X | | | 5 |
| Brasília | DF | G. Barriguda | -15.512647 | -48.124329 | | X | | | | 5 |
| Brasília | DF | G. Dois Irmãos | -15.519847 | -48.124629 | X | | | | | 6 |
| P. Bernardo | GO | G. Morro | -15.450447 | -48.150429 | X | | | | X | 6 |
| Brasília | DF | G. Moji | -15.560000 | -47.822800 | | X | | | | 6 |

| Region | State | Local | Latitude | Longitude | La | Fh | Nm | Pg | Pp | Ref |
|---|---|---|---|---|---|---|---|---|---|---|
| Brasília | DF | G. Água Rasa | -15.548100 | -47.750300 | | X | | | | 6 |
| Brasília | DF | G. Muralha | -15.503045 | -48.167591 | | X | | | | 6 |
| Brasília | DF | G. D. dos Vampiros | -15.561400 | -47.756900 | | | | X | X | 6 |
| Brasília | DF | G. Volks Club | -15.873458 | -47.810306 | X | | | | | 6 |
| Niquelândia | GO | C. da Lapa | -14.572942 | -48.956232 | X | | | X | | 7 |
| Niquelândia | GO | L. Riacho Fundo | -14.474643 | -48.334628 | X | | | | | 7 |
| Niquelândia | GO | G. Babaçú | -14.009041 | -48.292327 | | | | X | | 7 |
| Formosa | GO | G. T. da Onça | -15.483476 | -47.306596 | | | | X | X | 8 |
| C. do Brito | SE | C. Casa de Pedra | -10.834188 | -37.450988 | X | | | | | 9 |
| Coxim | MS | Serra Coxim | -18.589122 | -54.803728 | X | | | | | 10 |
| Saramandaia | MT | Saramandaia | -17.890389 | -53.510842 | | | X | | X | 10 |
| Vista Bonita | MS | Vista Bonita | -17.973722 | -53.644175 | | | X | | X | 10 |
| Pri. do Oeste | MT | PE N. Rio Taquari | -15.099497 | -53.343747 | | | | | X | 10 |
| Mineiros | GO | Parna das Emas | -18.254944 | -52.884242 | | | | X | X | 10 |
| Araruana | PB | PE Pedra da Boca | -6.455858 | -35.673907 | | | | X | | 11 |
| São Luis | CE | RPPN S. das Almas | -5.141986 | -40.616938 | | | | | X | 11 |
| C. da Barra | ES | Flona Rio Preto | -18.355278 | -39.844167 | | X | | | | 12 |
| Mambaí | GO | L. R. das Pedras IV | -14.533288 | -46.110710 | X | | | | X | 13 |
| Mambaí | GO | L. R. das Pedras I | -14.532268 | -46.105514 | X | | | | | 13 |
| Mambaí | GO | G. Judite | -14.407300 | -46.195500 | X | X | X | | X | 14 |
| Mambaí | GO | G. Faz. Bananal | -14.363600 | -46.208200 | | | X | | | 14 |
| Mambaí | GO | L. da Lapa | -14.482056 | -46.302906 | X | | X | X | | 14 |
| Mambaí | GO | T. dos Ossos | -14.482100 | -46.302900 | | | | X | | 14 |
| Mambaí | GO | L. Faz. Extrema | -14.439963 | -46.176553 | X | | | | | 14 |
| Mambaí | GO | L. Faz. Buritizinho | -14.452252 | -46.283072 | X | | | | | 14 |
| Mambaí | GO | G. Faz. Arroz | -14.455748 | -46.152692 | X | | | | | 14 |
| Ilha Grande | RJ | Ilha Grande | -23.211196 | 44.342666 | | X | | | | 15 |
| Miracema | RJ | Paraíso do Tobias | -21.404444 | -42.0675 | | | X | | | 16 |
| João Pessoa | PB | C. da Onça | -7.166666 | -34.916666 | | | X | | | 17 |
| St. Terezinha | PB | St. Terezinha | -7.083333 | -37.45 | X | | | | | 17 |
| Caracol | PI | Parna S. Confusões | -9.220000 | -43.497778 | | X | | | | 18 |
| Rio de Janeiro | RJ | Res. Rio das Pedras | -22.990556 | -44.100833 | X | | | | | 19 |
| Igarape Grande | AP | Flona Amapá | 1.283633 | -51.588819 | | | | | X | 20 |
| Igarapé Grande | AP | Parna M. Tumucomaque | 1.601528 | -52.490278 | | | | | X | 20 |
| Igarapé Grande | AP | Parna M. Tumucomaque | 2.193397 | -54.587658 | | | | | X | 20 |
| A. do Tocantins | TO | G. do Moura | -12.5815 | -46.516388 | | X | | | | 21 |
| Rio de Janeiro | RJ | Praia da Sumaca | -23.286667 | -44.528889 | | X | | | | 22 |
| V. do Xingu | PA | C. Leon. da Vinci | -3.152341 | -52.075452 | | | | X | | 23 |
| Altamira | PB | C. Pedra da Cachoeira | -3.312288 | -52.341538 | | X | X | X | | 23 |
| V. do Xingu | PA | C. Kararaô | -3.140925 | -51.818367 | | | | X | | 23 |
| Ilha de Maracá | RR | Ilha de Maracá | 3.416667 | -61.666667 | X | | | X | X | 24 |
| Altamira | PA | Rio Xingu | -3.65 | -52.366667 | | X | | | X | 24 |
| Manaus | AM | Rio Solimões | -2.416667 | -59.75 | | | | X | X | 25 |
| M. do Chapéu | BA | Abrigo da Vespa | -10.984028 | -41.433744 | | | X | | | 26 |
| Utinga | BA | G. Alto do Bonito | -12.038366 | -41.169804 | | | X | | | 26 |
| Nova Xavantina | MT | Bairo Flor de Liz | -14.666667 | -52.333333 | | | | | X | 27 |

