UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA

CAVE-DWELLING BATS IN THE CAATINGA: LANDSCAPE AND CAVE EFFECTS ON COMMUNITY STRUCTURE IN RIO GRANDE DO NORTE, BRAZIL

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2016

Universidade Federal do Rio Grande do Norte
Programa de Pós-graduação em Ecologia

Cave-dwelling bats in the Caatinga: landscape and cave effects on community structure in Rio Grande do Norte, Brazil

Dissertação apresentada ao programa de Pós-Graduação em Ecologia da Universidade Federal do Rio Grande do Norte, como parte do requerimento para obtenção do título de Mestre em Ecologia.

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Natal, 2016

Catalogação da Publicação na Fonte. UFRN / Biblioteca Setorial do Centro de Biociências

Mena, Juan Carlos Vargas.

Cave-dwelling bats in the Caatinga: landscape and cave effects on community structure in Rio Grande do Norte, Brazil / Juan Carlos Vargas Mena. – Natal, RN, 2016.

102 f.: il.

Orientador: Prof. Dr. Eduardo Martins Venticinque.
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Dissertação (Mestrado) – Universidade Federal do Rio Grande do Norte. Centro de Biociências. Programa de Pós-Graduação em Ecologia.

1. Morcegos cavernícolas. – Dissertação. 2. Caatinga. – Dissertação. 3. Morcegos - Rio Grande do Norte. – Dissertação. I. Venticinque, Eduardo Martins. II. Herrera, Bernal Rodriguez. III. Universidade Federal do Rio Grande do Norte. IV. Título.

RN/UF/BSE-CB CDU 599.4

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Aprovada em 19 de fevereiro de 2016

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AGRADECIMENTOS

Primeiro quero agradecer a Eugenia por todo o que ela representa para mim! Eu, não tenho palavras para te demostrar o grau de agradecimento há você. Você esteve presente de princípio ao fim nesta incrível viagem aqui no Brasil e teu amor, teu apoio, teu carinho, tua ajuda no campo e na elaboração desta dissertação, nossas discussões de assuntos acadêmicos relevantes ou banais, tuas piadas, teus abraços, tuas historias, teu carinho, enfim, tua companhia foi um ponto de inflexão na conclusão deste etapa importante na minha vida. Gracias!!!!!

Aos meus orientadores, Dadão e Bernal. Dadão você ultrapassou a linha de orientador a ser quase meu pai aqui em Natal. Agradeço de mil formas os conselhos, as ideias, teu tempo e carinho e tudo o que você fez para me fazer sentir como em casa! Bernal, hoje minha vida são os morcegos e é tua culpa! Se não fosse por as portas e as oportunidades que você abriu para mim, eu não sei onde que estaria. Obrigado por todo o que você tem ajudado a gente. Meus orientadores o respeito que sinto por vocês é grande, Gracias!!

Meus amigos Brasileiros, a saudade de minha terra cada vez é menor estou com vocês. Gracias Hada, Rafa, Rodrigo, Marina, Pocas, Duka, Guga, Lucão, Patri, Helô, JB, Caramujo, Laurinha, Angelica Guiga, Dri, Pichi y Juanpy, Gracias!! Vocês são incríveis!!

A meus guias de campo que me mostraram as maravilhosas cavernas da Caatinga Potiguar, Iatagan e Valtenci, todas as informações que esta dissertação tem aqui foram possíveis graças a ajuda de vocês!!! Bora nessas cavernas!!! Também quero agradecer a Diego Bentos por ter sido a primeira pessoa em me introduzir no mundo da espeleologia Potiguar e por fornecer dados chaves para o desenvolvimento deste trabalho, muito obrigado a vocês!

Quero agradecer várias instituições importantes que me apoiaram logística e financeiramente durante o processo de coleta de dados. Ao CNPq, CAPES, WCS, TFCA e CECAV muito, muito obrigado!

Agradeço a minha família lá na Costa Rica. Como minha família é muito grande vou mencionar a meus sobrinhos, tios, primos e meu avó Tata como pessoas importante em minha vida que sempre estão ali me apoiando! Em especial a minha madrinha Xinia e minha avô Sara que estão em outro lugar diferente ao nosso, a saudade que tenho de vocês é enorme!

Á meu irmão Robert, minha irmã Jessica, graças pelo amor, carinho e apoio desde longe para cumprir meus objetivos na minha vida!

Pai e Mai esta dissertação vai dedicada a vocês, porque vocês são minha inspiração nesta vida de luta, perseverança, além das adversidades que nós temos passado e cada vez que sinto saudade de vocês eu lembro que estou aqui por vocês. Sem vocês eu não estria aqui neste mundo! Los amo demasiado!!

Gracias a cada uno de ustedes!!

CONTENTS

RESUMO

As cavernas são abrigos importantes para morcegos em áreas cársticas e desempenham um papel fundamental para a proteção de suas populações. Vários fatores internos podem influenciar a seleção de uma caverna pelos morcegos, como o tamanho e as características microclimáticas dos substratos internos, que influenciam na riqueza e estrutura das comunidades. Porém, os efeitos de fatores externos, como componentes da paisagem e atividades antrópicas em torno da caverna, são pouco conhecidos. Os morcegos do Rio Grande do Norte (RN) são pouco estudados apesar do estado conter mais de 900 cavernas, principalmente na Caatinga, que podem fornecer abrigos importantes para as populações locais. Os objetivos desta dissertação são 1) determinar a composição das comunidades de morcegos cavernícolas e suas colônias no estado pela primeira vez; e 2) avaliar os efeitos da estrutura da paisagem e da caverna sobre a riqueza e a estrutura das comunidades em três áreas cársticas na Caatinga do RN. Foram amostradas 13 cavernas, oito no sistema de cavernas de Felipe Guerra, quatro no Parque Nacional Furna Feia, e uma em Mossoró durante três dias consecutivos por cada caverna mediante busca ativa e capturas com redes de neblina para um total de 37 noites amostradas. Foram capturadas 16 espécies pertencentes às famílias Phyllostomidae (12), Emballonuridae (1), Mormoopidae (1), Furipteridae (1), Natalidae (1). A maior colônia achada pertenceu a *Pteronotus gymnonotus* (> 10 000 indiv.) e a *Phyllostomus discolor* (101-1000 indiv.). A Furna Feia abrigou a maior riqueza (10 spp) e foi a maior caverna pesquisada. Usando essas 13 cavernas, em um buffer de 1 km de raio, foram extraídas 14 variáveis (espaciais, antropogênicas, dimensões da caverna e ambientais) e foi realizada uma análise com modelos simples e múltiplos. Os modelos foram selecionados utilizando o Critério de Informação de Akaike (AIC). Observamos que as comunidades de morcegos entre os sistemas de cavernas foram diferentes e afetadas significativamente pelas variáveis espaciais (posição espacial do sistema de cavernas) e pelas variáveis antrópicas (presença de assentamentos humanos e densidade de animais domésticos). As variáveis ambientais como porcentagem de cobertura de Caatinga e presença de corpos de agua não tiveram efeitos significativos na estruturação das comunidades. Os efeitos dessas variáveis refletiram na abundância (tamanhos de colônias) de espécies compartilhadas entre os sistemas de cavernas. Por outro lado, verificou-se que a riqueza foi explicada pelo tamanho da caverna. Quatro cavernas (Furna do Urubu, Gruta da Carrapateira, Gruta dos Três Lagos e a Gruta dos Trinta) foram selecionadas como prioridade de conservação devido a sua relevância quiropterológica por possuírem grandes colônias, alta riqueza e abrigos importantes para espécies ameaçadas de extinção no Brasil tais como *Lonchorhina aurita*, *Natalus macrourus* e *Furipterus horrens*.

Palavras chaves: Morcegos cavernícolas, comunidades, ecologia da paisagem, tamanho de caverna, Caatinga, Rio Grande do Norte, Brasil

ABSTRACT

Caves are an important roost for bats in karstic areas and play a critical role for the protection of bat populations. Several internal factors influence cave selection in bats such as cave structure and species microclimate preferences which and influence the richness and structure of cave-bat communities. However, the effects of external factors like landscape components and human activities around the cave are poorly known. The bats of Rio Grande do Norte (RN) are poorly studied, but the State contains more than 900 caves mostly in the Caatinga Domain of the sate which may offers important roost for local populations. The objectives of this dissertation are 1) to determine cave-dwelling bat community composition and their colonies; and 2) to assess landscape and cave structure variables in order to identify their effects on the richness and community structure in three karstic areas in a Caatinga of RN. It was sampled 13 caves, eight in Felipe Guerra Cave System, four in Furna Feia National Park, and one in Mossoro during three consecutive days for each cave through active search and captures with mist nets for 37 sampled days. I captured 16 species from five families: Phyllostomidae (12), Emballonuridae (1), Mormoopidae (1), Furipteridae (1), and Natalidae (1) families. The biggest colony was from *Pteronotus gymnonotus* (>10 000 indiv.) and from *Phyllostomus discolor* (101-1000 indiv.). The Furna Feia cave homed the highest richness (10 spp.) and was the biggest surveyed cave. Using a 1km buffer around these 13 caves, we extracted 14 variables (spatial, anthropogenic, cave dimensions and environmental) and performed an analysis with single and multiple models. The models were selected using the Akaike Information Criterion (AIC). We observed that the bat communities between the cave systems were different and significantly affected by spatial variables (spatial position of the cave system) and by anthropic variables (presence of human settlements and livestock density). Environmental variables such as percentage of Caatinga cover and presence of water bodies had no significant effect on the structure of communities. The effects of these selected variables were observed in differences in the abundance (colony sizes) of shared species between the cave systems. Conversely, we found that the richness of bats were explained by cave size. Results of this study led to pinpoint four caves (Furna do Urubu, Gruta da Carrapateira, Gruta dos Três Lagos and Gruta dos Trinta) as priority for conservation due to its chiropterological relevance for homing big colonies, high bat richness, and important roost for endangered species in Brazil such as *Lonchorhina aurita*, *Natalus macrourus* and *Furipterus horrens*.

Key words: Cave-dwelling bats, community, landscape ecology, cave size, Caatinga, Rio Grande do Norte, Brazil

GENERAL INTRODUCTION

Chiroptera is one of largest mammalian orders and is unique among mammals due to the evolution of powered flight (Voigt & Kingston, 2016). With about 1300 species worldwide, the diversity of bats is the second within mammals, with only rodents harboring more species (Fenton & Simmons, 2015). Bats are ubiquitous in the vegetated terrestrial ecosystems of the world and are particularly diverse and abundant in the tropics (Fenton *et al.*, 1992; Medellín *et al.,* 2000). The species richness increases when decreasing latitude (Willig & Selcer, 1989), and achieve their highest taxonomic, functional and morphological diversity at sites in tropical regions (Stevens & Willig, 2002; Ramos-Pereira & Palmeirim, 2013). For the Neotropics a number of 380 species in 98 genera have been described so far, making the biogeographic region with the highest bat diversity in the world (Solari & Martínez-Arias, 2014).

In Brazil, the diversity of bats is one of largest of the world (Reis *et al*., 2013). It homes about 14% of the Chiropterans of the world and 24.8% of the Brazilian species of mammals (Paglia *et al*., 2012). According to the Committee of the List of Brazilian Bats of the Brazilian Bat Research Society, the updated checklist of extant bats reported a richness of 178 species distributed in nine families and 68 genera; of which two genera and 10 species are endemics (Nogueira *et al*., 2014).

Bats in the Landscape

Bats exhibit a high degree of temporal and spatial mobility across the landscape and during nightly foraging flights, they may travel through many distinct habitats (Duchamp *et al.*, 2007). In general, organisms that require multiple habitats are more sensitive to habitat loss (Swihart *et al.*, 2003). Studies have shown low richness and abundance in bat assemblages in tropical landscapes related to habitat disturbance and forest fragmentation. (Brosset *et al*., 1996; Cosson *et al*., 1999; Schulze *et al*., 2000). Others have demonstrated no significant differences between fragmented and continuous forests, highlighting the ecologically importance of small fragments on the landscape that contains rich bat fauna (Estrada *et al*., 1993; Galindo-Gonzalez & Sosa, 2003; Gorresen & Willig, 2004; Bernard & Fenton, 2007). Moreover, it seems that in tropical heterogeneous landscapes the structure of bat assemblages in a particular area is determined by species-specific and guild-specific traits in responses to the composition and configuration of the landscape (Medellín *et* al., 2000; Pinto & Keitt, 2008; Klingbeil & Willig, 2009; Ávila-Cabadilla *et al*., 2012).

The importance of landscape heterogeneity to biodiversity may depend on the size of the geographic range of species, which in turn can reflect species traits (such as habitat generalization) and the effects of historical and contemporary land covers (Katayama *et al*., 2014). The size of the geographic range of species can be observed on the home ranges as a result of spatial use and foraging movements of an individual on the landscape. The scant knowledge about size of home range and feeding areas of Neotropical bats are limited to a few species of the New World Pyllostomids (Kalko, 1996). Differences in home ranges and feeding areas are found among trophic guilds and among species within guilds. These differences are tightly coupled with foraging strategies, distribution and availability of resources, as well as size of the animals (Kalko, 1998).

For Neotropical nectarivorous, carnivorous and gleaning animalivorous bats, home ranges has been assessed in <500 ha. (Kalko *et al*., 1999; Albrecht et al., 2007; Bernard & Fenton, 2003). However, for species belonging to other guilds it is known to commute long distances in one night like big species of frugivorous bats of genera *Artibeus* (0.6-8km) (Morrison *et al.,*1978; Handley Jr. *et al.,* 1991; Menezes Jr. *et al.,* 2008; Trevelin *et al*., 2013). In aerial insectivorous bats, home ranges are almost unknown. On hematophagous bats, commuting distances from 1.6 km to >8km has been reported (Greenhall *et al.*, 1983; Trajano, 1996; Bianconi *et al*., 2006; Medina *et al*., 2007).

Because of their dramatic ecological and evolutionary radiation, bats occupy almost every trophic level, from primary to tertiary consumers (Medellín *et al*., 2000). Bats feed on fruit (frugivorous), insect (insectivorous), nectar and pollen (nectarivorous), fish (piscivorous), blood (sanguinivorous), and other vertebrates (animalivorous) (Kunz, 1982; Fenton, 1992; Kunz &

Pearson, 1994; Kalko, 1998, McCraken, 2006). Because of the high trophic diversity found in bats, they are directly involved in key ecological processes and ecosystem services (Kunz *et al*., 2011).

Bats are important pollinators and seed dispersers of plants in tropical and subtropical habitats, including several species used by humans (Allen-Wardell *et al* 1998; Medellín, 1999; Lobova *et al.,* 2009; Quesada *et al.,* 2009; Kunz *et al*., 2011) and effective predators of vertebrates and invertebrates (Belwood & Morris, 1987; Fenton, 1995; Kalka *et al*., 2008). In turn, the contribution of these services by bats to healthy ecosystems provides additional benefits to humans by supporting vital regulatory processes such as nutrient cycling, water filtration, erosion control and climate regulation (Kunz *et al*., 2011). Moreover, aerial insectivorous bats are known to be controllers of populations of insects known to be pests in agriculture (Cleveland *et al.,* 2006; Aguiar & Antonini, 2008; Reiskind & Wund, 2009; Boyles *et al.,* 2011; Kunz *et al*., 2011).

It is important to take into account that landscapes with an abundance and diversity of suitable roost, adequate foraging habitat, and sources of open water that are well distributed across the landscape should provide conditions necessary to support healthy populations of bats in most forested ecosystems (Hayes, 2003). In Brazil, bats represents a significant portion of the mammals of the country and for directly participating in ecological processes associated with ecosystems, impacts from the strong alteration of the natural landscape may affect the bats population and the ecological services that they provide.

Caves and bats

Bats spend more than half of their lives in their roost environment and exhibit a variety of adaptations that may reflect compromises associated with mode of flight, social behavior, diet, and group size (Kunz, 1982). Caves in particular provides an stable and permanent roost that it is used for protection against predators, adverse environmental conditions, breeding, care of offspring, and for hibernation in temperate zones for bats (Kunz, 1982; Trajano, 1995; Tuttle & Moreno, 2005). Inside caves a wide variety of structural substrates including crevices, cavities, textured walls and ceilings, massive rooms, rock outcrops, and rock rubble on floors are used as a roost by different species of bats (Kunz *et al.*, 2012)

When choosing a roost, bats have specific microclimates requirements (Brunet & Medellín, 2001) and the spatial variation of microclimate conditions (temperature and humidity) and the internal structural substrates inside a cave can create a greater diversity of roosting sites (Brunet and Medellín, 2001) allowing it to be colonized by different species with different ecological adaptations (Altrigham *et al.,* 1996). However, the microclimates searched by bats can vary enormously depending of characteristics of the cave such as the geographical position (latitude and altitude) and cave architecture (*e.g.* depth, area, volume) (Kunz, 1982; Brunet & Medellín, 2001; Cardiff, 2006). These variables can influence the daily and seasonal variations on the atmospheric pressure, temperature, and humidity inside caves (Kunz *et al*, 2012). Even so, it is common to find caves providing shelter for a number of species, particularly in the Neotropics where caves have been reported hosting up to 13 species (Arita, 1993). Some caves can gather features required by species that forms large colonies and hence, these caves have been used for thousands of years (Tuttle & Moreno, 2005).

In biospeleology, bats are classified as trogloxenes. Trogloxenes are organisms regularly found in caves but must emerge of caves periodically in order to complete their life cycle (Trajano, 1995). Since bats returns to caves after feeding during the night, they play a crucial role in the maintenance of ecological processes in the internal ecosystems on caves (Ferreira *et al.*, 2007; Gnaspini & Trajano, 2000). They are responsible for the increase of organic matter in cave ecosystems through guano deposition under roosting sites. This guano is an important food source for the cave fauna due to the general lack of food in caves (Gnaspini & Trajano, 2000). Some of these species are dependent on guano for their existence and cave communities can perish if the input of guano falls below certain limits (Trajano, 1995).

In Brazil, the National Center of Research and Conservation of Caves (CECAV, Portuguese acronym) provided more than 12 000 records of caves in its database (CECAV/ICMBio, 2015). Despite Brazil's speleological potential, less than 5% of its natural underground cavities are known (Jansen *et al*., 2012). As for Brazilian cave-dwelling bats, 58 species have been recorded roosting in caves from which 13 species rely on caves, and 45 species were registered using caves as an alternative roost (Guimarães & Ferreira, 2014). Caves and any other underground habitats are critical sites for bats, especially for those species that rely almost exclusively on such sites for roosting and breeding (Hutson, 2001). Such sites play a key role in the protection of bat populations (Trajano, 1985; Arita & Vargas 1995; Arita, 1996; Bredt *et al.,* 1999), especially those species that form large colonies (Kunz 1982, Brunet & Medellin 2001). Unfortunately, underground habitats are particularly vulnerable to the effects of a range of human activities including tourism, caving, guano extraction, mining and quarrying

Chiropterofauna of the Caatinga

The Caatinga is a semi-arid habitat endemic of Brazil with an area of 826 411 km^2 (MMA/SBF, 2002). It extends over the States of Ceará, Rio Grande do Norte, most of Paraíba and Pernambuco, southeastern Piauí, west of Alagoas and Sergipe, north and central Bahia and northern Minas Gerais (Leal *et al.*, 2003). The predominant landscape refers to flattened depressions (300-500 m a.s.l), which are submitted to a rainfall regime ranging from 240 up to 900 mm/year and a 7-11-months of dry season (Sampaio, 1995; Prado, 2008).

Compared to other Brazilian ecosystems, the Caatinga has many extreme characteristics among the meteorological parameters: the highest solar radiation, lowest cloudiness, highest average annual temperature, lower rates of relative humidity, and highest potential evapotranspiration (Prado, 2008). It dominated mainly by a seasonal tropical dry forest characterized by thorn vegetation, small leaves (microfilia) with some xerophytic characteristics, including forest stands of woody plants to scrubby areas dominated by Bromeliaceae and Cactaceae species (Leal *et al.,* 2008; Santos *et al.,* 2011). Leaves and flowers are produced during a short rainy season and in the dry season; the Caatinga is leafless and dormant for much of the year (Leal *et al.,* 2003).

Although being the only major Brazilian natural area whose boundaries are entirely restricted to the national territory, little attention has been given to the conservation of the heterogeneous landscape of the Caatinga (Silva *et al*., 2004). Currently, the Caatinga has only 1% of its total area under conservation units of integral protection and 6.4% of protected areas of sustainable use (MMA/IBAMA, 2011). Moreover, the Caatinga is one of the most neglected and disturbed Brazilian ecosystem that is going through a rapid degradation and desertification due to human activities such as land-use changes, increasing social pressures and high natural resources dependence (Leal *et al*., 2003; 2005; Santos *et al*., 2011). In fact, in 2009 only 53.38% of natural forest cover remained of Caatinga vegetation (MMA/IBAMA, 2011).

