Bat assemblage in a karstic area from northern Brazil: seven new occurrences for Tocantins state, including the first record of *Glyphonycteris sylvestris* Thomas, 1896 for the Cerrado

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Abstract: The Cerrado, the second largest morphoclimatic area of South America, has many limestone outcrops with caves. However, studies of the bat fauna in karstic environments in the Cerrado are scarce. We present an inventory of bats in a karstic Cerrado area in the Tocantins state. We used mist-nets to sample caves, savannas, deciduous forests, and periurban environments. We captured 516 bats of 30 species, revealing that the study area is one of richest for bat species in the Brazilian Cerrado. Seven new occurrences of bat species were recorded for the Tocantins state, and we report the first record of *G. sylvestris* from the Cerrado biome. We recorded 21 species simultaneously at one cave, Gruta dos Moura, which is the highest species richness of bats for a single cave in the Neotropics.

Keywords: Chiroptera; conservation; community; Mammalia; Neotropical; range extension; savanna

INTRODUCTION

The Cerrado, the second largest morphoclimatic domain of South America, located in the central portion of the continent (Klink and Machado 2005). It has open vegetation (savanna) and semi-deciduous forest, with dry and mesic habitats (Oliveira-Filho and Ratter 2002). Human activities have drastically transformed part of the Cerrado, and 55% of its original territory was converted in pastures and agricultural fields (Klink and Machado 2005). Its high biological diversity and increasing rates of destruction make it a globally important biodiversity hotspot (Myers et al. 2000).

This morphoclimatic domain is one of the Neotropical ecoregions with lesser knowledge of its wildlife (Cavalcanti and Joly 2002) and biodiversity studies are imminently needed. In this aspect, species surveys are essential to understand regional patterns of biological diversity (Soulé and Wilcox 1980) and can generate important data required for biodiversity conservation plans (Bernard et al. 2011).

An important geological aspect of the Cerrado is the abundance of limestone outcrops and the existence of large caves complexes (Jansen et al. 2012) that are essential roosts for many bat species (Kunz 1982). However, studies of the bat fauna in the karstic environments of the Cerrado are scarce (Trajano and Gimenez 1998; Bredt et al. 1999; Esbérard et al. 2005). Bernard et al. (2011) considered the Cerrado to be the second least studied of the Brazilian biomes for bats, and only 6% of its territory was minimally sampled. Given the knowledge gaps in karstic areas, we inventoried bat species in a karstic Cerrado area in Tocantins state. Here, we present a list of bat species for two caves, new records of bats for Tocantins, and conservation considerations.

MATERIALS AND METHODS

Study sites

The study area is within the priority area for the conservation of Cerrado biodiversity (Cavalcanti and Joly 2002). Our sampling points are in the municipality of Aurora do Tocantins (12°42’ S, 046°24’ W, 470 m above sea level), located in the southeastern Tocantins state, northern Brazil. Aurora do Tocantins is within the Paraná watershed, a subbasin of Tocantins River, and situated in the Paraná Valley. The watershed is bounded by the Serra Geral de Goiás to the east and the Serra Geral do Paraná to the west. The study area has remnants of Cerrado vegetation, including deciduous forest and savanna (Oliveira-Filho and Ratter 2002).

The study area has several massive limestone outcrops. Among the 533 municipalities listed by the
m, 20 mm mesh). The mist-nets remained open all night (from sunset to sunrise), inspected at 30-minute intervals, and placed along trails within forest and savanna remnants. Bats were marked using small holes in wing membranes, a temporary marking technique (Bonacorsio and Symthe 1972).

The bats were identified from external characters (e.g., length of forearm, pelage coloration patterns, morphology of ears and tragus, etc.) and craniodental characters, following the literature descriptions (e.g., Simmons and Voss 1998; Lim and Engstrom 2001; Gardner 2008; Reis et al. 2007, 2013). We collected at least one individual of each species, and others that generated identification doubts. Vouchers were deposited in the mammalian collection of Museu Nacional, Universidade Federal do Rio de Janeiro (Appendix, Table A1). All procedures with animals followed the recommendations by Sikes et al. (2011).

The captures and specimen collections were authorized by SISBIO/IBAMA (authorization number 4028-1/28717). The nomenclature of bats followed Nogueira et al. (2014). The sampling effort was calculated following Straube and Bianconi (2002). We calculated the capture efficiency dividing the number of captures by the sampling effort in each locality sampled. The species richness estimation was made using Chao-1 method (Magurran

### Data collection and analysis

We sampled four sites (Site 1: 12°34’54”S, 046°30’59”W; Site 2: 12°35’31”S, 046°30’56”W; Site 3: 12°40’04”S, 046°28’04”W; Site 4: 12°42’46”S, 046°24’19”W) composed of remnants of semi-deciduous forest and savanna in a matrix of open areas (pastures) and agricultural fields (Figure 1; Table 1). In January 2012, we performed eight sampling nights using eight to ten mist-nets (average of 8.8 nets/night, SD ± 0.8) (Zootech®, 9×3