| Region | State | Local | Latitude | Longitude | La | Fh | Nm | Pg | Pp | Ref |
|---|---|---|---|---|---|---|---|---|---|---|
| Ubajara | CE | G. de Ubajara | -3.834313 | -40.899987 | | X | | | | 28 |
| Indiara | GO | G. do Joel | -17.204350 | -49.787143 | X | | X | | | 29 |
| Paraíso | MS | Paraíso | -19.05 | -52.966667 | | | X | | | 30 |
| Rio Verde de MT | MS | Rio Verde de MT | -18.983333 | -57.8 | | | X | | | 30 |
| Ipatinga | MG | Vale do Peruaçu | -19.496724 | -43.544894 | X | | | | | 31 |
| Itacarambi | MG | Vale do Peruaçu | -15.084700 | -44.262600 | | X | | | | 31 |
| Itacarambi | MG | G. do Carlucio | -15.086969 | -44.261303 | | X | | | | 31 |
| Curvelo | MG | Caverna | -19.816667 | -43.966667 | | | X | | | 31 |
| Medicelândia | PA | C. do Limoeiro | -3.538888 | -52.785277 | | | X | | | 32 |
| Iporanga | SP | Abismo da Chuva | -24.265965 | -48.423126 | | X | | | | 33 |
| Pres. Figueiredo | AM | Refúgio do Maroaga | -2.066667 | -59.683333 | | | | | X | 33 |
| Xingu | PA | Rio Xingu | -3.65 | -52.383333 | | | X | | | 34 |
| Serranópolis | GO | Pousada das Araras | -18.416667 | -52.00 | | | | | X | 35 |
| Medicelândia | PA | C. Planaltina | -3.377888 | -52.575440 | X | | X | X | X | 23/ 32 |

References (Ref): **1**- Present study; **2**- Arnone, 2008; **3**- Bernard; Fenton, 2002; **4**- Bordinon, 2006; **5**- Bredt; Magalhães, 2006; **6**- Bredt et al., 1999; **7**- Bredt; Júnior, 1996; **8**- Chaves et al., 2012; **9**- Santos, 2007; **10**- Coelho, 2005; **11**- Cruz et al., 2005; **12**- Duda et al., 2012; **13**- Esbérard et al., 2001; **14**- Esbérard et al., 2005; **15**- Esbérard et al., 2006; **16**- Esbérard et al., 2010; **17**- Feijo; Langguth, 2011; **18**- Gregorin et al., 2008; **19**- Luz et al., 2011; **20**- Martins et al., 2006; **21**- Novaes et al., 2012; **22**- Pol et al., 2003; **23**- Neckel; Tavares, 2008; **24**- Robinson, 1998; **25**- Sampaio et al., 2003; **26**- Sbragia; Cardoso, 2008; **27**- Silva; Anacleto, 2011; **28**- Silva et al., 2001; **29**- Silva et al., 2009; **30**- Taddei; Uieda, 2001; **31**- Tavares et al., 2010; **32**- Trajano; Moreira, 1991; **33**- Trajano; Gnaspinni, 1991; **34**- Voss; Emmons, 1996; **35**- Zortéa, 2001.