Of the six main ecoregions of Brazil, the Caatinga stands in fourth place for bats species richness. According to Paglia *et al*., (2012), 77 species of bats have been registered for the Caatinga. Nevertheless, compared with other Brazilian habitats, the mammals of the Caatinga are poorly understood (Oliveira *et al,* 2003, Astúa & Guerra, 2008). The total number of mammal species may be even higher, because some records of rodents and bats were unproven at specific level, added to the inconspicuousness of the groups, which may suggest an underestimation of ecosystem's the richness of the ecosystem (MMA / SBF, 2002).

In the last 10 years, three endemic new species of bats has been described for the Caatingas. Gregorin & Ditchfield (2005) described a new species of a nectar-feeding bat, under the name of *Xeronycteris vieirai*, based on four specimens collected within the Caatinga in the states of Paraíba, Pernambuco and Bahía. This discovery turned the described species into the first endemic genus and species of bat for the Caatinga. Five years later, Taddei & Lim (2010) analyzed three specimens of a Fruit bat of the genus *Chiroderma* from the Caatinga of Piauí which showed distinctive combination of both morphological and mensural characters indicating that they belonged to a distinct new species, named *Chiroderma vizottoi*. Moreover, there was the most recent discovery was of a nectar-feeding bat, of the genus *Lonchophylla*, described by Moratelli & Dias (2015) based on almost 100-year-old museum misidentified specimens. These specimens from Bahia and Pernambuco, named *Lonchophylla inexpectata,* were distinguished from all known species of *Lonchophylla* that occur in Brazil by dental traits, cranial size, and fur color. This last discovery adds a new species officially known to occur in the Caatinga.

Among this 78 species of bats present in the Caatinga, 39 species uses caves as their roosting sites meaning that almost 50% of the species of the bats of the Caatinga uses caves as a roosting site. This numbers suggest the importance of caves within the landscape for populations of chiropterans.

Caves and Bats in Rio Grande do Norte

The State of Rio Grande do Norte (RN) has a high speleological potential with more than 900 underground cavities registered so far (CECAV / ICMBio, 2015). RN is the 4th Brazilian state in number of caves, and the second (after Bahía state) in the Northeast of Brazil (CECAV / ICMBio, 2015). However, its cave fauna is almost unknown (Ferreira *et al.*, 2010). Ferreira *et al*. (2010) have done the only bio-speleological investigation in RN. Authors inventoried 17 caves in which they found invertebrates belonging to at least 36 orders and 91 families, three species of fish and 9 species of bats. It is worth noting that the vast majority of the caves of RN are located in karstic areas within the Caatinga. Actually, 95% (49 714 km^2) of the state is covered by Caatinga vegetation.

The chiropterofauna of RN is one of the most significant data gaps of Brazil (Bernard *et al*., 2011). There is not a proper scientific effort to explore chiropterofauna in RN, especially in areas of Caatinga, and consequently, is one of the Brazilian states with the lowest published investigations. Feijó & Nunes (2010) published the only study associated with bats for the state. They document the first record of *Myotis nigricans* for RN and the extension of the geographic distribution of the species in northeastern Brazil. The record was based on the body and cranial measurements analysis of three adults specimens captured in a Caatinga vegetation close to the limits with Paraíba state and deposited in the Mammal Collection of the Universidade Federal da Paraíba (UFPB). This single publication for the state demonstrate that bat diversity (alpha, beta and gamma), community composition, and location of important roosts for populations (caves for example) are poorly explored in the state. Efforts to fill in this gap of information us urgently needed.

Because of RN speleological potential, caves are an important roost resource for the bats in the region and underground habitats are particularly vulnerable to the effects of a range of local human activities including uncontrolled activities such as tourism, and illegal caving, mining and quarrying. Caves, mines, and other artificial underground habitats are particularly fragile and are critical sites for bats and for some species that rely almost exclusively on such sites for roosting and breeding (Hutson, 2001). Roosting sites such as caves and natural cavities play a key role in the protection of bat populations (Trajano, 1985; Arita & Vargas 1995; Arita, 1996; Bredt *et al.,* 1999; Furey & Racey, 2016), especially those species that form large colonies (Kunz, 1982; Brunet & Medellin, 2001).

Approach of this study

As an outcome of this dissertation, I provide herein data to determine RN's cave-dwelling bat richness and the first description of this community structure on the main karstic areas of the state, (Chapter 1). From the outside-of-the-roost point of view, bats emerges from caves at night and forages in different habitats. Consequently, they are sensible and respond in different ways to habitat composition and disturbance in the landscape. Therefore, it is important to determine if landscape variables influences cave-bat communities structure in the Caatinga. To address this, I used models to identify which landscape variables have stronger effects on the richness, the composition and the structure of local cave-bat communities. This kind of approach links the relationship of external landscape variables with the cave-bat communities, and will help to understand which landscape variables may explain richness and abundance (colony sizes) patterns within surveyed caves (Chapter 2).

As a pioneer approach, this investigation was possible thanks to the technological advances in the last years in the capture of satellite images in all Brazil which now has high detailed images of the latest different landscape features of the country in available databases. Using the obtained data, we were able to pinpoint relevant caves (roost) that are key for the conservation of populations (colonies) of cave-bats in the state. Finally, the data of this study provides the first analysis of richness, abundance and species composition, as well to highlight important caves for the conservation of cave-dwelling bats in the Caatinga of Rio Grande do Norte, Brazil

OBJECTIVES

1. Determine the richness (alpha and beta) of bats in different caves situated in the Caatinga of Rio Grande do Norte. (Chapter 1)
2. Describe the composition of cave-bat communities in different caves of the Caatinga in Rio Grande do Norte. (Chapter 1)
3. Assess the effects of landscape and cave size variables on the diversity of cave-dwelling bats in different caves. (Chapter 2)
4. Assess the effects of landscape and cave size variables on the composition of the cave-bat communities of the different caves. (Chapter 2)
5. Assess the effects of landscape and cave architecture (dimensions) variables on the abundance (colony size) of cave-bats present in the different caves. (Chapter 2)
6. Identify cave with high richness, big or unusual colonies, vulnerable or threatened species in order to pinpoint important cavities for conservation (Chapter 3).

DESCRIPTION OF STUDY AREA

The study was developed in three karstic areas within the Caatinga in the state of Rio Grande do Norte (RN) in the northeast of Brazil (Fig. 1). These karstic areas contains a good proportion of the all the caves registered so far to the state and are situated in the west portion of the state. The cave survey comprehend two caves systems and one locality with an isolated cave, all calcareous. (Fig. 1). Geologically, all of the study area corresponds to a tectonic uplift of the carbonate platform in the Jandaíra Aracati Platform.

<u>Furna Feia System (FFS):</u> The Furna Feia system is inside the Furna Feia National Park, a conservation unity (UC) that is localized in the west region of the state, in the micro-region of

Mossoró. The national park has an area of approximately 8 494 ha, distributed in the municipalities of Baraúna and Mossoró. It's the Rio Grande do Norte's first national park which represents a federal UC category of integral protection, allowing only the indirect use of natural resources which does not involves consumption, collection, destruction or damage if these resources. It was created through Presidential Decree S / N, on July 5 of 2012, and aims to preserve the its speleological complex and the biodiversity associated with the Caatinga vegetation, as well for the conduction of scientific research and the development of educational activities and environmental interpretation, and for recreation in contact with nature and eco-tourism (Brasil, 2012).

Geologically the area corresponds to a tectonic uplift of the carbonate platform in the Jandaíra Aracati Platform. The Serra Mossoró represents the apex of this topographical tectonically uplifted region and marks a natural divider of meteoric waters that flow to the east into the basin of the Rio Mossoró, and west to the basin of the Rio Jaguaribe. The rainy season is from February to April and the temperature ranges from 21° C to 36° C. The relative humidity is 70%.

The vegetation has a physiognomy of the deciduous hyperxerophilic Caatinga, characterizing an ecosystem with species typical of the northeastern semiarid of Brazil (Bento *et al*, 2013). The national park protects 248 underground cavities and a large remnant of Caatinga in the state (Bento et al., 2013). The flora and fauna comprehends 105 species of plants, 101 birds, 23 mammals, 11 reptiles and 11 troglobitic invertebrates. The surveyed caves were Furna Feia, Furna Nova, Caverna da Pedra Lisa, and Caverna do Porco do Mato.

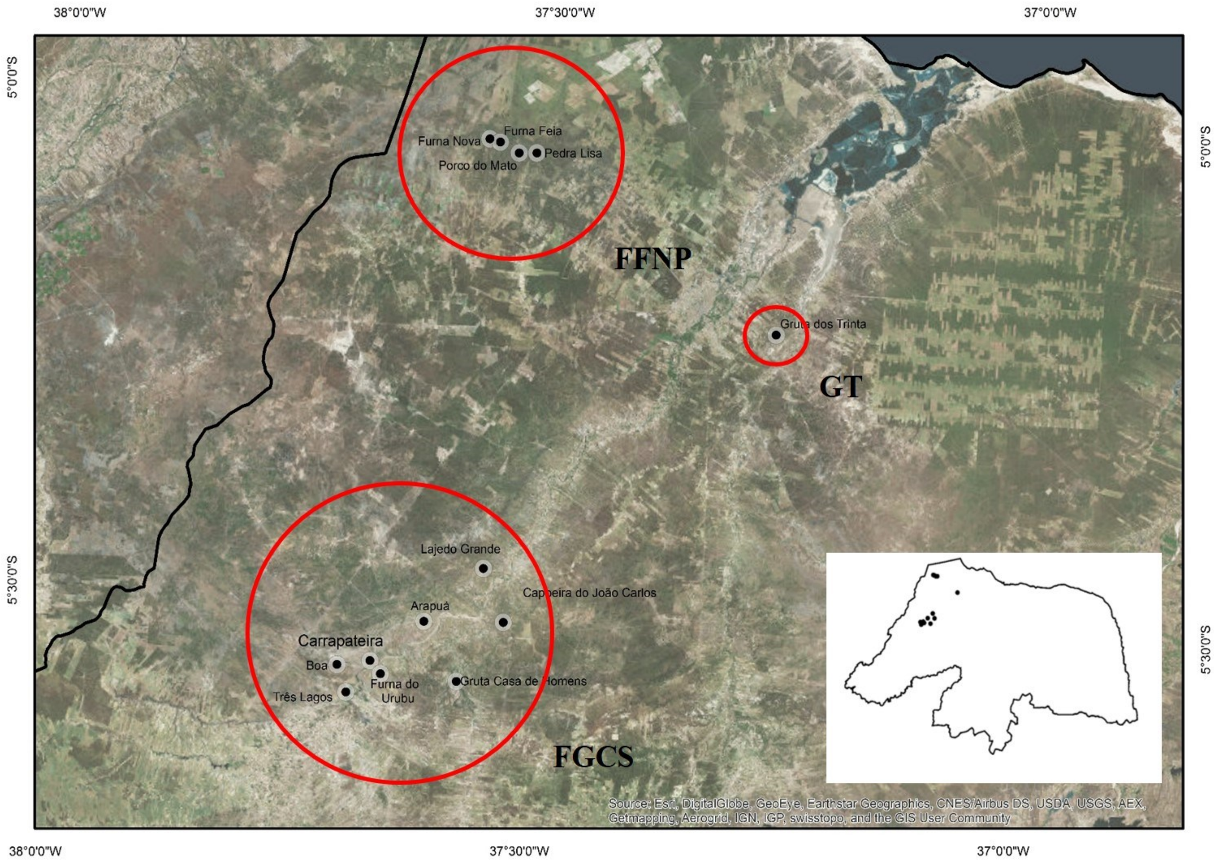

Figure 1. Map of the study area in west Rio Grande do Norte, Brazil. Black points area location of caves. Red circles are locations of caves systems. Systems are (FFNP) Furna Feia National Park; (GT) Gruta dos Trinta in Mossoró; and (FGCS) Felipe Guerra Cave System. Smaller map as reference of study sites in relation to the political limits of Rio Grande do Norte State in Northeastern Brazil.

Felipe Guerra System (FGS): Situated in the western region of the state, is inserted in the basin of the Apodi river in the semi-arid region of northeastern of Brazil. It forms part of the micro-region of the Chapada do Apodi, at an average altitude of 40 meters. The climate is predominantly BSwh' type (climatic classification of Köppen) characterized by very hot weather and semi-arid, with the rainy season is delayed for autumn. The average annual rainfall is around 670 mm, evaporation of 1760 mm. It has a water deficit of 1000 mm for about 9 months. Rainfall is irregular, in general, and occur in the period from February to July concentrating mostly during March to June. The relative humidity is quite variable, usually between 59 and 76%, and the annual average temperature around 27.8º C (21° - 36°C) (IDEMA, 2005).

This karstic area is about to be proposed as an Environmental Protection Area (APA acronym in Portuguese) to the correspondent Brazilian environmental institutions Proposal plans to protect an area of 80,560 hectares under the name Pedra Abelha environmental protection area. The system comprises the municipalities of Felipe Guerra, Governador Dix-Sept Rosado and Caraúbas and contains the city of Felipe Guerra with a population of almost 6000 people. This area contains the largest concentration of caves in RN harboring 341 caves, or 52.3% of known underground cavities of the state (Bento *et al*., 2015). Preliminary inventories of fauna found 18 species of reptiles, 6 amphibians, 127 birds and 22 species of non-volant mammals (Esperanza, 2015).

The area proposed for the establishment of the Pedra Abelha APA presents a speleological heritage of extreme importance. This proposes Conservation Unity (UC) stands on the state and national scenario for the protection and conservation of Caatinga vegetation ecosystems and its speleological heritage, housing also considerable biodiversity of flora and fauna. This heritage, however, is exposed to various human impacts that goes against the intrinsic fragility of both underground and superficial ecosystems, making it necessary and urgent actions for the conservation and sustainable use.

The surveyed caves in this system were: Furna do Urubu, Caverna Boa, Gruta dos Três Lagos, Furna da Carrapateira and Caverna do Arapuá, in the municipality of Felipe Guerra; Caverna do Lajedo Grande and Gruta Capoeira de João Carlos in Governador Dix-sept Rosado municipality; and Gruta Casa de Homens in the municipality of Caraúbas.

Mossoró: One isolated cave (Gruta dos Trinta) was surveyed in the municipality of Mossoró. This isolated cave is found on an isolated calcareous outcrop approximately at 5 km from Mossoró city, which is the second biggest and populous city of the state.

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Chapter 1

Cave-dwelling bats of Rio Grande do Norte: a first insight of richness, trophic guilds and colonies in a Caatinga of Northeastern, Brazil

CHAPTER 1

Cave-dwelling bats of Rio Grande do Norte: a first insight of richness, trophic guilds and colonies in a Caatinga of Northeastern, Brazil

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Key words: Bats, Caves, Colony, Diversity, Caatinga, Rio Grande do Norte

INTRODUCTION

Caves and other underground cavities are a common roost used by bats. Caves are optimal roost because are thermally stable and humid environments that protect bats against inclement weather and predators, therefore, these sites are used for social interactions, breeding, care of offspring, and as hibernacula in temperate zones (Humphrey, 1975; Kunz, 1982; Tuttle and Moreno, 2005).

Such underground cavities play a key role for protecting sub-populations of bats especially for species that form large colonies in a single cave (Trajano 1985; Arita and Vargas, 1995; Arita, 1996; Bredt *et al*., 1999). Unfortunately, cave habitats are particularly vulnerable to the effects of a range of human activities such as uncontrolled tourism, caving, guano collection and mining (Kunz, 1982; Furey and Racey, 2016). Therefore, the identification of important caves that harbors high diversity, unusual big colonies and/or vulnerable or threatened species are essential for protection actions for the conservation of bats (Arita, 1993; Trajano, 1995; Arita, 1996; Guimarães and Ferreira, 2014; Furey and Racey, 2015).

Brazil homes one of the biggest diversity of bats in the world. Of the 178 species of bats that occur in the country (Nogueira *et al*., 2014), at least 58 species (33%) have been recorded using caves as a main or alternative roost (Guimarães and Ferreira, 2014). From the speleological point of view, Brazil is also very diverse. More than 12.000 caves has been registered so far but despite its potential, less than 5% of its natural underground cavities are known (Jansen *et al*., 2012).

The available data of Brazilian cave-bat communities comprises surveys in only 269 caves mainly on the Atlantic Forest and Cerrado ecosystems in the central and the southern regions, leaving the Amazon and the Caatinga in the north and northeastern region, respectively, poorly known. Moreover, the knowledge of the diversity and structure bat communities that occur in caves in the Caatinga is poor due to the scarcity of studies (but see Gregorín and Mendes, 1999; Silva *et al*., 2001; Oliveira and Pessôa, 2005; Gregorín *et al.*, 2008; Sbraiga and Cardoso, 2008; Ferreira *et al.,* 2010).

In general, the Caatinga is a semi-arid domain endemic of Brazil with an area of 826 411 km^2 (MMA/IBAMA, 2011). It extends over the states of Ceará, Rio Grande do Norte, most of Paraíba and Pernambuco, southeastern Piauí, west of Alagoas and Sergipe, north and central Bahia and northern Minas Gerais (MMA/IBAMA, 2011, Leal *et al.*, 2003). The Caatinga is one of the less studied ecoregions in Brazil and this is reflected on the poor knowledge of its bat fauna (Oliveira *et al*., 2003). Moreover, is one of the most neglected and disturbed Brazilian ecoregion that is going through a rapid degradation and desertification due to human activities such as deforestation and agricultural expansion as a result of the increasing social pressures due to high natural resources dependence (Leal *et al*., 2003; 2005; Santos *et al*., 2011)

The state of Rio Grande do Norte (RN) is one of the smallest of Brazil occupying the northeasternmost tip of the South American continent. The state stands on the fourth position of in number of caves of all Brazil, and the second (after Bahía state) in the Northeast of Brazil (CECAV / ICMBio, 2015). However, its cave fauna is almost unknown (Ferreira *et al.*, 2010). It is worth noting that the vast majority of the caves of RN are located in karstic areas within the Caatinga. Actually, 95% (49 714 km^2) of the state is covered by Caatinga vegetation.

In karstic areas, karst outcrops have a great potential as shelters for bats and may influence the local species richness of bat communities (Struebig *et al*., 2009). However, the chiropterofauna of RN is one of the most significant data gaps of Brazil (Bernard *et al*., 2011) and the communities of cave-dwelling bats in the state are even less known. The few available data of cave-dwelling bats in RN comes from bio-speleological inventories that reported an accumulative richness of nine species for the state (Coelho, 2006; Ferreira *et al.,* 2010).

Because of RN speleological richness, caves are a potential roost for bat communities in the Caatinga of the state. Thus, the objective of this study was to survey, for the first time, three karstic areas in the Caatinga of Rio Grande do Norte in order to have a preliminary insight of community composition overviewing richness, present functional groups (trophic guilds), and to categorize colony sizes of cave-dwelling bats. We also selected some caves harboring high diversity, unusual big colonies and presence of threatened species of bats that are in a vulnerable and unprotected situation in order to provide useful data for prioritizing these caves for conservation actions.

MATERIALS AND METHODS

Site description

This study was developed in three karstic areas within the Caatinga in the state of Rio Grande do Norte (RN) in northeastern Brazil (Fig. 1 PART 1). The Caatinga homes a seasonal deciduous tropical dry forest characterized with plant species with thorns, small leaves (microfilia) with some xerophytic characteristics and includes from forest stands of woody plants to scrubby areas dominated by terrestrial bromeliads and columnar cactuses (Leal *et al.,* 2003; Santos *et al.,* 2011). Leaves and flowers are produced during a short rainy season and in the dry season is leafless and dormant for much of the year (Leal *et al*., 2003). Average annual precipitation ranges from 240 to 1500 mm and most of the rainfall is concentrated in three consecutive months (Leal *et al*., 2005), although long lasting droughts are frequent and subjected to annual variations.

Studied karstic areas are located about 330 km from the state capital of Natal on the west portion of the state where the biggest proportion of caves are registered. The surveys were developed in thirteen calcareous caves (Table 1) distributed in two caves systems and in one locality with an isolated cave. The first cave system is located in the Furna Feia National Park (FFNP) in the municipalities of Mossoró and Baraúna and recently created in June of 2012. FFNP is first national park stablished in the state with an area of 8494 hectares with the objective to preserve the speleological heritage and the biodiversity associated within the Caatinga vegetation. The national park protects 248 underground cavities (Bento *et al*., 2013).