### Figure 1. Study area in Aurora do Tocantins, northern Brazil, in the context of the Cerrado (in gray).

### Table 1. Sampling sites of community structure of bats from karstic Cerrado of Tocantins state, northern Brazil.

<table>
<thead>
<tr>
<th>Localities</th>
<th>Coordinates</th>
<th>Remnant size (ha)</th>
<th>Sampling effort (m²·h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>12°34’54”S, 046°30’59”W</td>
<td>350</td>
<td>14,256</td>
</tr>
<tr>
<td>Site 2</td>
<td>12°35’31”S, 046°30’56”W</td>
<td>700</td>
<td>2,856</td>
</tr>
<tr>
<td>Site 3</td>
<td>12°40’04”S, 046°28’04”W</td>
<td>400</td>
<td>2,856</td>
</tr>
<tr>
<td>Site 4</td>
<td>12°42’46”S, 046°24’19”W</td>
<td>4</td>
<td>2,856</td>
</tr>
</tbody>
</table>
2004) and the rarefaction curve with 95% confidence interval were performed using the software PAST 3.0 (Hammer et al. 2001).

To determine the composition of bat species occurring simultaneously in caves of Aurora of Tocantins, we chose two caves to sample: Gruta dos Moura (12°34’54"S, 046°30’59"W) and Gruta do Urso (12°34’56"S, 046°30’59"W). These caves were chosen for their ease of access and because of knowledge by one of us (LSA) of their interiors from previous studies (e.g., Castro et al. 2013; Rodrigues et al. 2014; Soibelzon et al. 2015; see these studies for a basic description of caves). These caves are separated by approximately 500 m and have no connection with each other. We set mist-nets in the entrance of the caves before nightfall (16:30 h). The mist-nets remained open for three hours after sunset. To determine which species use the cave as a roost, only individuals captured exiting the caves were considered. Captures made in caves were not considered in the quantitative analysis of community structure.

Table 2. Bats from karstic Cerrado of Tocantins state, northern Brazil, including number of captures per sampling site, total number of capture (N) and relative abundance (%).

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
<th>N</th>
<th>%</th>
</tr>
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<tr>
<td>Emballonuridae</td>
<td></td>
<td></td>
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<tr>
<td>Peropteryx macrotis (Wagner, 1843)</td>
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<td>0</td>
<td>0</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Micronycterinae</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Micronycteris sanborni Simmons, 1996</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Micronycteris schmidtorum Sanborn, 1935</td>
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<td>0</td>
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<tr>
<td>Desmodontinae</td>
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<tr>
<td>Desmodus rotundus (É. Geoffroy, 1810)</td>
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<td>0</td>
<td>197</td>
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<td>Diphylla ecaudata Spix, 1823</td>
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<td>Mimon bennettii (Gray, 1838)</td>
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<td>Phyllostomus discolor Wagner, 1843</td>
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<td>0</td>
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<td>Phyllostomus elongatus (É. Geoffroy, 1810)</td>
<td>5</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Phyllostomus hastatus (Pallas, 1767)</td>
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<td>Trachops cirrhosus (Spix, 1823)</td>
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<td>Glossophaginae</td>
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<td></td>
</tr>
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<td>Anoura caudifer (É. Geoffroy, 1818)</td>
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<td>0</td>
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<td>Glossophaga soricina (Pallas, 1766)</td>
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<td>Lonchophyllinae</td>
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<td>4</td>
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</tr>
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<td>Lonchophylla dekeyseri Taddei, Vizotto &amp; Sazima, 1983</td>
<td>8</td>
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<td></td>
</tr>
<tr>
<td>Artibeus planirostris Spix, 1823</td>
<td>34</td>
<td>21</td>
<td>32</td>
<td>20</td>
<td>107</td>
<td>20.7</td>
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<tr>
<td>Chiropotes villosus Peters, 1860</td>
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<td>Pteronotus vampyrus (Gray, 1843)</td>
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<tr>
<td>Noctilionidae</td>
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<td></td>
</tr>
<tr>
<td>Noctilio leporinus (Linnaeus, 1758)</td>
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<tr>
<td>Furipteridae</td>
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<tr>
<td>Furipterus horrens (F. Cuvier, 1828)</td>
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<tr>
<td>Molossidae</td>
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<tr>
<td>Molossops temminckii (Burmeister, 1854)</td>
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<td>1</td>
<td>0</td>
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<tr>
<td>Molossus molossus (Pallas, 1766)</td>
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<td>0</td>
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<td>2</td>
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<td>0.4</td>
</tr>
<tr>
<td>Vespertilionidae</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eptesicus diminutus Osgood, 1915</td>
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<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>Eptesicus furinalis (d’Orbigny &amp; Gervais, 1847)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Total</td>
<td>385</td>
<td>29</td>
<td>52</td>
<td>50</td>
<td>516</td>
<td>100</td>
</tr>
</tbody>
</table>
RESULTS
Assemblage structure
We captured 516 specimens of 30 species: one species of Emballonuridae, 22 species of Phyllostomidae, one species of Mormoopidae, one species of Noctilionidae, one species of Furipteridae, two species of Molossidae, and two species of Vespertilionidae (Table 2).

