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Species richness, geographic distribution, pressures, and threats to bats in the Caatinga drylands of Brazil

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ABSTRACT

Tropical dry forests (TDF) are threatened worldwide, affected by conversion to agriculture, fragmentation, fires, and climate change. Most of the remaining TDF are in South America, including Brazil's Caatinga. Understanding how the biota of TDFs responds to habitat loss and climate change is a scientific challenge, especially to diversified groups, such as bats, whose richness and ecological roles in TDF are usually underestimated. We updated and synthesized occurrence data and generated distribution models for Caatinga bats considering present and future scenarios. At least 96 species, 48 genera, and eight families were recorded, including two endemic species; five additional species may occur in the biome. The highest potential species richness occurs in the east, in the Caatinga/Atlantic Forest ecotone; the lowest in the west, in the Caatinga/Cerrado ecotone. Current and projected deforestation led to a reduction of 65% in areas with very high potential richness, and only 0.4% will remain within current protected areas. In a business as usual scenario (i.e., high and fast habitat loss + low in situ protection + high potential exposure to climate change) the bat fauna of the Caatinga will be negatively impacted. Improving the conservation of roosting and foraging sites, with the expansion and/or creation of protected areas is urgently needed.

1. Introduction

Tropical dry forests are frequently pointed out as among the most threatened habitats in the world, as they are severely affected by conversion to agriculture, forest fragmentation, fire, and climate change (Sánchez-Azofeifa et al., 2005; Miles et al., 2006; Portillo-Quintero and Sánchez-Azofeifa, 2010). Most of the remaining tropical dry forests are located in South America, including Brazil's Caatinga (Miles et al., 2006). Caatinga dry forests cover 844,453 km^2 in north-eastern Brazil (MMA, 2011), have large areas in contact with the Amazon, Atlantic Forest, and Cerrado, and are highlighted as the most biodiverse in the world (Leal et al., 2005). Despite this biodiversity, the Caatinga is among the least studied Brazilian terrestrial habitats: Its real species richness is surely higher than recorded, as 41% of the region has never been explored, and 80% of it remains under sampled (Tabarelli and Vicente, 2004). Currently, the Caatinga has at least 25 areas recognized as priorities for scientific investigation (MMA, 2007).

Similar to other tropical dry forests, the Caatinga has undergone strong human pressure and a severe loss of its original cover: data from 2009 pointed out that over 47% of the biome's vegetation have already been deforested or anthropized (MMA, 2011). However, extra-official estimates suggest that the real conservation status is more worrisome, considering that approximately 22 million people live in the Caatinga. The remaining area is highly fragmented, and the Caatinga has the smallest number and the lowest spatial coverage of fully-protected areas among all Brazilian terrestrial biomes (Leal et al., 2005).

In addition to severe habitat loss and low protection, studies point out that the Caatinga might undergo a more marked increase in temperature and decrease in heavy rains than the global average (PBMC, 2015). Climate models for the Caatinga predict an increase from 0.5 to 1 °C in temperature and a decrease from 10% to 20% in rainfall until 2040, and a gradual increase in temperature from 1.5 to 2.5 °C and a decrease in rainfall between 25% and 35% for the period 2041–2070 (PBMC, 2015). In fact, the period from 2012 to 2017 is already considered the greatest drought in the Caatinga in the last 100 years (MCTI, 2017).

Understanding how the dry forest biota, in particular, the Caatinga, responds to habitat loss and climate change is a scientific challenge. It is

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even more difficult for diverse groups, such as mammals, whose species vary from highly vulnerable to habitat loss to severely hunted (Newbold et al., 2014). The Caatinga's mammalian fauna includes at least 153 species of 10 orders, and bats represent the highest share of this richness, with ~90 species in eight families (Paglia et al., 2012; Carvalho-Neto et al., 2016).

Bats are especially important for some plant species in tropical dry forests (e.g., Ibarra-Cerdena et al., 2005; Arias-Coyotl et al., 2006; Martins et al., 2016), and based on a sample of 147 plant species in the Caatinga they represent approximately 13% of the local pollinating fauna (Machado and Lopes, 2004). For comparison, the proportion of chiropterophilous species in other tropical environments is usually much lower, ranging from 1.8 to 3.0% in the Cerrado (Oliveira and Gibbs, 2000) and 3.0% in rainforests (Bawa et al., 1985). Cactaceae, one of the three most abundant botanical families in the Caatinga, has 41 species endemic to this biome, and many of them are pollinated by bats (Machado and Lopes, 2004). The relationship between bats and plants in the Caatinga seems to be highly specialized: a single flower of *Pilosocereus gounellei* or *P. pentaedrophorus*, both pollinated by bats, produces a nectar volume 50 to 100 times higher than that produced by plants pollinated by other animals (Machado and Lopes, 2004). The Caatinga also has areas with a high potential to harbor caves, which are major roosting sites for bats, and some of them are considered as essential for the conservation of endangered species, such as *Natalus macrourus* (Delgado-Jaramillo et al., 2017).