The second cave system is located 58 km south of FFNP distributed in four municipalities (Felipe Guerra, Governador Dix-sept Rosado and Caraúbas). We choose to name it Felipe Guerra Cave System (FGCS). This karstic area contains the largest concentration of caves in RN harboring 341 caves (CECAV/ICMBio, 2015), which is 52.3% of known underground cavities in the state

(Bento *et al*., 2015). The area is about to be proposed as an Environmental Protection Area (APA acronym in Portuguese) to the correspondent Brazilian environmental institutions. The proposal plans to protect an area of 80 560 hectares under the name Pedra Abelha environmental protection area. This area homes a great speleological richness but is susceptible to disturbance due to its current unprotected scenario that compromises the remnants of Caatinga vegetation and its speleological heritage due to illegal mining, hunting and deforestation (Bento *et al.,* 2015).

Cave system	**Municipality**	**Cave Name**	**Coordinates**

Table 1. Caves surveyed in the Caatinga of Rio Grande do Norte from June to October of 2015

			Latitude	Longitude
Furna Feia National Park (FFNP)	Baraúna	Furna Nova	-5.034226	-37.571167
	Baraúna	Furna Feia	-5.036878	-37.560177
	Baraúna	Caverna Porco do Mato 1	-5.046638	-37.540114
	Baraúna	Caverna da Pedra Lisa	-5.045527	-37.521902
Felipe Guerra System (FGCS)	Felipe Guerra	Gruta dos Três Lagos	-5.593288	-37.687155
	Felipe Guerra	Caverna Boa	-5.566527	-37.697897
	Felipe Guerra	Gruta da Carrapateira	-5.560618	-37.663979
	Felipe Guerra	Furna do Urubu	-5.573047	-37.652420
	Felipe Guerra	Caverna do Arapuá	-5.518367	-37.610706
	Governador Dix-sept Rosado	Gruta Capoeira do João Carlos	-5.514716	-37.528770
	Governador Dix-sept Rosado	Caverna Lajedo Grande	-5.462278	-37.552471
	Caraúbas	Gruta Casa de Homens	-5.576272	-37.573807
Mossoró	Mossoró	Gruta dos Trinta	-5.212322	-37.264153

The third study site is the Gruta dos Trinta, an isolated cave situated in the municipality of Mossoró at approximately 5 km from the second biggest city of the state, Mossoró.

Data collection

From June 8 to October 23 of 2015, we surveyed thirteen caves (Table 1.) to determine the richness and the composition of bat communities. Each cave were surveyed during three consecutive days. For each day, we visited the cave during day light to make an active search of colonies and individuals inside the cave and at night, we captured individuals using mist-nets.

We deployed the mist-nets at the cave entrance, or entrances, to capture bats during their emergence of the cave. If the size of the cave was big enough, mist-net were deployed in strategically places inside the cave to capture the highest amount of species. Mist-net number and size (3-12m) used depended on the size of the entrance of the cave. Mist-nets were open during 6 hours and 30 minutes (17:30 hrs. - 24:00 hrs.). In multiple entrance caves, entrances were covered with plastic tarp and blocked any other possible exit holes or cracks in order to persuade bats to emerge into deployed mist-nets sites at selected entrances.

For captured individuals, information such as the sex, age (adult or juvenile), weight, reproductive status, morphometric measurements (forearm size, ears, tragus, and hind leg) and photography (Kunz, 1982; Bredt *et al.*, 1999) were taken. Age was determined by observing the fusion of epiphysis-shaft of the fourth metacarpal-phalangeal joint (Anthony, 1988). The reproductive condition of males was determined by the position of the testes, considering them reproductive when testicles where in scrotal position or non-reproductive when they were in abdominal position. The reproductive status of females was classified by touching their bellies and nipples observations (Racey, 1988), placing them in one of the following categories: non-reproductive, pregnant, lactating and post-lactating.

During the day, the active search consisted in inspecting the entire cave, if possible, by illuminating bat colonies, using binoculars and photos. We determined colony sizes through direct observation by counting roosting individuals during two-three hours (from 1300hrs. to 1600 hrs.), depending on cave size and access difficulties.

Counts through direct observation during the day ensures that all the bats that were found at that moment are using the cave as day roost. According to Kunz *et al*. (2009), the direct observation is the most straightforward method for identifying colonies and counting of roosting individuals during a specific period of time in caves and mines. The relatively high fidelity that bats exhibit to day-roosts (Kunz, 1982; Lewis, 1995) often makes it possible to estimate colony size by direct observation (Kunz, 2003; Kunz and Reynolds, 2003, McKracken, 2003). Nevertheless, this may be acceptable for species that forms small and compact colonies but for species clustered in large active colonies, estimation of colony size through direct observation may not be very reliable (Kunz *et al*., 2009).

With the data obtained of the direct observation technique, we choose to place the size of the colonies into categories, despite the possible bias that this method may lead to over and/or subestimation by the observers. Since one of the objectives of this study was to have a preliminary insight of the cave-dwelling bat colonies occurring in the state, we did not attempt to estimate population size or censusing bat colonies.

The sizes of the colonies were placed into categories based on Arita (1993; 1996). However, we modified the five categories used by Arita (1993; 1996) by adding one more category. The added category correspond to individuals that were captured entering the cave at night but no colony where spotted during active search suggesting the use of the cave as night roost. A night-roost are places used by bats as feeding perches. They ingest food transported from nearby feeding areas, which allows digestion and energy conservation, offer retreat from predators, and facilitate social interactions (Kunz, 1982). We choose to name this category as Night Visitor.

Colony size categories are: **1** (Night Visitor), **2** (<10 individuals), **3** (11-100), **4** (101-1000); **5** (1001-10 000); **6** (>10 000).

The registered species were assigned into functional groups (trophic guilds) based on the available natural history information about the primary diet of the species in Brazil (Reis *et al.,* 2007; Reis *et al*., 2013). The trophic guild classification were taken from Hill and Smith (1984). Guilds are: Aerial Insectivorous, Foliage-gleaning Insectivorous, Carnivorous, Piscivorous, Frugivorous, Nectarivorous, Omnivorous, and Sanguivorous. Although, species categorized as foliage-gleaning insectivores might be carnivores and vice versa (*e.g. Tonatia* sp., *Trachops cirrhosus, Chrotopterus auritus*) (Reis *et al.,* 2007; Reis *et al*., 2013), so we opted to assign them into a single category, Gleaning Animalivorous.

Captured bats were identified using books, field guides, identification key of southern Brazil and key articles with descriptions of Brazilian species (Willig, 1983; Miranda *et al*., 2011; Gregorin and Taddei, 2002; Gardner, 2007; Reis *et al.*, 2007; Araújo and Langguth, 2010; Reis *et al.*, 2013). Collected individuals were deposited at the collection of zoology of the Universidade Federal do Rio Grande do Norte. The survey and collection of specimens were allowed by the

Brazilian environmental agency (SISBIO license number 48325-2 MMA, IBAMA and ICMBIO). Taxonomy and nomenclature follows Nogueira *et al.* (2014).

Data analysis

We adopted the same capture effort (three days per cave) for 12 caves except for the Gruta dos Trinta that was surveyed for two days. The capture effort was measured as the sum of the total hours of mist net exposed in the nights multiplied by the total squared meters of all the mist nets used (Straube and Biaconi, 2002). We used species accumulation curves to measure the inventory efficacy and determine the completeness of the sampled communities. We performed two curves, one for FFNP and one for FGCS. The curves were obtained by using the number of days as sampling effort. The sample order was randomized 100 times to eliminate the influence of the order in which nights were added to the total surveyed nights. We did not performed a curve for the Gruta dos Trinta Cave because a two-day survey did not gave us enough data for the elaboration a curve for this cave. Curves were performed using R package “Vegan” (Oksanen *et al*., 2016) under R ver. 2.15.1 (Core-Team 2012) .

RESULTS

Bat assemblages

Based on the sampling effort of 18 973.5 m^2 h., 16 species of five taxonomic families were recorded using the sampled caves as day and/or night roost (Table 2). The mean richness of the 13 surveyed caves was of 6 ± 2 species that ranged from two species in Caverna do Arapuá in FGCS to 10 species in Furna Feia cave in FFNP (Table 1). The Felipe Guerra Cave System had the highest richness with 14 species, followed by the Furna Feia National Park with 10 species and the Gruta dos Trinta cave in Mossoró with five species (Fig 3).

Phyllostomids bats were the most common family with 12 species followed by one emballonurid, one mormoopid, one furipterid and one natalid (Table 2). Individuals of the genus *Lonchophylla* were identified to genus level only. Moratelli and Dias (2015) described a new species of Lonchophylla previously misidentified as *L.mordax.* This new species, *Lonchophylla inexpectata,* is easily confused with *L.mordax.* Because the two species occur in the Caatinga and the mentioned study was published after data collection, we chose to leave them as *Lonchophylla* sp. One individual of a *Micronycteris* bat was photographed at the Gruta dos Três Lagos cave. Species of these genus are difficult to differentiate and they are separated mainly by cranial and dental characteristics (see Simmons, 1996) that are not observed in a photography. We opted to leave the individual to genus level. For species photographic register, see Supplementary Material 2.

The species accumulation curves showed differences between the FGCS and FFNP (Fig. 2). Curve from FFNP seems to stabilize with fewer survey days than FGCS reaching closely to an asymptote. Curve from FGCS is almost stabilized at the end of the survey days but do not reaches clearly to an evident asymptote. Curves seems to show a good sampling effort of this study and suggest the probability of registering 1-2 species in FGCS with fewer extra survey days.

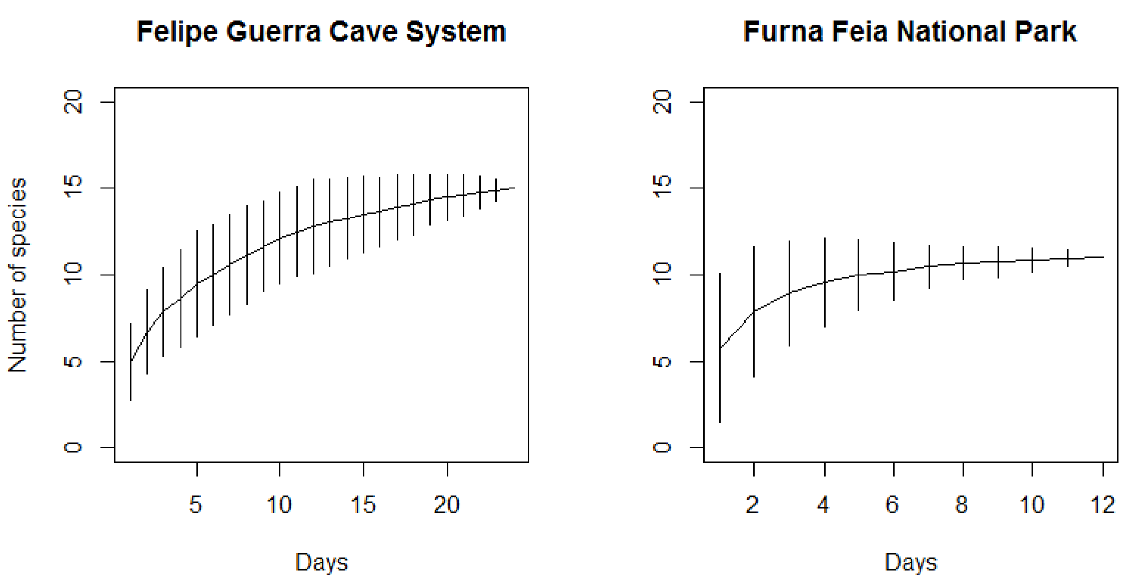

Figure 2. Species accumulation curves of cave-dwelling bats for the two surveyed cave systems in the Caatinga of Rio Grande do Norte, Brazil. The curves were obtained by using the number of days as sampling effort. The sample order was randomized 100 times to eliminate the influence of the order in which nights were added to the total surveyed nights. In Felipe Guerra Cave System, surveyes were carried out for 24 days in 8 caves. In Furna Feia National Park, surveys were for 12 days in 4 caves.

From the 13 caves surveyed, *Peropteryx macrotis* and *Diphylla ecaudata* were the most common species being encountered on 11 caves (84, 6%), followed by *Desmodus rotundus* found in nine caves (69, 2%) (Fig. 4). The species *Furipterus horrens* and *Tonatia bidens* were found in eight caves (61, 5%); *Glossophaga soricina* and *Artibeus planirostris* in seven caves (53, 8%); *Natalus macrourus* in four (30, 7%) and *Phyllostomus discolor* in three caves (23%). Seven species were found in only one cave. *Lonchophylla sp.* was found only in Gruta dos Trinta*, Chrotopterus auritus* in Gruta da Carrapateira; *Artibeus lituratus* in Furna Feia; *Pteronotus gymnonotus* in Furna do Urubu; and *Lonchorhina aurita, Micronycteris sp.,* and *Trachops cirrhosus* in the Gruta dos Três Lagos (Fig. 4).

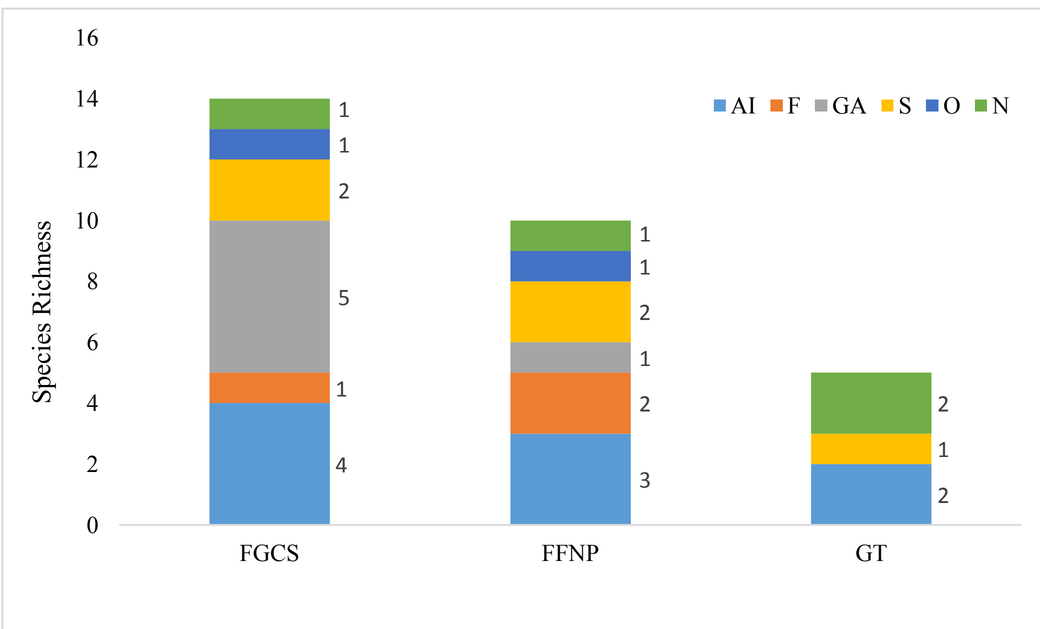

Figure 3. Composition of trophic guilds of registered cave-dwelling bats for each cave system in the Caatinga of Rio Grande do Norte, Brazil. (FGCS) Felipe Guerra Cave System; (FFNP) Furna Feia National Park; (GT) Gruta dos Trinta. Trophic guilds are: (AI) Aerial Insectivore; (F) Frugivore; (GA) Gleaning Animalivore; (O) Omnivore; (N): Nectarivore.

We registered bats belonging to five trophic guilds (Fig. 3). Four species were Aerial-Insectivores, five Gleaning-Animalivorous, two Sanguinivorous, two Frugivorous, two

Nectarivorous, and one Omnivorous. Both systems harbored the five registered guilds. The Gruta dos Trinta homed only three guilds. FGCS homed a highest richness of Gleaning Animalivorous bats (5 spp.) and of Aerial Insectivorous bats (4 spp.), but FFNP registered more species of Frugivorous bats (2 spp.). Even though the Gruta dos Trinta had the lowest richness of species and guilds it homed the highest richness of Nectarivorous bats (2 spp.) (Fig. 3).

Species colony sizes

The biggest colony of a single species was from the mormoopid *Pteronotus gymnonotus*. Assigned into the category 6, the colony was composed by around 10 000 individuals (or more). The colony roosts in one of the two big rooms of the Furna do Urubu cave in FGCS. This cave hosted the only colony of *P. gymnonotus* found in this study. In category 5, a colony of more than 1000 individuals of *Phyllostomus discolor* was found at the lower rooms at the Furna Feia cave concentrated in two big groups (Table 2). Due to the high number of bats in these colonies, counting the individuals was very difficult to achieve and approximated colony size was categorized based on author's experience of prior observations of bat colonies.

	Caverna Arapuá	Caverna da Pedra Lisa	Caverna Lajedo Grande	Gruta Casa de Homens	Gruta dos Trinta	Furna do Urubu	Caverna Boa	Caverna Porco do Mato	Cav.Capoeira João Carlos	Furna da Carrapateira	Gruta Três Lagos	Furna Nova	Furna Feia	**Occurence per cave**	**% of Occurrence**
Lonchophylla sp.					■									1	7.7
Chrotopterus auritus										■				1	7.7
Lonchorhina aurita											■			1	7.7
Micronycteris sp.											■			1	7.7
Trachops cirrhosus											■			1	7.7
Artibeus lituratus											■		■	1	7.7
Pteronotus gymnonotus						■					■			1	7.7
Phyllostomus discolor							■					■	■	3	23
Natalus macrourus					■		■					■	■	4	30.7
Glossophaga soricina		■			■			■	■	■		■	■	7	53.8

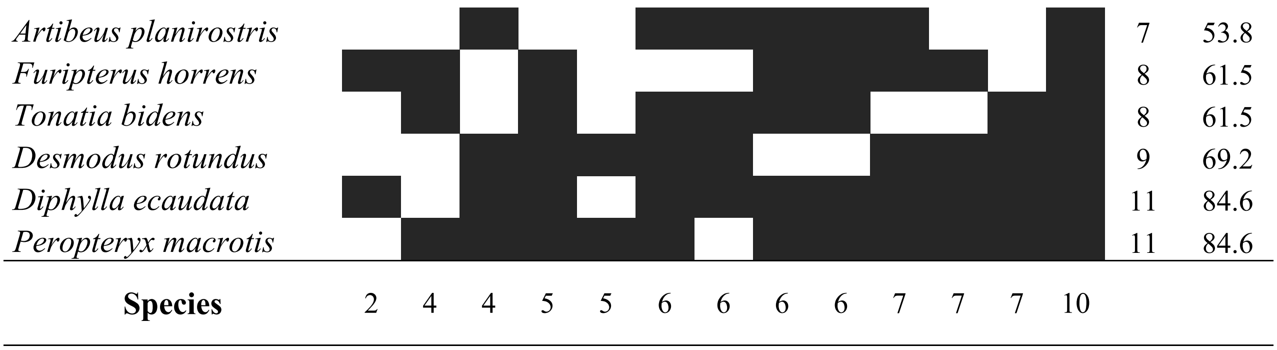

Figure 4. Distribution and occurrence of bat species among caves in the Caatinga of Rio Grande do Norte, Brazil. Filled squares shows the presence of a given species in a given cave. Caves are organized in increasing species richness along the horizontal axis. Along the vertical axis the Bat species are ordered by the number of caves in which each species is found.

In category 4, we found colonies of 100 to 150 individuals of *Desmodus rotundus* in Caverna Boa in FGCS and a colony of about 300-400 individuals of *Glossophaga soricina* in Gruta dos Trinta in Mossoró. We found colonies of category 3 (10-100 indiv.) in ten species. Eleven species were found forming colony sizes of category 2 (Table 2). These two last categories were the most common colony sizes found in the survey caves.

We registered four species using caves as night roost (Category 1). Individuals of *Tonatia bidens* were captured entering in five different caves, but no roosting colonies were found during these study. In two occasions in two different caves (Furna do Urubu and Caverna da Pedra Lisa) we captured *T.bidens* entering the cavities with food items on their mouth, both times with cerambycid beetles. An individual of *Artibeus planirostris* was captured entering into Furna do Urubu and in Caverna Porco do Mato. The only register of *Artibeus lituratus* in this study was from a single bat entering one of the main entrances of the Furna Feia cave; and one individual of *Diphylla ecaudata* captured entering the Caverna Porco do Mato, both caves in Furna Feia National Park (Table 2).