### 2.4. Environmental variables

The pre-selection of environmental variables improves and facilitates the modeling of potential distribution and reduces the dimensionality of the data and the computational cost (XIMENES et al., 2009). Thus, the pre-selection helps in the selection of variables that most affect the species occurrence (PHILLIPS et al., 2006). However, information regarding the environmental requirements of several species are unknown, as the case of the target species used in this study. In these cases, an alternative is to use the Maxent jackknife tool to select the environmental variables (PHILLIPS et al., 2006; PHILLIPS; DUDIK, 2008).

Thus, from 50 environmental variables organized and separated for Brazil by the Biodiversity Study Modeling Group of the Image Processing Division at the National Institute for Space Research (DPI / INPE), available at http://www.dpi.inpe.br/Ambdata/download.php, we selected a set of 10 variables for each target species using the Maxent Jackknife tool (PHILLIPS et al., 2006; PHILLIPS; DUDIK, 2008). The variables indicated by Maxent differ among the five bat species, reflecting the different sets of occurrence points used for each species, and totaling 24 variables (Table 2).

The selected variables (Table 2) were *vegetation* – a vegetation map of Brazil, reconstituted in 1992, from radar image-charts from the RADAMBRASIL Project obtained from the Brazilian Institute of Geography and Statistics (IBGE); *altitude* - generated from Shuttle Radar Topographic Mission (SRTM) with values expressed in meters; *tree cover* - is the cover of the annual forest canopy and was generated by remote sensing using the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor (HANSEN et al., 2003); *slope* - representing the horizontal surface slope (inclination angle); *orientation* - is the direction of change in slope and corresponds to the azimuth of the highest slope of the land; *drainage* - generated using a spatial interpolation algorithm on the drainage data from the HydroSHEDS Project (XIMENES, 2008); ten derived bioclimatic variables: *mean diurnal variation of temperature* (maximum temperature - minimum temperature); *seasonality of temperature*; maximum temperature of the warmest month; mean temperature of the wettest quarter; average temperature of the coldest quarter; *seasonality of precipitation*; precipitation of wettest quarter; precipitation of the driest quarter; precipitation of the warmest quarter; precipitation of the coldest quarter; and eight other variables related to the total precipitation in the months of February, April, May, June, July, August, October and

December. The derived bioclimatic variables and those related to precipitation were obtained from Global Climate Data (Worldclim) and represent the 1950-2000 period (HIJMANS et al., 2005).

### 2.5. Information on caves

We used a geospatial distribution database of 18,012 caves registered in Brazil (CECAV, 2018), from specialized literature, the National Cave Register of Brazil by the Brazilian Speleology Society (CNC/SBE), the Brazilian Speleological Inventory of the Redespeleo Brazil (CODEX), and from research and environmental studies. We also used digital data from the map of Potential Occurrence of Caves in Brazil, at a 1:2,500.00 scale (JANSEN et al., 2012), indicating "Very High" and "High" potential presence of caves.

### 2.6. Analysis criteria and areas with potential for caves

We evaluated the potential distribution map of each target species according to the values of the Receiver Operating Characteristic analysis (ROC), which characterizes the model at all possible thresholds with a unique number, the area under the curve (AUC) ranging from zero to one. Values closer to 1 comprise a good model, while AUC values near 0.5 correspond to a random prediction (PHILLIPS et al., 2006).

We used ArcGIS/ArcMap 10 (ESRI) to deal with potential distribution models generated in Maxent creating a layer with places where the probability of the target species occurrence is greater than 70%. The layers were contrasted individually with information about caves (CECAV database CANIE, 2018; and the potentiality map of JANSEN et al., 2012), to investigate the dependence of the five species for areas with a record of caves or high potential for the potential occurrence of these shelters.

Finally, the maps for potential distribution of the target species were compared and five locals with an overlap of three or more of these species were suggested as having high potential for cave occurrence.

## 3. RESULTS

The AUC values were close to one (Table 2), indicating good accuracy of the generated potential distribution models, which suggests that the Maxent jackknife tool selected appropriate environmental variables.

The potential distribution models generated for the five bat species (Figure 1; 2; 3; 4; 5), indicated that target species are distributed throughout locations containing reccords of, or high potential for, the presence of caves, confirming the dependence of the species on these subterranean shelters.