Studies that synthesize biodiversity patterns and model conservation scenarios are becoming more important in the decision-making process considering the fast rate of land use change currently experienced in several parts of the planet (e.g. Nori et al., 2015; Brum et al., 2017) and the exposure to climate change many taxa are already experiencing (e.g. Ribeiro et al., 2016; Wiens, 2016; Pacifici et al., 2017). This is the situation in the Caatinga: the area is experiencing pressures and threats leading to habitat loss and fragmentation, a scenario that tends to be complicated by the severe projected exposure to climate change. Considering the ecological functions bats deliver, assessing their species distribution and richness in the Caatinga is useful in the study of the effects of climate change on the local biota, as well as in the identification of priority areas for conservation. Such an approach for bats in Brazil is urgently needed (Bernard et al., 2011). In the present study, we updated and synthesized occurrence data for Caatinga's bats, and used the software MaxEnt to generate potential distribution models for bats in the Caatinga based on present and future scenarios. A potential richness map was produced for the Caatinga and contrasted with deforestation scenarios and existing protected areas, aiming at identifying priority areas for bat conservation in the largest tract of tropical dry forests in Brazil, and one of the largest in the world.

2. Methods

2.1. Study area

The Caatinga covers 11% of the Brazilian territory and 70% of the north-eastern region, harbouring approximately 63% of the human population of this region and 18% of the population of Brazil (Silva et al., 2004). Here, we considered the original extension of the biome (844,453 km^2) and added a 15-km buffer to include areas where the species can move beyond the political boundaries of the Caatinga. Considering this buffer, the area used in our models was 921,322 km^2.

The Caatinga vegetation is heterogeneous and divided into hyper-xerophilous (31%), hypo-xerophilous (39%), humid habitat islands (8%), and ecotones (*agreste*—12%) (Silva et al., 2004). The Caatinga heterogeneity is also present in the climate, as there is a long dry season, irregular rains, and average annual rainfall between 400 and 600 mm. The soils have a complex spatial distribution, ranging from shallow and rocky soils to sandy and deep soils.

2.2. Occurrence records

The occurrence records of bat species present in the Caatinga were not available in a single database. Therefore, we gathered all georeferenced occurrences for the species in the entire Brazil based on records available at Gbif (http://www.gbif.org/), splink (http://www.splink.org.br/), and vertnet (http://www.vertnet.org/), as well as compilations from museums and studies published in the scientific literature, set by the Laboratory of Bat Biology and Conservation at the University of Brasília (L. M. S. Aguiar, pers. comm.). These records passed through a taxonomic standardization, following the taxonomy of Nogueira et al. (2014). At first, we considered 17,576 records, which were filtered using the SDM tool (spatially rarefy occurrence data) to eliminate points with environmental autocorrelation, i.e., points with equivocated or duplicated records. We excluded 45 species with fewer than six records, and discarded records of species of the genus *Lonchophylla* because a recent taxonomic revision of the genus (Moratelli and Dias, 2015) pointed out that the identifications available for the Caatinga so far need reanalysis. After these treatments, 8849 records remained (See Appendix A.1 for the spatial distribution of the records). The records of species for the states covered by the Caatinga included 58 species in Pernambuco, 56 in Bahia, 47 in Ceará, 45 in Piauí, 32 in Paraíba, 30 in Minas Gerais, 14 in Alagoas, 7 in Sergipe, 3 in Rio Grande do Norte, and 2 in Maranhão.

2.3. Bioclimatic data

Potential species distribution was modelled considering 19 bioclimatic variables available at the WorldClim database (http://www.worldclim.org/—Appendix A.2) (Hijmans et al., 2005), which represent current and future conditions (for the year 2050) of temperature, rainfall, and associated variation, plus altitude at 2.5 arc min resolution (~5 km × 5 km). We analyzed pairs of variables via Pearson correlation in the software R, and, in the pairs that showed over 80% correlation, one of the variables was excluded. The number of variables used for each species depended on the number of records, so that we avoided using more variables than points (Appendix A.3).

2.4. Model construction

We used maximum entropy species distribution modelling (MaxEnt—Phillips et al., 2006), which uses presence data based on georeferenced points of occurrence and environmental variables to estimate the occurrence of species and model their potential distribution. To meet the proposed objective and optimize modelling, we built models avoiding the use of a default configuration and carried out tests for the choice of the best parameters, which brought robustness to the model and avoided the result of over-fitted and comprehensive models (Radosavljevic and Anderson, 2014).

To build the models, we first used the geographic area of Brazil. For species with fewer than 20 records, we made tests to assess the contribution of variables, and used a minimum of two localities per variable, with ten replicates for the Jackknife validation function with beta-regularization 2, which showed the best performance and fit. Beta-regularization 2 controls the fit of the model, in which lower values produce more fitted values and higher values produce more general models (Radosavljevic and Anderson, 2014). For species with > 20 records, we used 12 non-correlated variables. We performed *n*-1 cross-validation replicates to calculate confidence intervals, used the regularization multiplier 2, and set the software to use 75% of the data for calibration and 25% for internal evaluation (testing data). For model assessment, we considered the values obtained for the area under the curve (AUC) of training and test, which indicate the performance of the model by measuring its ability to predict occurrences. High-quality models showed AUC values close to 1.0 and low-quality models showed values below 0.7 (Metz, 1978).