DISCUSSION

Bat assemblages

The data obtained during this study have showed that the cave bat communities of Rio Grande do Norte are rich in relation to other communities surveyed in caves in the Caatinga. Despite the few available studies of cave bats in the Caatinga, richness reported in those studies shows to be lower than that obtained in our study (16 spp.).

In the Chapada Diamantina National Park in Bahía State, Gregorín and Mendes (1999), Oliveira and Pessôa (2005), and Sbraiga and Cardoso (2008) inventoried the chiropterofauna on several caves within the national park and reported an accumulative richness of 15 species. This area may have the highest effort of inventoried cave bat communities in the Caatinga domain, at least for the number of published papers on this national park. Another study done by Silva *et al*. (2001) in the Ubajara National Park in Ceará State reported a richness of seven species of cave bats.

Family Sub-family	**Species**	**Guild**	**Colony size of registered species in each cave**												
			FU	CB	FC	GTL	CA	CLG	CJC	GCH	FF	FN	CPL	CPM	GT
Emballonuridae															
	Peropteryx macrotis (Wagner, 1843)	AI	2		3	2		2	2	3	3	2	2	2	3
Phyllostomidae															
Desmodontinae	*Desmodus rotundus* (E.Geoffroy, 1818)	H	3	4	3	3		3		2	3	3			2
	Diphylla ecaudata Spix, 1823	H	3	3	2	2	2	2	2	2	2	2		1	
Glossophaginae	*Glossophaga soricina* (Pallas, 1766)	N			2				2		3	2	2	2	4
Lonchophyllinae	*Lonchophylla* sp. Thomas, 1906	N													3
Phyllostominae	*Chrotopterus auritus* (Peters, 1856)	C			2										
	Lonchorhina aurita Tomes, 1863	GI				3									
	Micronycteris sp. Gray, 1866	GI				2									
	Phyllostomus discolor (Wagner, 1843)	O		2							5	2			
	Tonatia bidens (Spix, 1823)	GI	1	1					1	1	2	2	2	1	
	Trachops cirrhosus (Spix, 1823)	C				3									
Stenodermatinae	*Artibeus lituratus* (Olfers, 1818)	F									1				
	Artibeus planirostris (Spix, 1823)	F	1	3	3			3	2		2			1	
Mormoopidae															
	Pteronotus gymnonotus (Wagner, 1843)	AI	6												
Furipteridae															
	Furipterus horrens (Cuvier, 1828)	AI			2	2	3		2	3	3		2	2	

Natalidae															
	Natalus macrourus (Gervais, 1856)	AI		2							3	3			3
Richness	**16**		**6**	**6**	**7**	**7**	**2**	**4**	**6**	**5**	**10**	**7**	**4**	**6**	**5**

Table 2. Community composition and colony sizes (categories) of cave-dwelling bats in the Caatinga of Rio Grande do Norte from June to October of 2015. Colony size categories in ranges of number of individuals: (1) Night visitor; (2) <10; (3) 11-100; (4) 101-1000; (5) 1001-10 000; (6) >10000. Trophic guilds are: (AI) Aerial Insectivorous; (GA) Gleaning Animalivorous; (F) Frugivorous; (N) Nectarivorous; (O) Omnivorous; (S) Sanguinivorous. Caves are: in *Felipe Guerra System*: (FU) Furna do Urubu; (CB) Caverna Boa; (FC) Furna da Carrapateira; (GTL) Gruta dos Três Lagos; (CA) Caverna do Arapuá; (CLG) Caverna Lajedo Grande; (CJC) Gruta Capoeira do João Carlos; (GCH) Gruta Casa de Homens. In *Furna Feia National Park*: (FF) Furna Feia; (FN) Furna Nova; (CPL) Caverna da Pedra Lisa; (COM) Caverna Porco do Mato 1. In *Mossoró*: (GT) Gruta dos Trinta.

This National Park in one of the smallest of Brazil and contains 11 caves, but only 3 caves where surveyed during that study. In Piauí State, Gregorín *et al.* (2008) reported 11 species in the Serra das Confusões National Park in two inventoried caves. It is important to mention that our study comprises more than one cave system and the number of days of sampling per cave (3 days) is higher than the above-mentioned studies.

The present study also have demonstrated that the richness of cave bat in RN is higher than the previous studies done in the state. Coelho (2006) made the first inventory of cave bats in the state in six caves of FGCS reporting a richness of nine species. Of those six caves, two caves were sampled in our study (Gruta dos Três Lagos and Furna da Carrapateira). Years later, Ferreira *et al.* (2010) reported the occurrence of eight species as result of inventories of the cave fauna of 17 caves in different areas of RN including four caves we sampled in our study, Furna do Urubu, Furna da Carrapateira, Gruta dos Três Lagos in FGCS and Furna Feia in FFNP. Both mentioned studies reports an accumulative richness of eight species but investigation reports 16 species.

The nine species (*P. macrotis, D. rotundus, D. ecaudata, L. aurita, T. bidens, T. cirrhosus, A. planirostris, G. soricina, N. macrourus*) mentioned by the studies above were captured and/or observed in the present investigation. In fact, we report seven species (*Lonchophylla* sp., *C. aurita, Micronycteris* sp., *P. discolor, A. lituratus, P. gymnonotus* and *F. horrens*) with no previous record roosting in caves of RN State. The record a higher richness in our study demonstrates the importance of data collection for more than one day per cavern (3 days per cave in our study) since the data of the previous studies were obtained by one-day surveys per cave.

In terms of richness per cave, the Furna Feia cave in FFNP homed the highest richness of bats of the surveyed caves (Fig. 3). On a recent bibliographic review of all Brazilian caves with available bat community data, Medeiros and Ferreira (2014) classified caves bat richness as very high those who homed more than nine species. Thus, Furna Feia cave can be assigned into this category. It is possible that the richness in this cave could be sub estimated since it was the biggest cave in our study and contains multiple entrances, some of big dimensions. Beside, captures were not done simultaneously in all entrances and rare species or with low densities, roosting in this cavity may have been overlooked. More effort of capture and active search is highly recommended in order to achieve the real completeness of the community in this cave.

The cave-bat assemblages of Rio Grande do Norte contained a high richness of bats from the Phyllostomidae family (Table 2). From the 16 species recorded, twelve species belonged to this family, composing the 75% of the whole community. Within the Phyllostomidae family, the subfamily Phyllostominae had the highest richness with six species (37.5%) and with the presence of 1-2 species in ten (76.6%) of the 13 surveyed caves.

This taxonomic dominance in the studied caves seems to be a common pattern since cave bat communities in Brazil are particularly rich by phyllostomines (Trajano, 1995; Bredt and Uieda, 1999). In fact, the guild of the Gleaning-Animalivorous contained the highest richness with 5 (31.2%) of 16 species. In general, Phyllostomines are tiny to very large size bats which includes the largest Neotropical bats (Reid, 2009). They are foliage-gleaner bats that generally feed on large size insects and vertebrates, with exception of some species that are omnivores, (Kalko *et al.*, 1998) and frequently roost in caves (Trajano, 1995). The FGCS homed all the species of registered phyllostomines with the presence of rare species with single registered colonies like *Lonchorhina aurita* in the Gruta dos Três Lagos.

The richness of nectarivorous bats was composed by two species. *Glossophaga soricina* was the most common in the present study occurring in seven caves. This nectar-feeding bat is a very common species in the Caatinga (Mares *et al.,* 1981; Oliveira *et al.*, 2003), and a common cave dweller (Gregorín & Mendes, 1999, Guedes *et al.*, 2000; Silva *et al.,* 2001; Sbraiga and Cardoso, 2008; Medeiros and Ferreira, 2014). In Brazil it is present in all habitats (Marinho-Filho and Sazima, 1998) and uses several different roosts besides caves like tunnels, culverts, hollow trees and buildings (dos Reis, 2007). In the karstic areas of RN, caves might be a very important roost for this species because of the high availability of underground cavities and its flexible roost selection.

Lonchophylla sp. was found only in the Gruta dos Trinta in Mossoró with a colony of about 40-50 individuals. Of the five species of *Lonchophylla* bats that occur in Brazil (Nogueira e*t al*., 2014; Moratelli and Diaz, 2015) four species uses caves as roosts (Reis, 2007; Reis *et al*., 2013; Medeiros and Ferreira, 2014). This evidences the importance of caves as a roost resource for the species of this genus. Previously it was thought that *L. mordax* was the only *Lonchophylla* occurring in the Caatinga but with the recent description of *L. inexpectata* (Moratelli and Diaz, 2015) that also occur in the Caatinga, we were not able to identify reliably the individuals forming that colony. We collected two individuals of the colony. The analysis for the identification is ongoing but results were not obtained during the elaboration of this investigation. It is important to determine the identity of this individuals since there is no previous record of *Lonchophylla* bats in the state.

The richness of frugivorous bats in the surveyed caves were low with only two registered species. *Artibeus planirostris* was a common cave-dwelling bat occurring in seven (53.8%) caves and it is the most common *Artibeus* bat in the Caatinga (Oliveira *et al.,* 2003). *A. planirostris* has been already reported roosting in Caatingas caves (Gregorín and Mendes, 1999; Oliveira and Pessôa, 2005; Sbraiga and Cardoso, 2010; Medeiros, 2014; Medeiros and Ferreira, 2014) but has a high flexibility when selecting a roost and has been observed in abandoned buildings, foliage and hollow trees (Hollis, 2005; dos Reis *et al.,* 2013). Although, caves might be a primary roost option for *A. planirostris* in the Caatinga of RN due to the abundance of these underground cavities in the landscape. The case of *Artibeus lituratus* is particular since only one individual were captured entering to the Furna Feia cave. Because of the huge size of this cave we might overlooked any colony of this species. Still, we believe that, if a colony lives in this cave its size might be very small due to the capture of only one individual. Moreover, there is the possibility that this individual were using the cave as a night roost to rest when commuting to foraging areas.

Both species of the *Artibeus* registered in the present study co-occur in most of Brazil (dos Reis, 2013), but bibliographic review of Medeiros and Ferreira (2014) showed that *A. planirostris* occurred more on caves in Caatinga than *A. lituratus*. In contrast, in caves in the humid Atlantic Forests, *A. lituratus* was more common in caves than *A. planirostris*. Moreover, because of the increasing deforestation that is happening rapidly in the Caatinga, the available roost for *Artibeus* bats might be getting restricted to underground cavities or man-made structures.

Still within Phyllostomidae family, surveyed caves had high occurrence of hematophagous bats (Subfamily Desmodontinae). *Desmodus rotundus* was one of the commonest bats in the study present in nine out of 13 caves. Is a very common cave-dwelling bat in Brazil (Trajano, 1984; Campanha and Fowler, 1993; Trajano, 1996; Bredt *et al.,* 1999, Arnone and Passos, 2007; Silva, 2013; Talamoni *et al.*, 2013; Medeiros and Ferreira, 2014) and common in Caatinga caves (Gregorín and Mendes, 1999; Sbraiga and Cardoso, 2010; Medeiros, 2014; Medeiros and Ferreira, 2014). *D. rotundus* is a very flexible bat that feeds on mammal blood and thanks to cattle expansion in the last decades, its populations have increased significantly all over its distribution (Altringham, 1996).

We found in Caverna Boa in FGCS the biggest registered colony of this species with about 100-150 individuals. Generally, *D. rotundus* forms colonies of 20-100 individuals (Greenhall *et al*., 1983), but colonies with more than 100 individuals could occur in areas where population control of anti-rabies programs are not done regularly (Uieda *et al*., 1996). We believe that in this area, population control of vampire bats has not been done, at least in the last years, which might explain the size of this colony in the mentioned area. Moreover, presence of goats, cows and pigs wandering freely close to houses and ranches is evident, especially close to the Felipe Guerra city. In a karstic area in Alto Vale do Rio Ribeira, in Southeastern Brazil, Trajano (1996) found that caves that were close to areas were livestock was abundant nearby, the colonies of *D.rotundus* were bigger and remain stable due to year round blood resource. This predictable and abundant blood resource close to the Caverna Boa, may maintain the food requirements of this colony and other colonies of *D. rotundus* in the studied cave system.

The other present hematophagous bat was *Diphylla ecaudata.* This species roost only in caves and mines (Greenhall *et al.*, 1984) and despite its wide distribution in Brazil is not a common species (dos Reis *et al.*, 2013). Nonetheless, Medeiros and Ferreira mentions that *D.ecaudata* is a common cave-dwelling bat in Brazil occurring in 71 caves of the 269 caves they analyzed. *D. ecaudata* was reported in Caatinga caves but as an uncommon species (Gregorín and Mendes, 1999; Sbraiga and Cardoso, 2010).

In our study, *D.ecaudata* was one the commonest species occurring in 84.6% of the surveyed caves. Spotted colonies during the active search were small and sometimes only one or two individuals were found motionless on bell holes or on flat roofs. Generally, *D. ecaudata* is known to form colonies up to 30 individuals, tends to be very nervous and flies away when disturbed (Greenhall *et al*., 1984). We think that during the active search, flashlights might disturb most of roosting individuals, leaving only motionless juveniles causing a subestimation of the local colonies. Although, a colony of about 50 individuals, including juveniles, were found in the Caverna Boa.

The aerial insectivorous bats (*Peropteryx macrotis*, *Pteronotus gymnonotus*, *Furipterus horrens*, and *Natalus macrourus*) highest taxonomic diversity at family level (Emballonuridae, Mormoopidae, Furipteridae, Natalidae respectively). The guild was present in all of the 13 surveyed caves with a richness of one to three species living in the same cave (Fig. 3). This four species are typical cave-dwelling bats in Brazil (Trajano, 1995).

P.macrotis occurred in the 84.6% of the surveyed caves (Fig.3). Even though colonies inside caves were not composed by a big number of individuals, except in the Gruta dos Trinta were the biggest colony was found, we believe that areas with abundant karstic outcrops favors the presence of this species because a lot of individuals where observed in cracks and walls outside of caves. In Brazil, *P.macrotis* has been reported roosting in caves, mines, shallow cracks and human constructions (dos Reis *et al.,* 2007) and within its distribution occurs abundantly in some localities (Reid, 1997). In Caatinga, caves the presence of this species has been already registered (Gregorín and Mendes, 1999; Sbraiga and Cardoso, 2010).

Natalus macrourus is a typical cave-dwelling bat (Reid, 2007). In Brazil, *N.macrourus* has been reported roosting only in caves (Trajano and Moreira, 1991; Taddei and Uieda, 2001; Tejedor, 2011) and already been reported for Caatinga caves (Trajano and Gimenez, 1998; Gregorín and Mendes, 1999; Sbraiga and Cardoso, 2010, Rocha *et al.,* 2013). *N.macrourus* was an uncommon species and was registered in small numbers in four caves (Caverna Boa, Furna Feia, Furna Nova, Gruta dos Trinta) distributed in the three studied karstic areas. We were not able to found a roosting colony inside the mentioned caves above and the presence of the species were done through captures and photographed flying individuals. We believe that the number of individuals might be underestimated and colonies might be bigger.

Furipterus horrens roost mainly in caves (Uieda *et al*., 1980; dos Reis *et al.,* 2007) and in Brazil this species has been recorded for 12 states in all regions, covering the Amazon, Caatinga, Cerrado and Atlantic Forest ecosystems (Reis and Gazarini, 2007, Tavares *et al*., 2008, Peracchi *et al*., 2011). Studies made by Guedes *et al.* (2000), Silva *et al.* (2001). Medeiros and Ferreira (2014) registered *F.horrens* roosting in caves within the Caatinga domain. According to Uieda *et al.* (1980), forms colonies up to 250 individuals separated in small groups of 30-40 bats. We were able to spot only two colonies in the Gruta Casa de Homens in FGCS and in the Furna Feia cave in FFNP homing colonies of 20-30 individuals and with about 100 individuals or more, respectively. Being the smallest bat in Brazil, its detectability through active search requires experience and patience. Furthermore, its capability of evading mist net is outstanding, thus, we were able to capture only three individuals. The species was a common cave dweller occurring in 8 of 13 caves (Fig. 3), something that was not expected as the species it is known to be less uncommon in humid areas. *F. horrens* might be more common in areas with large number of underground cavities, like in karstic areas of RN, than in areas were caves are scarce.

The studied cave systems evidenced the occurrence of several important caves for subpopulations of bats in the northeastern region of the Caatinga. The three surveyed karstic regions had two different scenarios of conservation. Caves inside the Furna Feia National Park (FFNP) are in good scenario of conservation as National Parks have the maximum category of protection in Brazil. In fact, FFNP was created through Presidential Decree S / N, on July 5 of 2012, in function of the preservation of the speleological complex and the biodiversity associated with the Caatinga vegetation. In contrast, the karstic areas in Mossoró (Gruta dos Trinta) and the Felipe Guerra Cave System are located in areas under no conservation category resulting in all underground cavities within these areas has no protection at all.

This areas are even more vulnerable due to the Decree 6640 stated in November 7, of 2008. This decree reduced the protection of Brazilian caves since, after its publication, only the caves considered of "maximum relevance" have the prerogative to full protection. A “maximum relevance” cave are determined by its biological, ecological, hydrological, geological, paleontological, socio-economical, scenic and archeological attributes. All the remaining cavities were classified as "high, medium and low-grade" and may be subject to irreversible negative impacts upon environmental licensing. Thus, subpopulations of species dependent of caves can be locally extinct by the destruction of their shelters (Aguiar *et al*., 2006).

The reduction of protection and the increased exploitation of Brazilian caves is a real threat not only to the conservation of bats that make use of these types of structures in Brazil, but also to the rich and unknown ecosystems associated with the group (Bernard *et al*., 2012). Bats are responsible for the increase of organic matter in cave ecosystems through guano deposition (Gnaspini and Trajano, 2000). This guano deposition sustains complex endemic invertebrate communities due to the general lack of food in caves (Ferreira and Martins, 1998; Gnaspini &

Trajano, 2000; Ferreira *et al*., 2010) and communities can perish if the input of guano falls below certain limits (Trajano, 1995).

Final considerations

The poor knowledge of cave-dwelling bat communities in RN and in the Caatinga and creates difficulties to achieve accurate conservation actions especially when caves in the region contains an important biological, geological and archeological heritage. However, areas such as the Felipe Guerra Cave System contains 87.5% (14 spp.) of the total richness registered in the three surveyed areas.

We believed that this information will be important to denote the importance of these cavities for the local cave bat assemblages and might provide strong justification for the establishment of a conservation unity in the area. Regardless of whether it is stablished any conservation unity on a short future, we urge for conservation actions starting with strict visitation control to prevent the colonies disturbance for four above-mentioned caves. If these four caves are submit to protection, together they will protect the 94% (15 spp.) of the total richness (16 spp.) of the current registered cave-dwelling bat communities in Rio Grande do Norte.

We encourage investigating aspects such as analysis and variation in the community structure that may cause species turnover, temporal changes on the richness or colony sizes that could respond ecological questions of how bats face the strong seasonal variation in semi-arid environments like the Caatinga. This study brought to light a first insight of the cave bat communities in a poorly studied state but with a potential to become an important region of the diversity of cave-dwelling bats in Brazil.

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Chapter 2:

Effects of landscape and cave structure on cave-dwelling bat communities in the Caatinga of Rio Grande do Norte in northeastern Brazil

CHAPTER 2

Effects of landscape and cave structure on cave-dwelling bat communities in the Caatinga of Rio Grande do Norte in northeastern Brazil

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Key words: Cave-dwelling bats, landscape, cave structure, Caatinga, Rio Grande do Norte

INTRODUCTION

Bats spend more than half of their lives in their roost environment and exhibit a variety of adaptations that may reflect compromises associated with mode of flight, social behavior, diet, and group size (Kunz, 1982). Caves in particular provides a stable and permanent roost that it is used for protection against predators, adverse environmental conditions, breeding, care of offspring, and hibernation in temperate zones (Kunz, 1982; Trajano, 1995; Tuttle & Moreno; 2005).

Several factors influence cave selection in bats. Internal factors like, cave dimensions and structural complexity (Brunet and Medellín, 2001), species-specific microclimate preferences (Ávila-Flores and Medellín, 2004), interspecific interactions (Arita and Vargas, 1995, Rodríguez-Duran, 1998) and external factors like human disturbance (Kunz, 1982), or; food availability in the surrounding landscape (Furey and Racey, 2015), influence the number and diversity of bats in caves. Cave environment in the tropics are typically more stable and uniformly inhabited (Brosset, 1966), and it is common to find caves containing richness of bats above 10 species (Arita, 1993, Trajano and Gimenez, 1998; Gregorín and Mendes, 1999; Brunet and Medellín, 2001; Esbérard *et al*., 2005).