**Table 2**. Analysis of potential distribution of five cave bats (*Pteronotus gymnonotus; Pteronotus parnellii; Furipterus horrens; Lonchorhina aurita* and *Natalus macrourus*) using Maxent. Presenting the area under the curve (AUC) values and environmental variables ordered by contribution percentage (in parentheses), representing the 10 that most contributed to the modeling, as follows: V1 - vegetation; V2 - altitude; V3 - tree cover; V4 - Slope; V5 - orientation; V6 - drainage; V7 - average diurnal temperature variation; V8 - seasonality of temperature; V9 - maximum temperature of the warmest month; V10 - mean temperature of the wettest quarter; V11 - average temperature of the coldest quarter; V12 - seasonality of precipitation; V13 - precipitation of the wettest quarter; V14 - precipitation of the driest quarter; V15 - precipitation of the warmest quarter; V16 - precipitation of the coldest quarter; V17 - February total precipitation; V18 - April total precipitation; V19 - May total precipitation; V20 - June total precipitation; V21 - July total precipitation; V22 - August total precipitation; V23 - October total precipitation; V24 - December total precipitation.

| | *P. gymnonotus* | *P. parnellii* | *F. horrens* | *L. aurita* | *N. macrourus* |
|---|---|---|---|---|---|
| AUC | 0.937 | 0.950 | 0.973 | 0.965 | 0.959 |
| Environmental variables (% Contribution) | V5 (25.8) | V1 (29.1) | V1 (27.4) | V1 (16.4) | V1 (30.1) |
| | V15 (21.7) | V15 (15.5) | V16 (19.8) | V2 (11.5) | V9 (13.8) |
| | V12 (11.5) | V12 (10.5) | V2 (11.1) | V7 (10.4) | V2 (9.6) |
| | V7 (6.2) | V8 (7.6) | V13 (7.3) | V18 (9.6) | V11 (6.1) |
| | V2 (4.3) | V18 (5.9) | V19 (5) | V8 (8.5) | V4 (5.6) |
| | V9 (3.9) | V9 (5) | V21 (4.9) | V4 (8.3) | V12 (5.2) |
| | V6 (3.8) | V21 (4.7) | V20 (4.8) | V12(4.8) | V10 (3.3) |
| | V20 (3.8) | V17 (3.9) | V7 (3.6) | V24 (4.1) | V24 (2.7) |
| | V8 (3.2) | V22 (2.8) | V18 (2.5) | V14 (3.9) | V3 (2.4) |
| | V1 (3) | V2 (2.3) | V15 (2.4) | V13 (3.4) | V23 (2.1) |

The environmental variables that contributed most to the model *Pteronotus gymnonotus* were orientation, precipitation in the warmest quarter and seasonality of precipitation (Table 2). Throughout the area with 70% probability of occurrence of this species there is information of caves in the states of AL, BA, CE, DF, ES, GO, MA, MG, PA, PB, PE, PI, RJ, RN, RR, RO, SE, SP and TO (Figure 1).

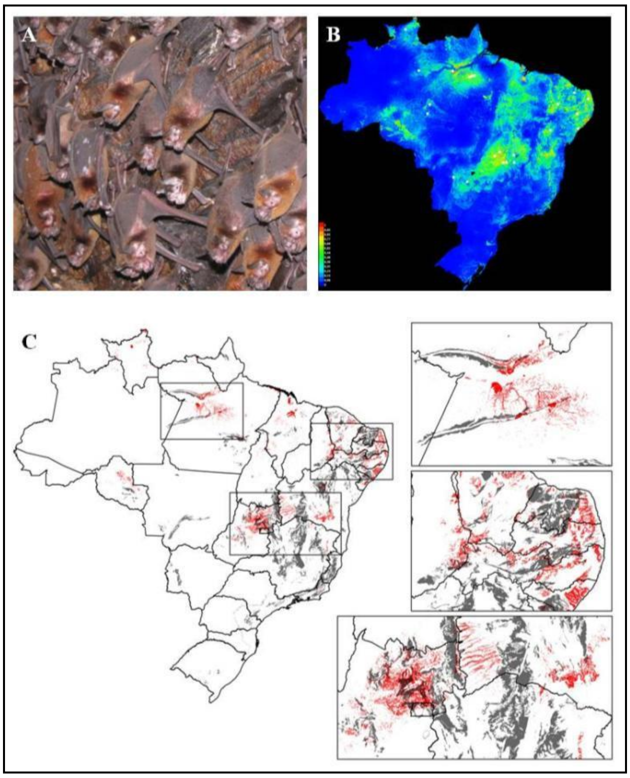

**Figure 1**. *Pteronotus gymnonotus* (A) and its potential distribution in Brazil (B), prepared by the Maxent, considering 30 points of occurrence (see Table 1t the beginning of this Appendix). Potential distribution with probability of occurrence above 70% (red), sites with "Very High and High" cave occurrence potential obtained from the Map of Potential Occurrence of Caves in Brazil (JANSEN et al., 2012), with black dots with 60% transparency (C).