Different authors found a positive correlation between cave size and bat richness. Larger and more geomorphologically complex caves harbored the richest bat assemblages (Arita, 1996; Brunet and Medellín, 2001, Cardiff, 2006; Niu *et al.*, 2007; Luo *et al.*, 2013). The species-area relationship may explain patterns of high richness in big caves. In central Mexico, Brunet and Medellín (2001) found a positive relationship between cave surface area and species richness; and associated it with the species-area relationship. They suggested that the bigger the cave, the higher the number of species that could roots inside the cave due to a higher diversity of available roost sites.

However, if bats spend half of their lives in their roost, what happens in the other half of their lives? What is the influence of different biotic and abiotic components around caves on the structure of cave bat communities? In bio-speleological terms, bats are classified as trogloxenes. These are organisms regularly found in caves but that must emerge periodically in order to complete their life cycle (Trajano, 1995). During nightly foraging flights, bats exhibit a high degree of temporal and spatial mobility across the landscape and they may travel through many distinct habitats (Duchamp *et al*., 2007). In consequence, the suitability of roost, foraging areas, and water are fundamental to the management of landscapes for bat communities in forested ecosystems (Hayes, 2003).

The landscape and its composition around the caves should be, in some degree, important factors in roost selection for the different species. However, the influence of the external environment on cave selection by bats has been poorly studied (Furey and Racey, 2015).

To understand the effects of the landscape on cave-bat communities it is important to take into account not only landscape variables but also the role of caves itself, such as dimensions for example, in order to have an insight of how this two factors are structuring the communities. The aim of this study is to use cave dimensions and surrounding landscape variables to create models to identify which variables or group of variables has effects on the richness and community structure of cave-dwelling bats in the different karstic areas in a Caatinga in the state of Rio Grande do Norte in northeastern Brazil.

We expect that a landscape scale that caves with high forest cover, presence of water bodies and with low presence of anthropogenic components around them will have rich and abundant bat communities with the occurrence of unique species (Integral landscape hypothesis). This by assuming that the landscape components are in integral conditions. Conversely, areas with low forest cover and with high anthropogenic components will have poor diverse communities composed by abundant generalist species. At a local scale, we expect that the caves with the biggest size will harbor the highest diversity of cave bats (Cave-size hypothesis). Larger caves will provide much more variety of roosting sites that will satisfy the specific microclimate (temperature and humidity) and internal geomorphological preferences (crack, crevices, cavities, chambers, texturize walls) for a relative high number of species.

MATERIALS AND METHODS

Study Area

This study was developed in two karstic areas within the Caatinga domain in the State of Rio Grande do Norte (RN) in northeastern Brazil. The Caatinga homes a seasonal deciduous tropical dry forest characterized with plant species with thorns, small leaves with xerophytic characteristics, also with the presence of woody plants and scrubby areas dominated by terrestrial bromeliads and columnar cactuses (Leal *et al.,* 2003; Santos *et al.,* 2011).

The climate is predominantly BSwh' type (Köppen) characterized by very hot weather and semi-arid, with the rainy season is delayed for autumn. Rainfall is irregular, in general, and occur in the period from February to July concentrating mostly during March to June The average annual rainfall ranges from 240 to 1500 mm and an evaporation of 1760 mm. It has a water deficit of 1000 mm for about 9 months. The relative humidity is quite variable, usually between 59 and 76%, and the annual average temperature around 27.8º C (21° - 36°C) (IDEMA, 2005). Average annual precipitation (Leal *et al*., 2005), although long lasting droughts are frequent and subjected to annual variations. Unfortunately, natural forested areas in the Caatingas has been deeply altered in the last decades. The inappropriate land use by human activities (*e.g*. lumber extraction, agriculture) and continuous depredation of native vegetation by cattle and goats is causing a rapid environmental damage and desertification on the Caatinga (Leal *et al*., 2005).

Rio Grande do Norte is characterized by being one the smallest States of Brazil (52 811.047 km²), with a Caatinga covering the 95% of the state and by containing more than 900 underground cavities positioning it in fourth place in number of cavities per state in Brazil. The west portion of the state contains the highest number and density of the underground cavities of the State. We studied 13 caves in this west portion about 330 km from the State capital Natal close to the limit of Ceará State. The thirteen caves (Table 4) are distributed in two separated caves systems and one locality with an isolated cave. All studied caves had a calcareous lithology. One cave system is located in the Furna Feia National Park (FFNP) stated in June of 2012 as the first national park in the State. The FFNP is about 8,494 hectares of protected Caatinga forest in the municipalities of Mossoró and Baraúna in the northwestern corner of RN. The national park protects 248 underground cavities, the second area of the State with the highest number of caves (Bento *et al*., 2013).

The second cave system is located in the municipalities of Felipe Guerra, Governador Dix-sept Rosado and Caraúbas. We opted to name this system Felipe Guerra Cave System (FGCS). The FGCS contains the largest concentration of caves in RN (341 cavities) which is the 52.3% of the known underground cavities for the State (Bento *et al*., 2015). This karstic area is about to be proposed to the correspondent Brazilian environmental institutions as an Environmental Protection Area (APA acronym in Portuguese) under the name APA Pedra Abelha (see Bento *et al*., 2015). The proposed protection area is about 80 560 hectares which possess a speleological heritage of extreme importance. The last study site is a cave named Gruta dos Trinta in the municipality of Mossoró at approximately 5 km from the second biggest city of the State, Mossoró.

Cave selection

Because of the high number of caves registered for the State, surveyed caves were selected based on characteristics such as: *i)* previous confirmed presence of bats, *ii)* topographic data of the linear length, volume, linear development and horizontal projection. This data was to be used as internal variables. With this information, we selected 31 caves. We did an analysis of geographical independence with all caves in order to select from the 31 caves the ones that had at least 2 km of distance between each other in order to create a circular (1km radius) buffer around each cave.

Thirteen caves were selected to perform the analysis inside this buffer (Table 3). An area of 314 hectares will be analyzed in this 1 km buffer. As bats has a high spatial mobility, we expect that with this amount of area analyzed will include home ranges of most of bat trophic guilds expected in the study area. Although, little is known about home ranges sizes of Neotropical bat species. The scant knowledge about size of home range and feeding areas of Neotropical bats are limited to a few species of the New World Pyllostomids (Kalko, 1998). Differences in home ranges and feeding areas are found among trophic guilds and among species within guilds. These differences are tightly coupled with foraging strategies (perch-hunting vs. continuous flight), distribution and availability of resources (patchy, big bang vs. continuous, steady-state food), as well as size of the animals (Kalko, 1998).

Table 4. Caves selected for analysis in this study in the west side of Rio Grande do Norte, Brazil.

Cave System	Cave Name	Coordinates	
		Latitude	Longitude
Furna Feia System	Furna Nova	-5.034226	-37.571167
	Furna Feia	-5.036878	-37.560177
	Caverna Porco do Mato 1	-5.046638	-37.540114
	Caverna da Pedra Lisa	-5.045527	-37.521902
Felipe Guerra System	Gruta dos Três Lagos	-5.593288	-37.687155
	Caverna Boa	-5.566527	-37.697897
	Furna da Carrapateira	-5.560618	-37.663979
	Furna do Urubu	-5.573047	-37.652420

	Caverna do Arapuá	-5.518367	-37.610706
	Gruta Capoeira do João Carlos	-5.514716	-37.528770
	Caverna do Lajedo Grande	-5.462278	-37.552471
	Gruta Casa de Homens	-5.576272	-37.573807
Mossoró	Gruta dos Trinta	-5.212322	-37.264153

For nectarivorous, carnivorous and gleaning insectivorous bats, home ranges has been assessed in <500 ha. (Kalko *et al*., 1999; Albrecht *et al*., 2007; Bernard & Fenton, 2003). However, species belonging to other guilds are known to commute long distances in one night like larger frugivorous species of *Artibeus* (0.6-8km) (Morrison *et al.,*1978; Handley Jr. *et al.,* 1991; Medina *et al.,* 2007; Menezes Jr. *et al.,* 2008; Trevelin *et al*., 2013). For Neotropical aerial insectivorous species home ranges are poorly known and for hematophagous bats commuting distances from 1.6 km to >8km has been reported (Greenhall *et al.*, 1983; Trajano, 1996; Bianconi *et al*., 2006; Costa *et al*., 2006; Medina *et al*., 2007).

Cave and spatial variables extraction

We arbitrarily chose variables that may had biological implications on bat ecology based on a bibliographic review. For the construction of the models we selected 14 variables categorized in internal, external and spatial variables (Table 4). Each variable will be quantified inside the 1km buffer for each of the 13 selected caves using ArcGis 10.1. For internal variables, we used topographical data of cave dimensions: 1) Linear Development, 2) Horizontal Projection, 3) Volume, 4) Area and 5) Vertical Unevenness. This data were obtained from the database of the National Center of Research and Conservation of Caves (CECAV, 2015) of Brazil.

As for landscape environmental variables, we used: 6) Percentage of Caatinga coverage. The coverage quantity of Caatinga was assessed using the "ZONAL STATISTICS" tool from the spatial analysis module of ArcGis 10.1 and data were obtained from the database of the Ministerio de Meio Ambiente (MMA) of Brazil deforestation data of 2009. 7) Distance of lakes or water reservoirs; and 8) Distance of rivers. The distance of these two variables from caves was done with the "NEAR" tool of ArcGis 10.1 software.

On the anthropogenic variable we used 9) Sheep density, 10) Goats density, 11) Cattle density, 12) Human demographic density. All of them were taken from the census of 2010 made by the IBGE (Instituto Brasileiro de Geografia e Estatistica). We first spatialize the values of the number of individuals per census sector (district) and then we calculated the density (number of individuals / hectare) to subsequently calculate the density in the 1km radius buffer of each of the 13 sampled caves. All analyzes were performed in ArcGIS 10.1. The projection was WGS84 and on the UTM zone 25 projection system. Spatial variables such as 13) Latitude and 14) longitude of each cave were taken with a Global Positioning System (GPS) device in each sampling site.

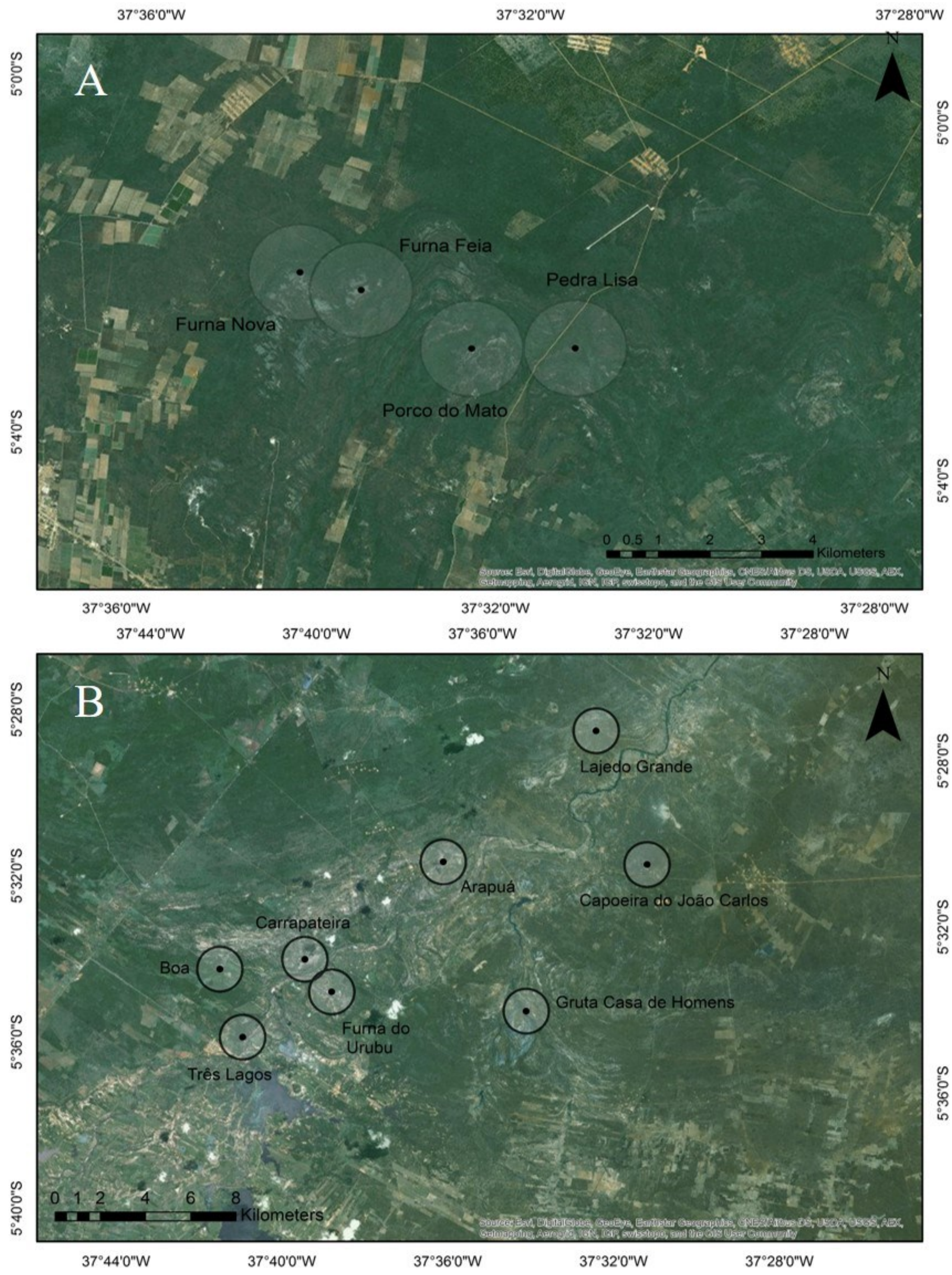

Figure 5. Map of the study area with 12 selected caves. Each cave shows a 1 km. buffer around. (A) is Furna Feia National Park in the municipalities of Mossoró . (B) is Felipe Guerra Cave System in the municipalities of Felipe Guerra, Governador Dix-sept Rosado and Caraúbas. The Gruta dos Trinta cave in Mossoró not shown.

Table 5. Description of variables used to perform models in order to explore the effects on the richness and abundance (rank colony size) of communities of cave-dwelling bats in the Caatinga of Rio Grande do Norte, Brazil

Type of Variables		Description
Cave	Linear Development	It is the distance measured along the axis oriented parallel the longitudinal directions of all galleries and genetically continuous depths, whatever their inclinations. Data were obtained from the database of the National Center of Research and Conservation of Caves of Brazil (CECAV, 2015)
	Horizontal Projection	Consist consists in length of a cave by its projection in floor. After making the map, an imaginary axis is drawn following the preferred directions of the ducts. The sum of line segments that make up this axis, measured with the aid of a scale, would be the "size" of the cave. Data were obtained from the database of the National Center of Research and Conservation of Caves of Brazil (CECAV, 2015)
	Volume	Data were obtained from the database of the National Center of Research and Conservation of Caves of Brazil (CECAV, 2015). Values are given in cubic meters (m^3)
	Area	Data were obtained from the database of the National Center of Research and Conservation of Caves of Brazil (CECAV, 2015). Values are given in squared meters (m^2)
	Vertical Unevenness	The difference between the coordinate of the highest point and the lowest point of the whole cavity. This data were obtained from the database of the National Center of Research and Conservation of Caves of Brazil (CECAV, 2015)
Landscape	Percentage of Caatinga cover in 1km (%Caat)	Percentage of remaining coverage Caatinga estimated from sampling point with a buffer of 1 km. The values are given in percentages. The data were obtained in "Projeto de Monitoramento do Desmatamento dos Biomas Brasileiros por Satélite – PMDBBS." http://siscom.ibama.gov.br/monitorabiomas/
	Distance of Lakes or water reservoirs	Euclidean distance from the nearest lake or water reservoirs. The distance calculation is done in ArcGis 10.1. Fonte: http://downloads.ibge.gov.br/downloads_geociencias.htm
	Distance of rivers	Euclidean distance from the nearest river. The distance calculation is done in ArcGis 10.1. Fonte: http://downloads.ibge.gov.br/downloads_geociencias.htm
Anthropogenic	Sheep density	Data taken from the census of 2010 made by the IBGE (Instituto Brasileiro de Geografia e Estatistica). The values where spatialized by the number of individuals per census sector (district). Density (number of individuals / hectare) was calculated in1km radius buffer of each of the 13 sampled caves. All analyzes were performed in ArcGIS 10.1.
	Goats density	Data taken from the census of 2010 made by the IBGE (Instituto Brasileiro de Geografia e Estatistica). The values where spatialized by the number of individuals per census sector (district). Density (number of individuals / hectare) was calculated in 1km radius buffer of each of the 13 sampled caves. All analyzes were performed in ArcGIS 10.1.
	Cattle density	Data taken from the census of 2010 made by the IBGE (Instituto Brasileiro de Geografia e Estatistica). The values where spatialized by the number of individuals per census sector (district). Density (number of individuals / hectare) was calculated in 1km radius buffer of each of the 13 sampled caves. All analyzes were performed in ArcGIS 10.1.
	Demographic density	Data taken from the census of 2010 made by the IBGE (Instituto Brasileiro de Geografia e Estatistica). The values where spatialized by the number of individuals per census sector (district). Density (number of individuals / hectare) was calculated in 1km radius buffer of each of the 13 sampled caves. All analyzes were performed in ArcGIS 10.1. http://downloads.ibge.gov.br/downloads_geociencias.htm
Spatial	Latitude	Obtained in each sampling site (cave)
	Longitude	Obtained in each sampling site (cave)

Bat data collection

To determine the richness and the composition of bat communities in selected caves, surveys were carried out at day and night during three consecutive days for each cave from June 8 to October 23 of 2015. At day, active search was made through direct observation for roosting species individuals to two-three hours by illuminating bat colonies, using binoculars and photos. Direct counts during the day ensures that recorded bats are using the cave as day roost.

Before sunset, mist-nets were deployed at cave entrance or entrances to capture bats during their emergence of caves. If the size of the cave was big enough, mist-net were deployed in strategically places inside the cave to record the highest amount of species. Mist-net number and size (3-12m) used depended on the size of the entrance of the cave. Mist-netting sessions were from 1730 hrs. to 2400 hrs. (6 hrs. 30 min.). In multiple entrance caves, we covered with plastic tarp and any other possible exit holes or cracks in order to persuade bats to emerge into deployed mist-nets sites at selected entrances.

For abundance data, we categorized colony sizes of each species in each cave based and modified from Arita (1993; 1996) into six categories established on the number of captures and observed individuals. However, we modified the five categories initially used by Arita (1993; 1996) by adding one more category. The added category correspond to individuals that were captured entering the cave at night but no colony where spotted during active search suggesting the use of the cave as night roost. A night-roost are places used by bats as feeding perches. They ingest food transported from nearby feeding areas, which allows digestion and energy conservation, offer retreat from predators, and facilitate social interactions (Kunz, 1982). We choose to name this category as Night Visitor. Therefore, colony size categories are **1** (Night Visitor), **2** (<10 individuals), **3** (11-100), **4** (101-1000); **5** (1001-10 000); **6** (>10 000).

Statistical Analysis

Cave system and bat community comparison

We used Bray-Curtis index of dissimilarity to generate a distance matrix between bat species composition of the thirteen surveyed caves to perform a non-metrical multidimensional analysis (NMDS) (Kruskal, 1964) for a graphical inspection and for testing if there is a difference in the species composition between the Felipe Guerra cave system (N=8) and Furna Feia National Park (N=4). We calculated the NMDS in two-dimensional solution. The stress was used as an adjustment measure between the obtained values of the analysis and the original matrix of community distance. We performed two NMDS, one for qualitative data (0 or 1) and one for the categorical data of colony size (0–6).

For the interpretation of the ordination axis, we calculated the Spearman correlation with the scores of axes I and II of qualitative (presence/absence data) and ranking abundance NMDS with the data of bat species ranking abundance; and with the environmental, cave structure and anthropogenic data (see Table 4). This analysis was used to interpret which variable and species affects the scores in the ordination space. A SIMPER analysis was effectuated to estimate the weight of each species in the community dissimilarity between the sites FGCS and FFNP. Finally, we performed a multivariate analysis of variance (MANOVA) in order to compare differences between this two cave systems using the scores of the two axis of NMDS performed with ranking abundance data.

Data reduction and model selection

We used a principal component analysis (PCA) for each of the three relative variable sets: i) *Cave* structure (linear development, horizontal projection, volume, area and vertical unevenness); ii) *Environmental* variables: forest cover (% of Caatinga), lake distance, and river distance); iii) *Anthropogenic* variables: 1) Sheep density, cattle density, goat density, and 2) human demographic density). For detail of candidate models, see Table 5. The extracted scores were used for simple and multiple linear regressions.