For *Pteronotus parnellii*, the main variables selected were vegetation, precipitation of the warmest quarter and seasonality of precipitation (Table 2). Throughout the area with 70% probability of occurrence of this species there is information of caves registered in the states of AL, BA, CE, DF, GO, MG, MS, MT, PA, PB, RO and TO (Figure 2).

The three main environmental variables indicated for *Furipterus horrens* were vegetation, precipitation of the coldest quarter and altitude (Table 2). Throughout the area with 70% probability of occurrence of this species there is information of caves in states of BA, DF, GO, TO, MG, SP and PR (Figure 3).

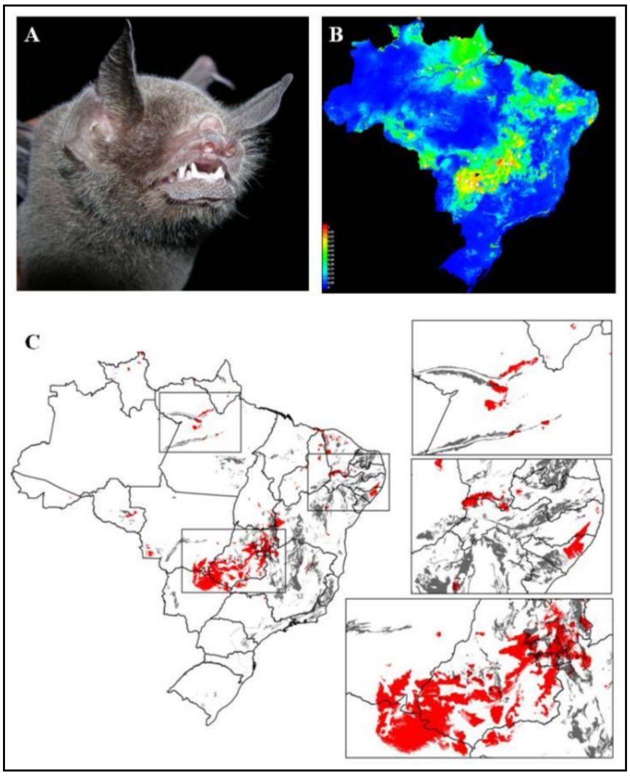

**Figure 2**. *Pteronotus parnellii* (A) and its potential distribution in Brazil (B), prepared by the Maxent, considering 30 points of occurrence (see Table 1t the beginning of this Appendix). Potential distribution with probability of occurrence above 70% (red), sites with "Very High and High" cave occurrence potential obtained from the Map of Potential Occurrence of Caves in Brazil (JANSEN et al., 2012), with black dots with 60% transparency (C).

The vegetation, altitude and mean diurnal temperature variation were the environmental variables that contributed most to the potential distribution model of *Lonchorhina aurita* (Table 2). Throughout the area with 70% probability of occurrence of this species there is information of caves in states of AL, BA, CE, DF, ES, GO, MG, PB, PE, PI, RJ, RN, SE, SP and TO (Figure 4).

For *Natalus macrourus* the environmental variables that most influenced the modeling of potential distribution were vegetation, the maximum temperature of the warmest month and the altitude (Table 2). Throughout the area with 70% probability of occurrence of this species there is information of caves in states of BA, DF, ES, GO, MG, MT, MS, PA, CP and SP (Figure 5).

Analyzing the potential distribution of the species *Natalus macrourus*, *Peteronotus parnellii* and *Pteronotus gymnonotus* we observed areas of overlap in Santarém, Uruará and Altamira in Pará state (Figure 6a) and São Miguel dos Campos, Marechal Deodoro, Rio Largo and União dos Palmares in Alagoas state and Quipapá and Palmares in Pernambuco state (Figure 6c). In the municipalities of Campo Formoso and Santo Sé in Bahia state there is an overlap between *Furipterus horrens*, *N. macrourus* and *P. gymnonotus* (Figure 6b).

In Minas Gerais state three sites are indicated: in Teofilo Otoni and Joaíma in the eastern part of the state by the overlapping of *N. macrourus*, *P. gymnonotus* and *Lonchorhina aurita* (Figure 6d); in Mato Verde and Monte Azul in the northeast with overlapping of *F. horrens*, *N. macrourus* e *P. parnellii* (Figure 6e) and in Arinos and Buritis in north by the overlapping of *F. horrens, L. aurita* e *P. parnellii* (Figure 6f). In Goiás state two areas stood out: one located in Padre Bernardo, Mimoso de Goiás and Girassol, reaching the northern part of the Federal District (Figure 6g) where there is an overlap of all five species. The second area comprises São João d'Aliança and Flores de Goiás, in which only *P. gymnonotus*, did not appear as of potential distribution (Figure 6h).