Table 6. Candidate models used to test the effect of the explanatory variables on the richness and composition of cave-dwelling bats in Rio Grande do Norte, Brazil.

Variables	Models
Null model	null
Environmental *(% Caatinga + Lake Distance + River Distance)*	Simple
Anthropogenic 1 (*Cattle, sheep and goat density*)	Simple
Anthropogenic 2 (*Human demographic density*)	Simple
Latitude	Simple
Longitude	Simple
Cave (*Area+Volume+Uneveness+Linear develop. +Horizontal projection*)	Simple
Anthropogenic 1 + 2	Multiple
Cave + Environmental	Multiple
Cave + Environmental + population density 1	Multiple
Cave + Environmental + population density 2	Multiple
Cave + Environmental + population density 1 + 2	Multiple
Cave + Anthropogenic 1	Multiple
Cave + Anthropogenic 2	Multiple
Cave + Anthropogenic 1+2	Multiple
Environmental + Anthropogenic 1	Multiple
Environmental + Anthropogenic 2	Multiple
Environmental + Anthropogenic 1+2	Multiple

Once extracted the scores of each of the PCAs, these values were used as explanatory variables that affect richness and composition of the cave bat community. The comparison of the simple and multiple linear regressions of the effect of the environmental, cave dimension, and anthropogenic variables was done by using the Akaike information criterion (AIC) (Williams *et al.*, 2002). The AIC compares the different models through a combination by maximum likelihood that determines which model better explains the observed data. The lower the value of AIC scores more plausible is the model adjustment to the data. We used a correction for small samples on the estimation the AIC values that were available in the software SYSTAT 12.

RESULTS

Bat community composition

The mean richness of the 13 analyzed caves was of 6 ± 2 species ranging from two species in Caverna do Arapuá in Felipe Guerra Cave System to 10 species in Furna Feia cave in Furna Feia National Park. The Felipe Guerra Cave System had the highest beta diversity with 14 species, Furna Feia National Park with 10 species and in Mossoró 4 species, for a cumulative richness of 16 species. For species richness, composition and colony sizes by cave see Chapter 1.

The NMDS ordination showed a separation between FGCS and FFNP in the ranking of colonies sizes (stress= 0.169) and qualitative data (0.178) respectively (Fig. 6). We opted to use only the ranking size of colonies data because it presented a smaller stress and a better distribution of variation contained in the two axes (46% in the first and 23.7% in the second) (figure 1a and 1b). For the ordination with ranking colony size, the Axis 1 was positively correlated with ranking abundance of *Natalus macrourus* (rho Spearman = 0.771), *Desmodus rotundus* (rho Spearman = 0.629), *Phyllostomus discolor* (rho Spearman = 0.615) and negatively with *Furipterus horrens* (rho Spearman = -0645). The second axis was positively related to *Glossophaga soricina* (rho Spearman = 0.886), *Lonchophylla mordax* (rho Spearman = 0.463) and negatively with *Diphylla ecaudata* (rho Spearman = -0.811), *Desmodus rotund*us (rho Spearman = -0.567) and *Pteronotus gymnonotus* (rho Spearman = -0.463) (Supplementary Materials 3).

Regarding the explanatory variables, the first axis was positively correlated with cave variables and the second axis with spatial variables (latitude [rho Spearman = 0.742] and longitude [rho Spearman = 0.775]) and with Caatinga vegetation cover (rho Spearman = 0.492); and negatively correlated with demographic density (rho Spearman = -0.709), goat (rho Spearman = -0.609) and sheep (rho Spearman = -0.564) densities (Supplementary Materials 4).

Moreover, the MANOVA analysis showed a difference on the bat species composition between FGCS and FFNP (MANOVA - Pilai Trace=0.511; df=2,9; p-value=0.04). The univariate tests show the marginal difference only in the second axis (F=3.9; df=1,10; p-value=0.077).

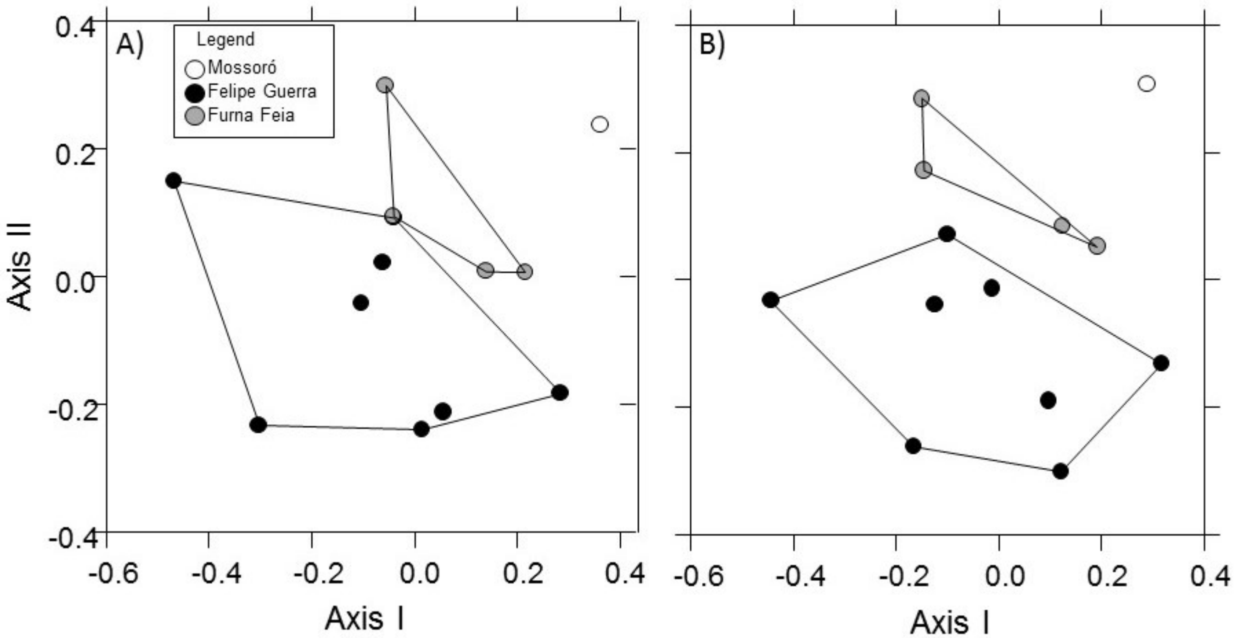

Figure 6. NMDS ordination for (A) qualitative data (presence and absence) and (B) ranking size colonies of bat species of all sampled caves in RN State, Brazil. Of the original Bray-Curtis dissimilarity index, A) retained 58.8% in Axis 1 and 19% in Axis 2; and B) Axis 1 retained 46.1% and Axis 2 retained 23.7%. Each point represents a cave. Black points represents caves from the Felipe Guerra Cave System. Gray points represents caves from the Furna Feia National Park. Unfilled point represents the Gruta dos Trinta cave in Mossoró.

The SIMPER analysis showed that the highest mean abundance difference of bat species occurrence in FGCS and FFNP belonged to *Glossophaga soricina* (15.59%), followed by *Tonatia bidens* (10.57%), *Desmodus rotundus* (10.52%) and *Artibeus planirostris* (10.14%) (Table 7). This four species explained 46.8% of dissimilarity. *G. soricina* and *T. bidens* were more abundant in the FFNP and *D. rotundus* and *A. planirostris* more abundant in FGCS. Five species occurred only in the FGCS (*Pteronotus gymnonotus*, *Lonchorhina aurita*, *Chrotopterus auritus, Trachops cirrhosus* and *Micronycteris* sp.) with low abundance (except *P. gymnonotus* with a colony about 10 000 indiv.) and low occurrences restricted to single caves. *Artibeus lituratus* occurred only in one cave in FFNP with a single captured individual.

Table 7. The SIMPER results of comparisons of Bray Curtis dissimilarity index between chiropterofauna of Felipe Guerra (FG) and Furnas Feia (FF) caves system in RN State, Brazil. The overall average dissimilarity = 43.47. Table shows for each species: Average dissimilarity, Percentage of contribution, Cumulative percentage, Mean abundance of FG and (FF).

Species	Av. dissim	Contrib. %	Cumulative %	Mean abund. FG	Mean abund. FF
Glossophaga soricina (Pallas, 1766)	6.778	15.59	15.59	0.25	1
Tonatia bidens (Spix, 1823)	4.593	10.57	26.16	0.5	1
Desmodus rotundus (E.Geoffroy, 1818)	4.573	10.52	36.68	0.75	0.5
Artibeus planirostris (Spix, 1823)	4.408	10.14	46.82	0.625	0.5
Phyllostomus discolor (Wagner, 1843)	3.842	8.839	55.66	0.125	0.5
Natalus macrourus (Gervais, 1856)	3.842	8.839	64.5	0.125	0.5
Furipterus horrens (Cuvier, 1828)	3.757	8.644	73.15	0.625	0.75
Diphylla ecaudata Spix, 1823	2.764	6.36	79.51	1	0.75
Peropteryx macrotis (Wagner, 1843)	2.528	5.815	85.32	0.75	1
Artibeus lituratus (Olfers, 1818)	1.646	3.786	89.11	0	0.25
Pteronotus gymnonotus (Wagner, 1843)	1.009	2.32	91.43	0.125	0
Lonchorhina aurita Tomes, 1863	0.9315	2.143	93.57	0.125	0
Chrotopterus auritus (Peters, 1856)	0.9315	2.143	95.71	0.125	0
Trachops cirrhosus (Spix, 1823)	0.9315	2.143	97.86	0.125	0
Micronycteris sp. Gray, 1866	0.9315	2.143	100	0.125	0

Direct ordination of bat community

We performed a direct ordination of the bat community with the three environmental variables (Percentage of Caatinga cover, Lake and River distance to cave) in order to visualize the data to see if caves with high Caatinga cover and close lakes and rivers will have rich communities.

<u>Percentage of Caatinga cover</u> – No pattern were found in relation to a high cover with a high bat richness. Eight caves were located in areas with >95% of Caatinga cover but their richness ranged from 2-10 species. All four caves in FFNP had a Caatinga cover of >95% including the Furna Feia cave that had the highest richness in the study (10 spp). Furthermore, five species (*C. auritus*, *P. gymnonotus, T. cirrhosus, Micronycteris* sp., *L. aurita* and *Lonchophylla* sp.) were found exclusively in caves in sites with <40% of Caatinga cover, all of them in the FGCS. Two caves (Furna da Carrapateira and Furna do Urubu) had 0% of forest cover but both hosted an accumulative richness of 12 species. Seven species (*T.bidens, G.soricina, F.horrens, P.macrotis, D.ecaudata, A.planirostris* and *D.rotundus*) were registered indistinctly in caves with 0-100% of Caatinga coverage. (Fig. 7)

<u>Water associated variables</u> (Lake and River distance to cave) – we found that the occurrence of *Chrotopterus.auritus*, *Pteronotus gymnonotus, Trachops cirrhosus, Micronycteris* sp., *Lonchorhina aurita* and *Lonchophylla* sp. occurred only in caves that were close to water bodies (*e.g.* lakes, wetlands, water reservoirs, dams, rivers) (Fig. 7). These species occurred in caves that were from 83-1029 m from a river (See Supplementary Material 4). This distance can be considered relatively close because some caves were locate from 2569-8833m from a river. The rest of species did not show any pattern of cave selection related to water distance.

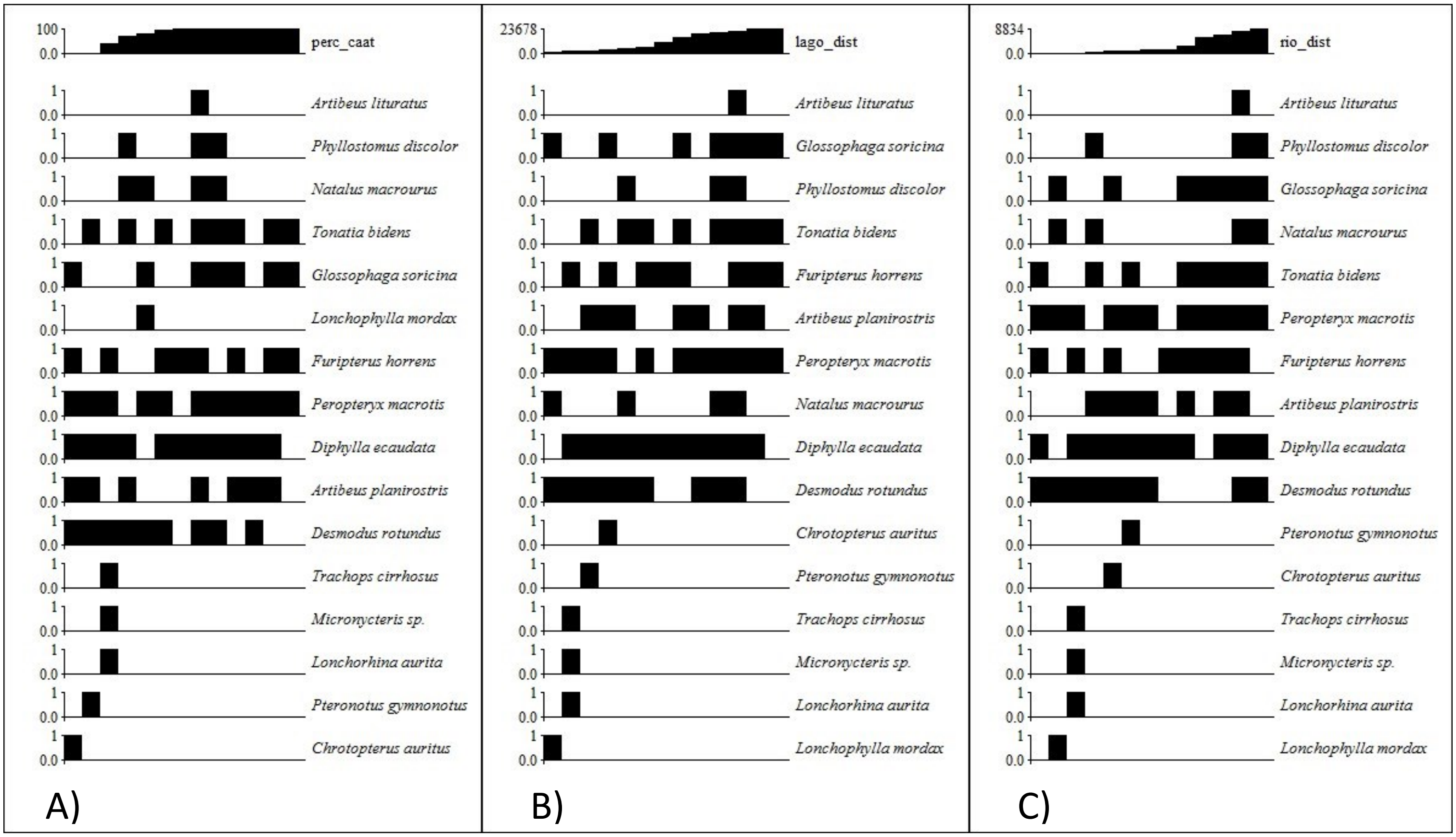

Figure 7. Direct ordination of qualitative data of species of cave bat communities related to values of A) Percentage of Caatinga cover, B) Lake Distance and C) River Distance for each of the 13 caves in RN, Brazil. On the first row of the graph, y-axis is the quantitative gradient of percentage of Caatinga in A), and distance in meters of the cave to a river B) and lake C); on the x-axis is values of the variable for each of the 13 surveyed caves. On the remaining rows below it is shown the species composition of bats for each of the 13 caves, where the x-axis is presence/absence (0-1) and on the y-axis is the occurrence of the species on a cave.

Variable data reduction for model selection analysis

The PCA loadings of cave variables showed that all variables were represented positively in the first axis containing 85.65% (Table 4). As for the environmental variables the loadings were represented positively in the first axis retaining 78.3% of the explained variance. The second axis retained 18.2% of the variance and was not used for subsequent analysis. Finally, the PCA of anthropogenic variables showed a solution with two axes retaining 89.02% of the explained variance, with 54.5% in the first axis and 34.7% in the second axis. The first axis positively represented the variation in the density of sheep, goats and cattle, and the second positively for human demographic density. In this case, for subsequent analysis we used these two axes.

Table 8. Loadings of PCAs performed for Cave, Environmental and Populations Density variables of sampled caves in RN State, Brazil.

	Component loadings		
Cave Variables	1	2	3
Linear continuum development	0.974	0.149	0.155
Horizontal Projection	0.969	0.183	0.148
Volume	0.968	0.08	-0.012
Area	0.938	0.099	-0.324
unevenness	0.76	-0.648	0.027
Variance proportion	85.65	9.85	3.03
Environmental Variables			
Lakes distance	0.963	0.103	-0.25
Rivers distance	0.885	0.425	0.189
Caatinga cover	0.799	-0.594	0.092
Variance proportion	78.30	18.15	3.56
Anthropogenic Variables			
Sheep density	0.981	0.008	0.079
Cattle density	0.807	-0.508	0.27
Goats density	0.753	0.516	-0.399
Human demographic density	0.014	0.929	0.369
Variance proportion	54.51	34.70	9.36

Model selection analysis for richness and species composition

Among all candidate models, the only one selected to explain the richness of bats was the explanatory variable related to cave (CAVE_PCA1) (Δ AIC <2) (table 5). The simple cave model retained 56.96% of the variance explained by all models. The four models with significant regressions retained 87.71% of the information. CAVE_PCA1 was present in all models, and the information added by the other variables was small and not significant (Anthropogenic: POP_PCA1 - std coeff = 0.240, p = 0.296; POP_PCA2 - std coeff = -0185; p = 0.428 and environmental - std coeff = -0076; p = 0.75).

Table 9. Model selection by Akaike Information Criteria (Δ AIC ≤2) of all candidate models for explaining bat richness. Akaike weight is provided by maximum likelihood estimates for all models (ω AIC). The R^2 in bold belongs to significant regressions and ω AIC cum is the cumulative Akaike weight. We used de AICc for model ranking. This is one correction used for small samples.

Models	**R^2**	**AICc**	**ΔAICc**	**ωAICc**	**ω AICc cum**
Cave (Cave_PCA1)	**0.49**	52.819	0	56.96	56.96
Cave + Anthropogenic (POP_PCA 1)	**0.54**	55.663	2.844	13.74	70.70
Cave + Anthropogenic (POP_PCA 2)	**0.52**	56.295	3.476	10.02	80.72
Cave + Environmental (ENV_PCA1)	**0.49**	57.015	4.196	6.99	87.71
Null model	0.00	58.033	5.214	4.20	91.91
Cave + Anthropogenic (PCA 1 + PCA 2)	0.58	60.143	7.324	1.46	93.37
Latitude	0.07	60.614	7.795	1.16	94.52
Cave + Environmental + Anthropogenic (PCA 1)	0.55	60.965	8.146	0.97	95.49
Cave + Environmental + Anthropogenic (PCA 2)	0.55	61.039	8.22	0.93	96.43
Longitude	0.03	61.093	8.274	0.91	97.34
Environmental	0.01	61.378	8.559	0.79	98.13
Anthropogenic (Cattle, Sheep and Goats) PCA 1	0.01	61.39	8.571	0.78	98.91
Anthropogenic (Human demographic density) PCA 2	0.00	61.492	8.673	0.75	99.66
Environmental + Anthropogenic (PCA 1)	0.05	65.161	12.342	0.12	99.78
Environmental + Anthropogenic (PCA 2)	0.01	65.71	12.891	0.09	99.87
Anthropogenic (all) PCA 1 + PCA 2	0.01	65.715	12.896	0.09	99.96
Cave + Environmental + Anthropogenic (PCA 1 + PCA 2)	0.58	67.57	14.751	0.04	99.99
Environmental + Anthropogenic (PCA 1 + PCA 2)	0.06	70.632	17.813	0.01	100.00

Among all candidate models, none had a better fit than the null model for composition represented in axis I of NMDS ordination (Table 6). However, the second axis (Table 7) showed a strong spatial pattern, with a pronounced effect of longitude (ω AICc = 34.87) and latitude (ω AICc = 26.35). Another selected model (Δ AIC ≤ 2) was the effect of population density (POP_PCA1 + POP_PCA2) with an AIC ω = 25.4. These three models together explained 86.62% of the variation.

Table 10. Model selection by Akaike criteria (Δ AIC ≤ 2) of all candidate models for explain bat composition (Axis 1of NMDS ordination). Akaike weight is provided by maximum likelihood estimates for all models (ω AIC). The R^2 in bold is significative regressions and ω AIC cum is the cumulative Akaike weight. We used de AICc for model ranking. This is one correction used for small samples.

Models	**R^2**	**AIC**	**ΔAIC**	**ω AICc**	**ω AICc cum**
Null model	0.00	1.102	0	27.33	27.33
Cave	0.23	1.159	0.057	26.56	53.90
Longitude	0.23	3.896	2.794	6.76	60.66
Latitude	0.03	4.206	3.104	5.79	66.45
Anthropogenic (Cattle, sheep and goats) PCA 1	0.02	4.31	3.208	5.50	71.94
Anthropogenic (Human demographic density) PCA 2	0.02	4.328	3.226	5.45	77.39
Environmental	0.01	4.418	3.316	5.21	82.60
Cave + Environmental	0.28	4.57	3.468	4.83	87.42
Environmental + Anthropogenic (PCA 1)	0.09	4.974	3.872	3.94	91.37
Cave + Anthropogenic (PCA 1)	0.23	5.457	4.355	3.10	94.47
Cave + Anthropogenic (PCA 2)	0.23	5.475	4.373	3.07	97.54
Anthropogenic (all) PCA 1 + PCA 2	0.04	8.398	7.296	0.71	98.25
Environmental + Anthropogenic (PCA 2)	0.02	8.611	7.509	0.64	98.89
Cave + Environmental + Anthropogenic (PCA 1)	0.34	9.003	7.901	0.53	99.41
Cave + Environmental + Anthropogenic (PCA 2)	0.29	10.03	8.926	0.32	99.73
Cave + Anthropogenic (PCA 1 + PCA 2)	0.23	11.01	9.908	0.19	99.92
Environmental + Anthropogenic (PCA 1 + PCA 2)	0.09	13.28	12.182	0.06	99.98
Cave + Environmental + Anthropogenic (PCA 1 + PCA 2)	0.37	15.83	14.731	0.02	100.00

Table 11. Model selection by Akaike criteria (Δ AIC ≤2) of all candidate models for explain bat composition (**Axis 2** of NMDS ordination). Akaike weight is provided by maximum likelihood estimates for all models (ω AIC). The R^2 in bold is significative regressions and ω AIC cum is the cumulative Akaike weight. We used de AICc for model ranking. This is one correction used for small samples.

Models	R^2	**AICc**	**ΔAICc**	**ω AICc**	**ω AICc cum**
Longitude	**0.557**	-9.214	0	34.87	34.87
Latitude	**0.538**	-8.654	0.56	26.35	61.23
Anthropogenic (all) PCA 1 + PCA 2	**0.667**	-8.58	0.634	25.40	86.62
Anthropogenic (Human demographic density) PCA 2	**0.334**	-3.909	5.305	2.46	89.08
Anthropogenic (Cattle, Sheep and Goats) PCA 1	**0.333**	-3.886	5.328	2.43	91.51
Environmental + Anthropogenic (PCA 1 + PCA 2)	**0.821**	-3.272	5.942	1.79	93.30
Cave + Anthropogenic (PCA 1 + PCA 2)	**0.667**	-3.009	6.205	1.57	94.86
Environmental	0.284	-2.961	6.253	1.53	96.39
Environmental + Anthropogenic (PCA 2)	**0.672**	-2.116	7.098	1.00	97.40
null model	0	-2.091	7.123	0.99	98.39
Environmental + Anthropogenic (PCA 1)	0.376	-0.426	8.788	0.43	98.82
Cave + Anthropogenic (PCA 1)	0.35	0.101	9.315	0.33	99.15
Cave + Anthropogenic (PCA 2)	0.347	0.167	9.381	0.32	99.47
Cave + Environmental	0.305	0.974	10.188	0.21	99.68
Cave	0.015	1.372	10.586	0.18	99.86
Cave + Environmental + Anthropogenic (PCA 2)	0.673	3.454	12.668	0.06	99.92
Cave + Environmental + Anthropogenic (PCA 1 + PCA 2)	**0.821**	4.138	13.352	0.04	99.96
Cave + Environmental + Anthropogenic (PCA 1)	0.403	4.564	13.778	0.04	100.00

DISCUSSION

Richness and abundance at a Landscape scale

The structure of cave bat communities in the studied cave systems were stronger affected by anthropogenic variables (Human and domestic animal densities) and by the spatial position (specific conditions of each cave system) instead of high a Caatinga cover, and closeness of water bodies (river and lakes). The effects of these variables were observed in the presence of specific species that were found only in one particular cave and in no other cave, and in differences in the abundance (colony sizes) of shared species between the cave systems. these results are not consisten with the proposed integral landscape hypothesis.

The models that explained better the community composition were related to spatial variables (Table 11). The distance between the FFNP and FGCS are enough to say that they are independent and differentiated karstic cave systems. Because of this spatial distance, the cave systems are located in areas with different specific landscape conditions that may have influence in the composition of the cave-bat communities. For example, the analyzed buffers of the four surveyed caves in the FFNP were located in areas of >95% of Caatinga coverage, very distant from water bodies and with low or no values of anthropogenic variables, less heterogeneous if compared to FGCS. In the other hand, caves in the FGCS had buffers composed with anthropogenic and environmental variables that ranged from relatively high to low quantitative values (Supplementary Material 4). The FGCS contains patches of Caatinga, agricultural plantations, small towns, and is crossed by the perennial Apodí River, this compounds creates a much more heterogeneous landscape than FFNP.

We found that FGCS were more bat diverse than the FFNP and this might be explained by several reasons. If FGCS is more heterogeneous than FFNP, a differentiated richness can be explained by the habitat heterogeneity hypothesis (HHH). The "habitat heterogeneity hypothesis" states that an increase in the number of habitats and/or an increase in their structural complexity, at a different scale, leads to an increased species diversity (MacArthur and MacArthur, 1961; MacArthur and Wilson, 1967; Connor and McCoy, 1979). A larger number of habitats practically means a larger number of foraging areas (exploitable niches) by different bat species. Nonetheless, the difference in the richness between this two systems may be explained by the fact that the number of sampled caves were higher in FGCS (n=8) than FFNP (n=4) causing a higher richness due to sampling differences.

Anthropogenic variables (Cattle, Sheep, Goat and human densities) was the second model with significant effects on the structure of the communities. These was observed on differences in the abundance (colony sizes) of shared species between the two cave systems. The abundance of

Glossophaga soricina, *Tonatia bidens*, *Desmodus rotundus*, and *Artibeus planirostris* were responsible for 46.8% of the dissimilarity between FGCS and FFNP. *G. soricina* (15.59% contrib.) and *T. bidens* (10.57% contrib.) had a higher abundance in FFS in relation to FGS, and conversely, *D. rotundus* and *A. planirostris* were more abundant in FGCS than in FFNP.

Even though this species were found in both systems, the differences in their abundances may be explained, in some extent, by the availability of food resources between the systems that are influenced by the degree of integrity of the landscape (foraging sites) around their roost (caves). When comparing the two cave systems we found differences in the landscape and anthropogenic variable were FFNP were more integral (high percentages of Caatinga coverage and low values anthropogenic variables), while FGCS is more disturbed with relative lower Caatinga cover and with human settlements and livestock activities. This landscape differences might favor a hiher abundance of species much more generalist or flexible to human disturbance on the landscape.

For example, the colonies of the common vampire bat *Desmodus rotundus* and the fruit-eating *Artibeus planirostris* were bigger in FGCS than in FFNP. These bigger colonies may be related to a stable and abundant food resource availability related to human activities such as high concentration of livestock (blood) for vampire bats and human-planted trees and plants producing fruits for frugivore bats. *D.rotundus* feeds on mammal blood and its known as an opportunistic species with a big adaptive potential (Reid, 1997, Sekiama *et al.*, 2013) were the introduction of livestock by humans had cause a significant increase in their populations. The Furna do Urubu and Caverna Boa contained the biggest colonies of more than 100 individuals. This caves had highest scores of cattle, sheep and goat densities, which may explain the high abundances of *D. rotundus* in these two caves. In a karstic area in Alto Vale do rio Ribeira, in Southeastern Brazil, Trajano (1996) found that caves, no matter the size, that were close to areas were livestock was abundant nearby, colonies of *D. rotundus* were bigger and remain stable due to year round blood resource.

The case of *A. planirostris* may also be explained by the high values of human population density due to the availability of fruits in FGS, especially close to towns and plantations. We saw inside caves, where *A. planirostris* occurred, seedlings under colonies roost of different species of plants. Seedlings that we were able to identify belonged to *Copernicia prunifera* (Carnaúba), *Licania* sp. (Oiticica) and *Anacardium* sp (Cajú), all native plants and the exotic *Prosopsis juiliflora* (Algaroba).

These species of plants has a human use and very common close to houses and rivers (Peters, 2011). Fruits of *Licania* sp. can be used for extraction of natural colorants, biodiesel production and as an ornamental tree. *C. prunifera* is used for wax, fruits and pith are eaten, the leaves are variously employed and wood is used in buildings (Johnson, 1972). Big plantations of *C. prunifera* are common on FFS landscape. *A.planisrotris* is a ubiquitous fruit-eating bat and a very flexible bat both in foraging habitats and roost selection that it is present from undisturbed areas to altered and urban areas (Hollis, 2005; Reis *et al*., 2013). The specie may have an important role in the dispersion of seeds of mentioned plants above but we suggest studying more deeply these bat-plant interactions due to its ecological and economical importance for the region.

The FGCS registered four species that were restricted to specific caves, with single colonies that did not occurred in other systems. This pattern was present in two caves: in Gruta dos Três Lagos (*Lonchorhina aurita*, *Trachops cirrhosus*, *Micronycteris* sp.) and Furna do Urubu (*Pteronotus gymnonotus*). These two caves shared common characteristics; they were close to the Apodi river with about 195 m of the Gruta dos Três Lagos and at about 1029 m of the Furna do Urubu. The presence of this river close to their roost may be an important factor that those species selected these caves as a roost.

T. cirrhosus is known to forage close to water looking for prey (*e.g.* fogs, lizards, birds,) associated to this habitats (Barkley *et al.,* 1981; Cramer *et al.,* 2001; Rodrigues *et al.,* 2014*)* and the short distance to this aquatic habitats may be a reason for this species to occur in the Gruta dos Três Lagos. Furthermore, *T. cirrhosus* is a little more flexible in roost selection and has been found roosting in caves, hallow trees, and abandoned buildings (Cramer *et al.,* 2001, Reis *et al,* 2007). Instead, *L. aurita* is a species that only roost in caves and mines (Lassieur and Wilson, 1989; Reid, 2007; dos Reis *et al.,* 2013), thus, this cave is critical for the maintenance of this only known colony in the State.

Richness and abundance at a local scale

We found that the simple model of cave variables retained 56.96% of the variance explained by all models being consistent with the proposed cave-size hypothesis. This demonstrates, as expected, that bigger caves homes higher bat richness than smaller ones. Several authors had found that the cave size was used to explain maximum richness on cave systems in particular areas explained by the species-area relationship. Brunet and Medellín (2001) found a significant positive correlation between the logarithm of species richness and the logarithm of cave surface area in 20 caves in central Mexico. Authors attribute the high bat richness to roost site diversity indicated by spatial variation in relative humidity and presence of conical depressions (bell holes) in cave ceilings explained by the species–area relationship.

In eastern China, Niu *et al.* (2007) similarly found that bat species distributions were highly dependent on the type and size of roost, with large caves supporting unusually high species richness and abundances. In Madagascar, Cardiff (2008) surveyed 25 caves in the Ankarana National Park and demonstrated that caves that were longer, more complex, with larger entrances, with entrances at lower elevation, and with less temporal variation in temperature had significantly higher species richness. Moreover, Luo *et al*. (2013) found in 255 subterranean cavities in central and eastern China that the bat species richness was positively correlated with cave size and negatively correlated with human disturbance.

Even though that the multiple cave dimensions that we used in our models showed that these variables explain our richness, we did not collected data such as preferred microclimatics of the registered species nor internal geomorphological complexity in caves. Brunet and Medellín (2001), and Cardiff (2008), collected roost data such as microclimatic (*e.g.* relative humidity and temperature) and internal complexity (cave geomorphology) that might complement the observed richness patterns with the species area relationship. Nevertheless, the methodology applied in this study shows a first step for a trend that apparently it is addressing to the species-area relationship.

We strongly recommend collecting internal roost variables in order to understand better the patterns herein elucidated.

As bats selects its roost based on species-specific microclimatic preferences, like temperature and humidity (Ávila-Flores and Medellín, 2004), therefore, a big cave have a high probability to offer different microhabitats in a bigger gradient so multispecies association can occur. In our study we can metion that

In the other hand, we found that cave size did not had strong effects of the abundance on the registered species. Several factors might be involved that explain this finding. The existence of other factors such as species biology and their roosting ecology might constrain species abundances and thus the colony sizes inside caves. The roosting ecology of bats is eventually moderated by constrains of phylogenetic inertia and compromise of opposing selective pressures derived from both roost and non-roost sources (Kunz and Lumsden, 2003). Colony sizes are known to be regulated by biological traits of each species like mating systems (McCraken and Wilkinson, 2000) that may reflect the social structure of a particular species, such as harem formations or monogamous pairs (Kunz, 1982), by food availability (Hristov *et al*., 2010), and by human disturbances (Betke *et al*, 2008).

In conclusion, we found that the composition of the cave-dwelling bat communities between FGCS and FFNP were different in colony sizes (abundance), species composition and richness. FGCS were richer in bats species (14 spp.) than FFNP (10 spp.). FFNP contained the cave with the highest richness of the study (Furna Feia cave = 10 spp.) and that the other surveyed caves within the national park contained sub-sets of communities of the Furna Feia cave.

At a landscape scale, the analyses that we presented herein showed that the composition of cave bat communities within de 1km buffer around caves were affected by variables other than environmental ones. Our results were not consistent with the proposed Integral Landscape Hypothesis where caves with high Caatinga cover and presence of water bodies around caves will contain rich and abundant bat communities. Instead, models that contained spatial and anthropogenic variables such as the human and domestic animal population densities helped to explain better the composition of cave-bat community than environmental variables between the two cave systems. At a local scale, our results were consistent with the cave-size hypothesis as we found in our models that bigger caves contained higher bat richness.

Final considerations

We have to take into account that the observed patterns are just in a small window of time and that we have time-differentiated data between landscape variables that are information taken databases and the bat data collection. The deciduous characteristic of Caatinga and its strong seasonality may have wider influences on richness and community composition that are not perceived herein. Due to the little similarity of the approach of this study with other studies, aspects to improve in the methodology are necessary in order to strengthen the approach. We recommend that analysis should be done taking into account the dry and wet season in order to find temporal patterns on the cave bat communities (species turnover), to increase the number of sampling units (caves) and amplifying buffers (>1km) around the cavities taking into account all home ranges of most cave species

We found that the approach used in this study help us to see in a wider perspective by taking into account cave system instead of one or few caves that can be used as a tool for recommendation for conservation actions in areas with multiple caves. Luckily, caves in Furna Feia National Park are protected by maximum protection category in Brazil. Nonetheless, conservation actions in the Felipe Guerra Cave System is urgent as the landscape data showed higher values of anthropogenic variables with a probable increase in the last years. This cave system homes the 87.5% (14 spp.) of the cave-dwelling bat diversity registered in the study and contains the highest number of underground cavities of Rio Grande do Norte. If conservation actions are not excuted rapidly, the chiropterological and speleological heritage will be gradually lost.

We encourage to focus on studying important caves like Furna do Urubu, Gruta da Carrapateira, Gruta dos Três Lagos and Caverna Boa, due to their chiropterological relevance since they home high richness of multispecies associations, unique colonies and vulnerable species. We highly recommend punctual conservation action into these above-mentioned caves that will assure the protection of populations of cave-bats in the Caatinga landscape.

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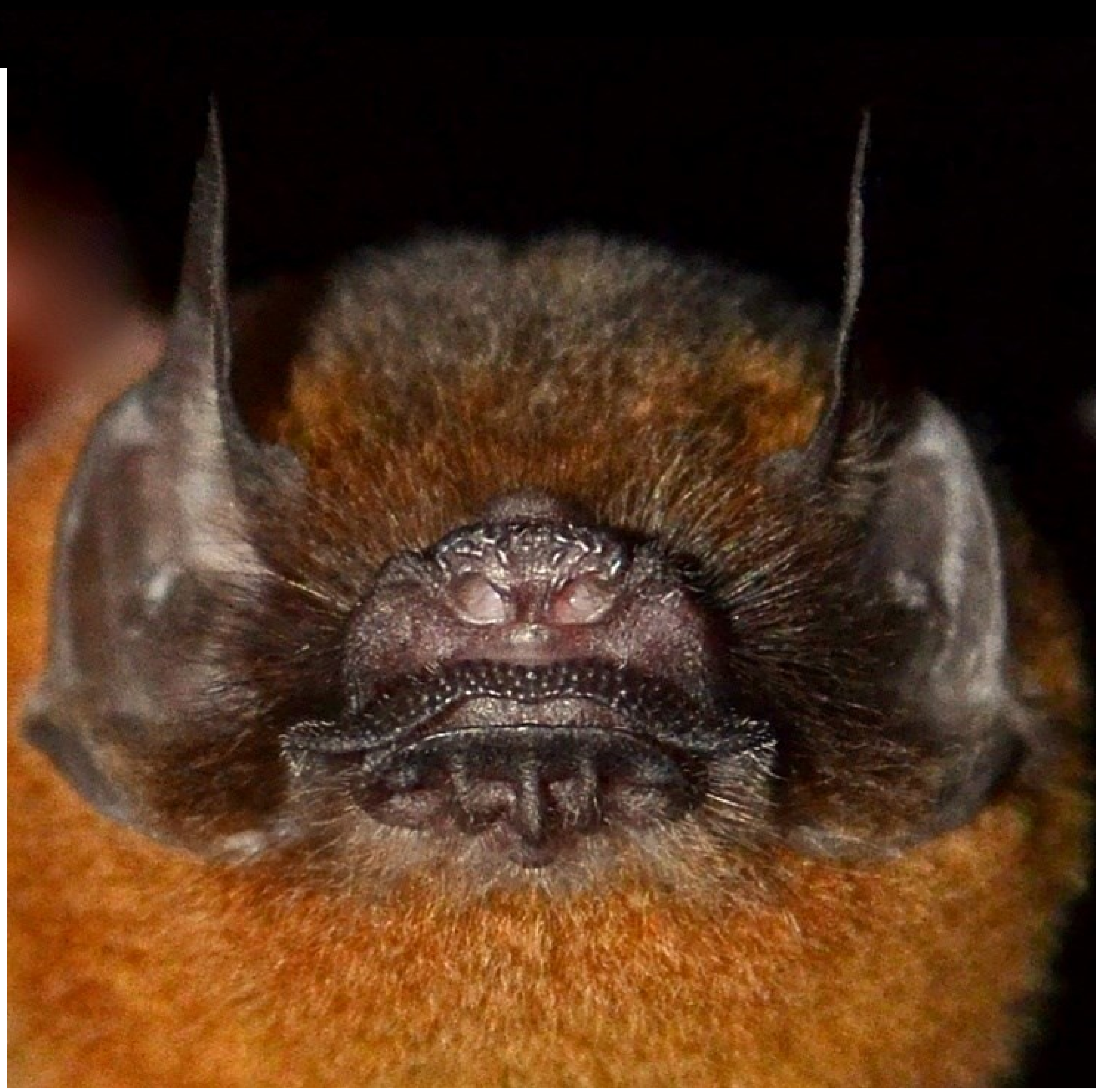
Chapter 3

Important caves for the conservation of bats in the Caatinga of Rio Grande do Norte, Brazil



Important caves for the conservation of bats in the Caatinga of Rio Grande do Norte, Brazil

INTRODUCTION

In November 7 of 2008 it was published the Decree 6640 that changed drastically the protection of all underground cavities in Brazil. Prior to its publication, all Brazilian caves were protected so that the influence areas and the use of the cavities should occur in conditions that ensure their physical integrity and the maintenance of its ecological balance. Nowadays, the Decree 6640 considers for full protection only caves categorized as "maximum relevance". A “maximum relevance” cave is determine by its biological, ecological, hydrological, geological, paleontological, socio-economical, scenic and archeological attributes. All the remaining cavities are classified as "high, medium and low-grade" and may be subject to irreversible negative impacts upon environmental licensing. Thus, subpopulations of species dependent of caves can be locally extinct by the destruction of their shelters (Aguiar *et al*., 2006).