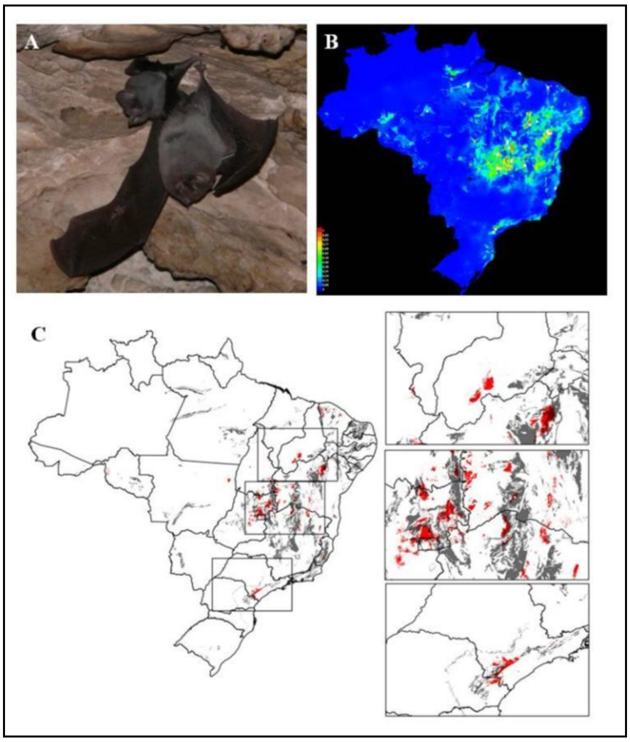


**Figure 3**. *Furipterus horrens* (A) and its potential distribution in Brazil (B), prepared by the Maxent, considering 30 points of occurrence (see Table 1). Potential distribution with probability of occurrence above 70% (red), sites with "Very High and High" cave occurrence potential obtained from the Map of Potential Occurrence of Caves in Brazil (JANSEN et al., 2012), with black dots with 60% transparency (C).

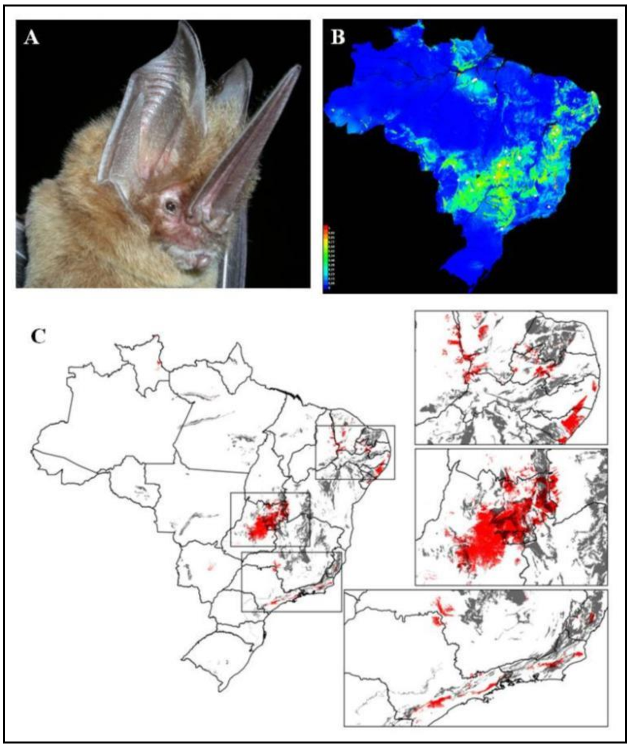


**Figure 4**. *Lonchorhina aurita* (A) and its potential distribution in Brazil (B), prepared by the Maxent, considering 30 points of occurrence (see Table 1t the beginning of this Appendix). Potential distribution with probability of occurrence above 70% (red), sites with "Very High and High" cave occurrence potential obtained from the Map of Potential Occurrence of Caves in Brazil (JANSEN et al., 2012), with black dots with 60% transparency (C).

A considerable part of the areas indicated here as exhibiting high potential for cave occurrenceis found outside conservation units (CU). Few exceptions include part of the Pouso Alto Environmental Protection Area (EPA), in Goiás state (Figure 6h) and part of the Cafuringa EPA and the Planalto Central EPA (Figure 6g). In Minas Gerais, only a small part of the area indicated in the northeastern state (Figure 6e) is legally protected, since it belongs to the Rio Pardo State Park. In Pará state, only a small part of the proposed area is inserted in the Santa Maria Uruará EPA and the Tapajós National Forest (FLONA). Finally, in Alagoas state, although most part of the Murici Ecological Station (ESEC) is inserted in the areas indicated as having possible cave presence (Figure 6c), the unprotected portion of these areas is much larger.

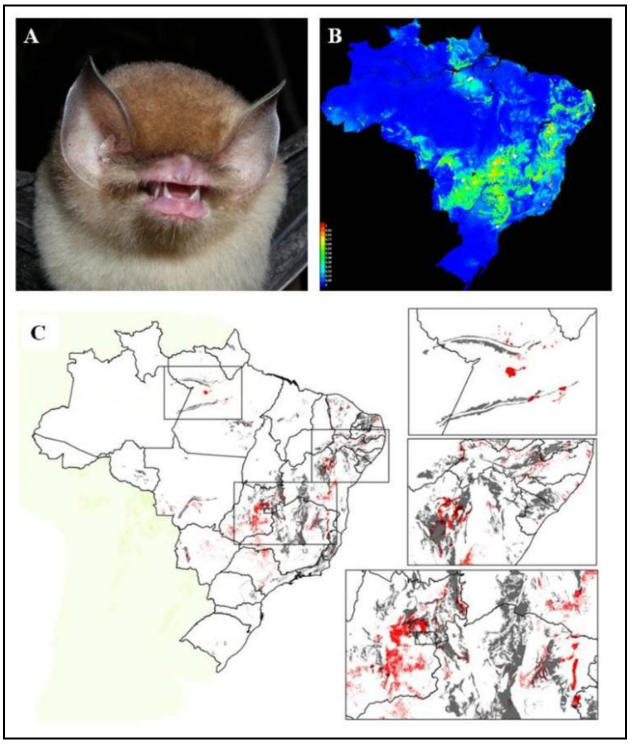

**Figure 5**. *Natalus macrourus* (A) and its potential distribution in Brazil (B), prepared by the Maxent, considering 30 points of occurrence (see Table 1t the beginning of this Appendix). Potential distribution with probability of occurrence above 70% (red), sites with "Very High and High" cave occurrence potential obtained from the Map of Potential Occurrence of Caves in Brazil (JANSEN et al., 2012), with black dots with 60% transparency (C).

## 4. DISCUSSION

Distribution modeling has been used to define the probability of species occurrence and has been applied in a wide range of objectives, such as: the prediction of rare or endangered species (ARAÚJO; WILLIAMS, 2000; BLANK; BLAUSTEIN, 2012), selection of priority areas for conservation (COSTA et al., 2010; VIEIRA et al., 2012), prediction of species in poorly studied areas (HERNANDEZ et al., 2008), studies in macroecology (RAHBEK et al., 2007; DINIZ-FILHO et al., 2009), reintroduction of species (HIRZEL et al., 2002), impacts of climate change (HIJMANS; GRAHAM, 2006; WIENS et al., 2009), possible infectious disease dissemination routes (COSTA et al, 2002; FLORY et al., 2012), among others.

Among these uses, it is important to emphasize that this is the first study to use the distribution modeling to predict the occurrence of caves. However, despite the high area under the curve (AUC) values, obtained from receiver operating characteristic analysis (ROC), the models must be treated with caution, since they only foreshadow appropriate conditions for the species occurrence (GUISAN; THUILLER, 2005; LATIMER et al., 2006).