The reduction of protection and the increased exploitation of Brazilian caves is a real threat not only to the conservation of bats that make use of these types of structures in Brazil, but also to the rich and unknown ecosystems associated with the group (Bernard *et al*., 2012). Bats are key to the maintenance of cave ecosystems since they are responsible for the increase of organic matter through guano deposition (Gnaspini and Trajano, 2000). This guano deposition sustains complex invertebrate communities, including endemic species, due to the general lack of food in caves (Ferreira and Martins, 1998; Gnaspini and Trajano, 2000; Ferreira *et al*., 2010) and communities can perish if the input of guano falls below certain limits due to reduction of colony sizes caused by roost disturbance (Trajano, 1995).

Rio Grande do Norte (RN) is currently fourth in number of caves (949) in Brazil (CECAV / ICMBio, 2015) but unfortunately suffers conflicts with its speleological heritage that involves several anthropogenic activities. Activities such as mining in areas authorized by the DNPM (National Department of Mineral Production of Brazil), exploration and extraction of oil (petroleum), unorganized rural settlements, agriculture expansion and disorderly cave visitation are some of the several direct and indirect impacts that underground cavities and its associated fauna suffers in the State (Cruz *et al*, 2010).

With the creation of the Furna Feia National Park, the scenario of conservation of underground cavities changed positively in RN. Based on technical studies conducted from 2002 to 2011 and with a broad support of society, the establishment of this national park resulted in a significant expansion of the conservation of the Caatinga and the speleological heritage in RN and Brazil (Bento *et al*., 2013).

However, the area with the highest concentration of State caves, with 496 registered caves (CECAV / ICMBio, 2015) in the municipalities of Felipe Guerra, Governador Dix-Sept Rosado and Caraúbas named as Felipe Guerra Cave System (FGCS), remains completely unprotected. The area features the speleological heritage with a great relevance in the RN. The FGCS contains the largest concentration of caves in RN (341 cavities) which is the 52.3% of the known underground cavities for the State (Bento *et al*., 2015). This karstic area is about to be proposed to the correspondent Brazilian environmental institutions as an Environmental Protection Area (APA acronym in Portuguese) under the name APA Pedra Abelha (see Bento *et al*., 2015). The proposed protection area is about 80 560 hectares which possess a speleological heritage of extreme importance

IMPORTANT CAVES FOR THE CONSERVATION OF CAVE-BATS IN RIO GRANDE DO NORTE

Based on the results of this investigation and the current scenario that affects unprotected caves in the State, we pinpointed caves considered priorities for conservation. These priorities where based on caves containing high relative richness, unusual big colonies, single registered colonies for the State, as well the occurrence of rare or threatened species of bats. We describe and discuss some of the most relevant chiropterological attributes of three caves in the municipality of

Felipe Guerra Cave System (Furna da Carrapateira, Gruta dos Três Lagos, Furna do Urubu) and one cave in Mossoró (Gruta dos Trinta).

Gruta dos Trinta

The Gruta dos Trinta in Mossoró is a cave in a vulnerable situation due to its location close to the urban area of Mossoró city. This city is the second biggest city of the State with a population of about 288 162 people (IBGE, 2015) with an evident horizontal expansion of its urban area that threatens the integrity of the cave. Actually, the cave is located about 5 km of the peripheral limits of the city (Fig 1). The thrash and ropes found inside evidences the uncontrolled visitation by local people for adventure-recreational activities.

Despite that the cave had a low relative bat richness (5 spp.) we found big colonies of phyllostomid nectar-feeding bats. This cave homed the two biggest colonies of nectarivorous bats found in the study. A big colony of *Glossophaga soricina* of more than 500 individuals (category 4) and the only known colony of *Lonchophylla* sp. (category 3) were found occupying the deepest part of the cave. Nectar feeding bats of the Phyllostomid family are known to pollinate flowers of about 360 species in 159 genera and 44 families of plants in the New World (Fleming *et al.,* 2009). Moreover, nectarivorous bats are very important pollinators of Agavaceae and Cactaceae species of economic and ecological importance in arid and semi-arid environments (Kunz *et al*., 2011). The disturbance through uncontrolled visitation may cause the abandonment of the colonies of the cave compromising the ecological services that these species provide for the region.

This cave also homes a colony of *N. macrourus* a vulnerable species included in National Official List of Endangered Fauna of Brazil (MMA/ICMBio, 2014). Besides being a strictly cave-dwelling bat, it inhabits only in deep caves, especially in hot and humid ones, and its occurrence may be limited by the availability of this kind of caves (Reis *et al*., 2007). As an insectivorous species, has a high frequency echolocation and it is hardly captured by mist nets, so is hardly detected. The estimate of the colony was not achieved in its totality and should be further studied to assess a good estimation of the colony in the cave. Homing a vulnerable species and big colonies of nectarivorous bats, the Gruta do Trinta is a cave that should be priority of conservation in the State.

Furna da Carrapateira

This cave had the greatest richness in species and trophic guilds recorded in the FGCS. The high diversity of guilds suggest that the cavity offers roost to a wide range of functional groups that are important to epigean (surface) ecosystems where the cave is located. This high richness inside this cave allow resident colonies of bats of the different trophic guilds to provide important ecosystem services such as seed dispersal, pollination, and population control of vertebrates and invertebrates (see Kunz, 2011).

For example, the cave contains a colony of the frugivore *Artibeus planirostris* of approximately 60-80 individuals. The occurrence of this species in the landscape is important for the seed dispersal of native plants, including those of human-use like carnaúba (*Copernicia prunifera*) and oiticica (*Licania* sp.). We also observed seeds and seedlings of these species inside the cave in passages and galleries as well under roosting colonies. Another example is the register of *Chrotopterus auritus* using this cave resulting in the first record of this species for the State. This species is considered an indicator species of intact and healthy environments because it usually dwells in undisturbed forests (Medellin, 1989; Reis *et al*., 2007). Still, the FGCS, where the Furna da Carrapateira cave is located, is the system with more anthropogenic impact was observed if compared with the protected FFNP. It is unknown if this species may be less sensible to this kind of landscape in the Caatinga or if the species is very vulnerable particularly in the area with a risk of a possible abandonment of the cave.

Gruta dos Três Lagos

The grotto is another important cave in the FGCS. This cave, alongside with the Furna da Carrapateira, homed the highest richness (7 spp.) of the FGCS (Fig. 4). We also reported a higher richness than the reported by Coelho (2006). The cave provided day-roost for three species of gleaning-animalivorous bats with no record of colonies in other caves. The species are *Lonchorhina* *aurita, Trachops cirrhosus* and unidentified species of the genus *Micronycteris.* It is worth to mention that this cave home the only known colony in the State of *L. aurita*, species considered vulnerable in the National Official List of Endangered Fauna of Brazil (2014).

This cave might be the most vulnerable of the FGCS. The Gruta dos Três Lagos contains internal water with three interconnected clear water pools and is located very close (~ 1km) from human settlements, such as the Felipe Guerra city with a population of about 6000 people. Due to this particularity, it receives constant visitation of the local people for swimming and other recreational activities that causes disturbance to the bat colonies. Thrash and candles on entrances and inside was observed during survey. This visitation may cause the abandonment of this single known colony of *L. aurita* in the State. Coelho (2006) reported the occurrence of *L. aurita* and *T. cirrhosus* in the cave but numbers of individuals was not reported in their study, thus, we could not know if the colony size varied or decreased during the last years.

Furna do Urubu

The Furna do Urubu is a very particular cave with the characteristics of a "hot cave". The term "hot cave" according Ladle *et al*. (2012) are underground cavities in the Neotropics that are characterized by high ambient temperatures generated by the body heat of high densities of certain species of bats roosting in poor ventilated chambers. Many of these species have limited geographic distribution and some occur only in hot cave environment. In addition to bats, stable microclimate and abundant bat guano provides shelter and food for a high diversity of invertebrates (Trajano, 1995; Gnaspini and Trajano, 2000).

A colony of about 10 000 individuals of the aerial insectivore *Pteronotus gymnonotus* is the species found in one chamber of the Furna Urubu. It is the only cave of this kind known in the State so far. The mormoopid bats of the *Pteronotus* genus are known to form colony of thousands of individuals and roosting in large rooms with little ventilation (Rodríguez-Durán, 2009). The formation of "hot caves" requires a minimum number of individuals to create the characteristic microclimate and a decrease in the abundance of less than the minimum critical number of bats for a particular camera could threaten the viability of the colony and the associated invertebrate communities (Rodríguez-Durán, 2009; Ladle *et al.*, 2012).

Aerial insectivorous bats, such as *P. gymnonotus,* have an immense capability of nightly insect consumption with an important role in the control of arthropod populations (Kunz *et al.,* 2011). They are known the be controllers of agricultural pests like beetles, moths, mosquitos and midges (Boyles *et* al., 2011). This colony of about 10 000 individuals of *P. gymnonotus* provides an immense benefit to local agricultural crops in Felipe Guerra and adjacent areas through this control of arthropod populations. If disturbance of this roost plus the loss of feeding areas through deforestation will likely cause a reduction in the size of the colony or the total abandonment of the cave, causing a potential reduction in the ecological and environmental services insectivorous bats provides to the region.

Final Considerations

The poor knowledge of cave-dwelling bat communities in RN and in the Caatinga creates difficulties to achieve accurate conservation actions. Areas such as the Felipe Guerra Cave System contains 87.5% (14 spp.) of the total richness registered in the three surveyed areas. We believed that this information will be important to denote the importance of these cavities for the local cave bat assemblages and might provide strong justification for the establishment of a conservation unity or conservation actions in the area.

Regardless of whether it is stablished any conservation unity on a short future, we urge for conservation actions starting with strict visitation control to prevent the colonies disturbance for four above-mentioned caves. If these four caves are submitted to protection, they will protect the 94% (15 spp.) of the total richness (16 spp.) of the registered cave-dwelling bat communities in Rio Grande do Norte. We believe that the study of more caves, due to the high number of underground cavities that occur in state, will yield some new species to the overall diversity of cave-dwelling bats in Rio Grande do Norte.

Additionally, we encourage investigating ecological aspects of those communities such as structure, species turnover, temporal changes of richness or colony sizes that could respond questions of how bats face strong seasonal changes in weather and food availability in semi-arid environments like the Caatinga. This study brought a first insight of the cave-dwelling bat communities that occur in a poorly studied state but that possess a unique landscape with a potential to be an important reference of chiropterology and speleology in Brazil.

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SUPLEMENTARY MATERIAL 1

Species, trophic guilds, occurrence, colony sizes and conservation status of Cave-Dwelling bats in the Caatinga of Rio Grande do Norte registered in thirteen caves from June to October, 2015. Caves are Furna do Urubu (FU); Cavernas Boa (CB); Gruta da Carrapateira (GC); Gruta dos Três Lagos (GTL), Caverna do Arapuá (CV); Caverna do Lajedo Grande (CLG); Gruta Capoeira de João Carlos (GCJC); Gruta Casa de Homens (GCH); Furna Feia (FF); Furna Nova (FN); Caverna Porco do Mato (COM); Caverna da Pedra Lisa (CPL) and Gruta dos Trinta. Conservation status was taken from the International Union for the Conservation of Nature, and Instituto Chico Mendes de Conservação da Biodiverside/ Ministerio de Meioambiente.

Family / Subfamily / *Species*	Trophic Guild	Colony Sizes	Cave occurrence	Conservation Status	
				IUCN	ICMBio/MMA
Emballonuridae					
Peropteryx macrotis (Wagner, 1843)	Aerial Insectivorous	1, 2	FU, GC,GLT, CLG, CCJC, GCH, FF, FN, CPL, CPM, GT	LC	LC
Phyllostomidae					
Desmodontinae					
Desmodus rotundus (E.Geoffroy, 1818)	Sanguivorous	2, 3, 4	FU, CB, GC, GTL, CLG, GCH, FF , FN, GT	LC	LC
Diphylla ecaudata Spix, 1823	Sanguivorous	1, 2, 3	FU,CB, GC, GTL, CA, CLG, CCJC, GCH, FF, FN, CPM	LC	LC
Glossophaginae					
Glossophaga soricina (Pallas, 1766)	Nectarivorous	2, 3, 4	FC, CCJC, FF, FN, CPL, CPM, GT	LC	LC
Lonchophyllinae					
Lonchophylla sp. Thomas, 1903	Nectarivorous	3	GT	-	-
Phyllostominae					
Chrotopterus auritus (Peters, 1856)	Gleaning Animalivorous	2	FC	LC	LC
Lonchorhina aurita Tomes, 1863	Gleaning Animalivorous	2	GTL	LC	VU

Micronycteris sp. Gray, 1866	Gleaning Animalivorous	2	GTL	-	-
Phyllostomus discolor (Wagner, 1843)	Omnivorous	2, 5	CB, FF, FN	LC	LC
Tonatia bidens (Spix, 1823)	Gleaning Animalivorous	1, 2	FU, CB, CCJC, GCH, FF, FN, CPL, CPM	DD	LC
Trachops cirrhosus (Spix, 1823)	Gleaning Animalivorous	2	GTL	LC	LC
Stenodermatinae					
Artibeus lituratus (Olfers, 1818)	Frugivorous	1	FF	LC	LC
Artibeus planirostris (Spix, 1823)	Frugivorous	1, 2, 3	FU,CB, GC, CLG, CCJC, FF, CPM	LC	LC
Mormoopidae					
Pteronotus gymnonotus (Wagner, 1843)	Aerial Insectivorous	6	FU	LC	LC
Furipteridae					
Furipterus horrens (Cuvier, 1828)	Aerial Insectivorous	2, 3	GC, GTL, CA, CCJC, GCH, FF, CPL, CPM	LC	VU
Natalidae					
Natalus macrourus (Gervais, 1856)	Aerial Insectivorous	2, 3	CB, FF, FN, GT	NT	VU

SUPPLEMENTARY MATERIAL 2

Face detail photos of species of bats captured in thirteen caves during June to November 2015 in the Caatinga of Rio Grande do Norte, Brazil. Aerial Insectivores are **a)** *Peropteryx macrotis*, **b)** *Pteronotus gymnonotus,* **c)** *Natalus macrourus*, **d)** *Furipterus horrens*. Gleaning Animalivorous are **e)** *Tonatia bidens*, **f)** *Lonchorhina aurita*, **g**) *Micronycteris* sp., **h)** *Chrotopterus auritus*, **i)** *Trachops cirrhosus*. Sanguinivorous are **j)** *Diphylla ecaudata,* **k)** *Desmodus rotundus*. Nectarivorous are **l)** *Glossophaga soricina*, **m)** *Lonchophylla* sp. Frugivorous are **n)** *Artibeus lituratus,* **o)** *Artibeus planirostris* and Omnivorous is **p)** *Phyllostomus discolor*.

SUPPLEMENTARY MATERIAL 3

Spearman correlation of NMDS ordination axes with the ranking abundance of each bat species sampled in 13 caves in RN State, Brazil

Species	Axis I	Axis II
Natalus macrourus (Gervais, 1856)	**0.771**	0.372
Desmodus rotundus (E.Geoffroy, 1818)	**0.629**	**-0.567**
Phyllostomus discolor (Wagner, 1843)	**0.615**	0.078
Furipterus horrens (Cuvier, 1828)	**-0.645**	0.176
Glossophaga soricina (Pallas, 1766)	0.304	**0.886**
Diphylla ecaudata Spix, 1823	0.299	**-0.811**
Pteronotus gymnonotus (Wagner, 1843)	0.154	**-0.463**
Lonchophylla sp. Thomas, 1906	0.386	**0.463**
Artibeus planirostris (Spix, 1823)	0.394	-0.219
Artibeus lituratus (Olfers, 1818)	0.231	0.231
Tonatia bidens (Spix, 1823)	0.217	0.328
Peropteryx macrotis (Wagner, 1843)	0.201	0.344
Lonchorhina aurita Tomes, 1863	-0.386	-0.386
Micronycteris sp. Gray, 1866	-0.386	-0.386
Trachops cirrhosus (Spix, 1823)	-0.386	-0.386
Chrotopterus auritus (Peters, 1856)	0	0

SUPLEMENTARY MATERIAL 4

Spearman correlation of NMDS ordination axes with the explanatory variables (cave, environmental and population density) in 13 caves in RN State, Brazil.

Group	Variable	Axis I	Axis II
Cave	Linear development	**0.742**	0.088
Cave	Horizontal Projection	**0.692**	0.181
Cave	Area	**0.61**	0.071
Cave	Volume	**0.582**	-0.121
Cave	unevenness	0.448	-0.341
Spatial	Latitude	-0.005	**0.775**
Spatial	Longitude	0.247	**0.742**
Environmental	Caatinga cover	-0.147	0.492
Environmental	Lakes distance	-0.203	0.44
Environmental	rivers distance	-0.033	0.396
Populations Density	Cattle density	-0.151	-0.462
Populations Density	sheep density	-0.12	**-0.564**
Populations Density	goats density	-0.14	**-0.609**
Populations Density	human demographic density	0.056	**-0.709**

SUPLEMENTARY MATERIAL 5

Raw data used for model analysis of thirteen caves in the Caatinga of Rio Grande do Norte. Bat richness per cave **(Spp)**. *Spatial variables* are Latitude (**Lat**) and Longitude (**Long**). *Cave variables* are linear development extension (**LD**), Horizontal projection (**HP**), Unevenness (**UEV**), Volume (**Vol**), and **Area**; all data are shown in meters. *Population density* are Human Population density (**HumP**), Sheep density (**ShP**), Goat Density (**GoD**), and Cattle density (**CaD**), values correspond to number of individuals/hectare. *Environmental variables* are River distance to cave (**RivD**), Lake Distance to cave (**LakeD**), distances values are in meters, and Percentage of Caatinga coverage **(%Caat**).

Cave System	Cave	Spp	Lat	Long	LD (m)	HP (m)	UEV (m)	Vol (m^3)	Area (m^2)	Hum.P	ShD	GoD	CaD	Riv D	Lak D	%Caat
Furna Feia National Park	Furna Nova	7	-5.034226	-37.571167	239.3	211.3	29.8	6517.0	2786.6	0.012	0.04	0.03	0.03	8833.708	19992.04	100
	Furna Feia	10	-5.036878	-37.560177	739.1	707.5	30.0	49699.6	21250.0	0.012	0.04	0.03	0.03	7885.613	21062.59	99.685
	Caverna Porco do Mato	6	-5.046638	-37.540114	140.4	137.5	3.9	2062.1	1636.4	0.012	0.04	0.03	0.03	6811.293	23423.58	100
	Caverna Pedra Lisa	4	-5.045527	-37.521902	149.7	142.3	6.0	1557.7	2558.9	0.012	0.04	0.03	0.03	5526.442	23677.55	100
Felipe Guerra System	Gruta dos Três Lagos	7	-5.593288	-37.687155	65.0	62.0	12.0	410.2	148.2	0.016	0.13	0.45	0.1	195.052	2133.505	39.432
	Caverna Boa	6	-5.566527	-37.697897	264.5	255.7	17.8	10165.2	13966.1	0.016	0.13	0.45	0.1	361.021	4563.381	70.978
	Gruta da Carrapateira	7	-5.560618	-37.663979	242.2	229.5	10.5	5064.1	4631.6	0.016	0.13	0.45	0.1	667.057	3686.544	0
	Furna do Urubu	6	-5.573047	-37.652420	283.5	274.6	19.2	9264.8	7760.9	0.029	0.14	0.67	0.11	1029.276	2571.501	0
	Caverna do Arapuá	2	-5.518367	-37.610706	110.0	97.0	12.0	1466.0	564.0	0.015	0.04	0.36	0.03	1469.951	10137.84	99.054
	Gruta Capoeira do João Carlos	6	-5.514716	-37.528770	55.0	49.0	12.2	650.100	324,6	0.001	0.07	0.42	0.11	2569.64	14837.19	100
	Caverna Lajedo Grande	4	-5.462278	-37.552471	155.4	136.1	15.9	5465.900	1.600,8	0.023	0	0	0	1414.948	18407.22	100
	Gruta Casa de Homens	5	-5.576272	-37.573807	31.0	30.0	1.3	248.900	278,1	0.003	0.18	0.17	0.44	63.272	6484.486	96.845
Mossoró	Gruta dos Trinta	5	-5.212322	-37.264153	271.6	270.8	3.6	558.100	645.0	0.008	0	0	0	83.155	1473.347	79.811

SUPLEMENTARY MATERIAL 6

Surveyed caves of the Furna Feia System (National Park) with photos of cave and some bat colonies.

SUPLEMENTARY MATERIAL 7

Surveyed caves of the Felipe Guerra System with photos of cave and some bat colonies.