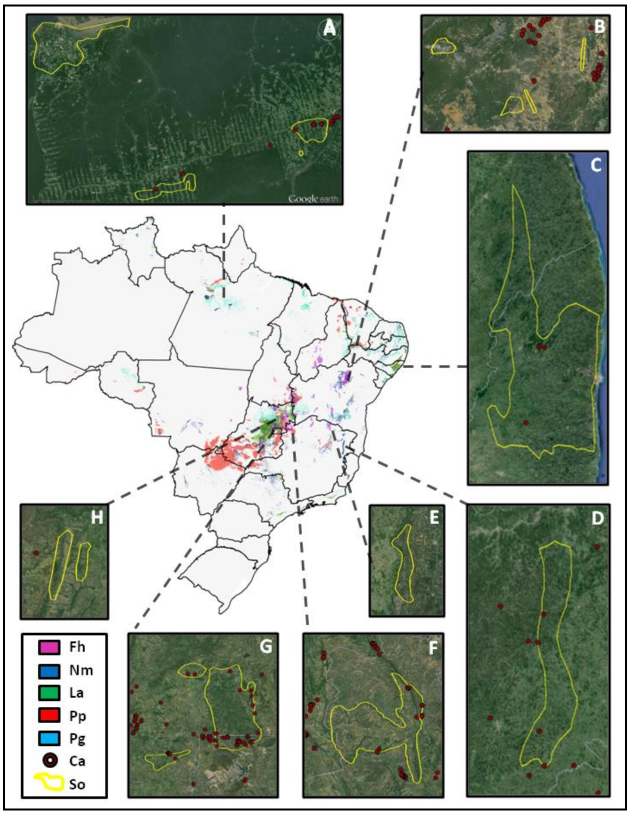


**Figure** 6. Areas indicated as with high cave occurrence potential (Ca), because of potential overlapping distribution of cave bats. A) *Natalus macrourus* (Nm), *Peteronotus parnellii* (Pp) and *Pteronotus gymnonotus* (Pg) in Pará; B) *Furipterus horrens* (Fh), Nm and Pg in Bahia; C) Nm, Pp and Pg in Pernambuco; D) Nm, *Lonchorhina aurita* (La) and Pg in eastern Minas Gerais; E) Fh, Nm and Pp in northeastern Minas Gerais; F) Fh La and Pp in the north of Minas Gerais; G) Fh, La, Nm, Pp and Pg in Goiás and the Federal District in the north; and H) Fh, La, Nm and Pp in northeastern Goiás.

The presence of registered caves (CECAV, 2018) or areas with high potential for cave occurrence (JANSEN et al., 2012) superposing to the areas indicated by the potential distribution models of the bat species is easily visualized. Thus, the occurrence of bat species used in this study is directly related to the existence of caves, confirming their classification as cave-dwelling and increasing the credibility of the models.

The variable representing the "Vegetation" classification system (VELOSO et al., 1991), was the most important contributor to the modeling, except for *P. gymnonotus*, for which the contribution was the lower (3%). This result was expected, reinforcing the importance of preserving areas around the caves to maintain the bat fauna.

However, informations regarding the ecological requirements of the target species are scarce, preventing further discussion.

Both *Pteronotus* species used in this study showed six variables in common, certainly related to the 11 sampling points used in the model in which the two species, *P. gymnonotus* and *P. parnellii*, co-inhabited. This behavior of preferentially seeking refuge with other Mormoopidae is indeed observed for the genus (VIZOTTO et al., 1980; HERD, 1983).

Potential distribution models produced by Maxent for the five target species of this study, as expected, largely corroborate the occurrence already known in the literature (TAVARES et al., 2008; REIS et al., 2011). The exception would be the species *Furipterus horrens,* for which certain known occurrence sites (AM, PE, SC – TAVARES et al., 2008; and PB – REIS et al., 2011) were not suitable for modeling (Table 1). Although the species had obtained the highest AUC value, this is one of the constraints of the modeling.

The five classes present in the cave occurrence potential map (JANSEN et al., 2012), group lithological categories according to the rock solubility characteristics, containing caves registered in all classes: Very High (5749 caves); High (2293); Average (1317); Low (844); and Improbable Occurrence (54). However, the potential distribution model proposed here indicates for cave occurrence according to the the target species occurrence probability, regardless of the classification of Jansen et al. (2012). Thus, the cave bat potential distribution models may be used to refine the cave potential occurrence map (JANSEN et al., 2012), indicating locations more likely for the existence of caves in all five classes, regardless of lithology.

Interpretations regarding the 17 areas suggested as those witht high cave presence potential equally suggest the occurrence of bat species included in this analysis. However, the diagnosis as to the presence of bats should be further considered, since factors related to the history of the landscape influence the geographical distribution of species, such as dispersion limitations, especially in large scale studies (SOBERON; PETERSON, 2005). In the case of caves, the indications should be more accurate, since the model indicates adequate conditions for the occurrence of the species (GUISAN; THUILLER, 2005; LATIMER et al., 2006.). In the case of preferentially cave-dwelling bats, one condition is the existence of natural subterranean cavities.

## 5. CONCLUSION

This is the first study to use potential distribution modeling of cave bats as a tool to identify potential sites for the occurrence of caves. Thus, it provides guidance for researchers who work with the exploration and registration of caves in Brazil and contributes to enhance the knowledge about cave dwelling bats. This new tool acheived accuracy when using Maxent to select the environmental variables and develop potential distribution models. The 17 areas with potential for cave occurrence, shown in this study, are independent of lithology and are distributed mainly in the states of Alagoas, Bahia, Distrito Federal, Goiás, Pará, Pernambuco and Minas Gerais. However, only a small part of the proposed areas is legally protected. Thus, future studies using this information should verify the presence of caves in these areas, but these actions should be conducted as soon as possible since it is necessary to increase the number of registered caves to improve the effectiveness of the Speleological Heritage protection.

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