The total sampling effort was 22,824 m²·h and the total capture efficiency was 0.022 bats/m²·h. The Chao-1 index estimated 45 species as the maximum richness (SD ± 1.0), which is an indication that with increased capture effort more species will be recorded for the region. The rarefaction curve also indicates that more species will be recorded by increasing the capture effort (Figure 2). The family with the most number of captures was Phyllostomidae, with 95% of the captures.

Desmodus rotundus (É. Geoffroy, 1810) was the most abundant species with 197 captures (38%), followed by Artibeus planirostris Spix, 1823 and Carollia perspicillata (Linnaeus, 1758), with 107 (21%) and 60 captures (12%), respectively. No recapture was made.

New records
We provide seven new occurrence records to Tocantins state: Peropteryx macrotis (Wagner, 1843), Anoura caudifer (É. Geoffroy, 1818), Chrototerus auritus (Peters, 1856), Diphylla ecaudata Spix, 1823, Glyphonycteris sylvestris Thomas, 1896, Mimon bennettii (Gray, 1838) and Chiroderma villosus Peters, 1860 (Figure 3). Previously in the same locality, Furipterus horrens (F. Cuvier, 1828) and Phyllostomus elongatus (E. Geoffroy, 1810) were already reported as first occurrences for Tocantins state (Novaes et al. 2012, 2014).

The capture of G. sylvestris is the first record of this species for the Cerrado domain and expands the species’ distribution by approximately 1,500 km south of the Amazonian populations and more than 850 km north of the Atlantic Forest populations (Figure 4). Occurrence data of this species in South America are shown in Table 3.

Caves survey
Through direct observations, mist-netting at caves exits, and manual captures, we recorded 22 species occupying two caves, with a great difference in species richness between them: Gruta dos Moura has 21 species (including 11 exclusive species) and Gruta do Urso has 11 species (with one species recorded only in this cave; Table 4). We compiled the bat richness in 139 caves from seven countries in the Neotropics (Brazil, Bolivia, Colombia, Cuba, Honduras, Mexico, and Venezuela). The species richness in caves ranged from zero in Buena

Figure 2. Rarefaction curve for the bat community in Aurora do Tocantins, northern Brazil.

Vista Cave, Mexico, to 17 at Gruta da Judeite, Brazil (Appendix, Table A2). Our literature review indicates Gruta dos Moura as the richest cave for bat species in the Neotropics.

**DISCUSSION**

**Assemblage structure and new records**

Bat inventories in the Cerrado presented a richness ranging from three to 39 species (e.g., Gonçalves and Gregorin 2004; Bordignon 2006; Zortéa and Alho 2008; Cunha et al. 2009; Bezerra and Marinho-Filho 2010; Ferreira et al. 2010; Zortéa et al. 2010; Cunha et al. 2011; Gregorin et al. 2011; Sousa et al. 2013; Muylaert et al. 2014; Shapiro and Bordignon 2014). However, this richness can be considerably higher in areas with caves (Bredt et al. 1999; Esbérard et al. 2005; Gregorin et al. 2011). Brunet and Medellín (2001) indicate that species richness tends to be higher in karstic areas compared with environments without caves. Probably, the high species richness of bats in Aurora do Tocantins is due to limestone caves, which increase the availability of roosts, making possible the coexistence of a large number of species (Trajano 1995).

Bat species richness in Aurora do Tocantins is higher than the average found in other Cerrado localities, only behind Estação Ecológica Serra Geral de Tocantins, with 39 species (Gregorin et al. 2011). However, the difference between those areas can be explained by the
difference in sampling effort employed, with the effort being greater in Serra Geral do Tocantins (Gregorin et al. 2011). The capture efficiency obtained by us was 0.022 bats/m²·h, also considered high for Cerrado areas, with minimum values of 0.002 bats/m²·h in the Serra Geral do Tocantins (Gregorin et al. 2011) and maximum around 0.032 bats/m²·h in the Aporé-Sucuriú Complex of Mato Grosso do Sul (Bordignon 2006).

This study recorded seven new occurrences of species for Tocantins state, increasing the state’s species diversity to 60 (Novaes et al. 2012; Reis et al. 2013; Novaes et al. 2014; Lapenta and Bueno 2015). Other than G. sylvestris, occurrences of six widely distributed species in the Brazilian Cerrado were expected in Tocantins and required only formalization with voucher deposits. Our report of G. sylvestris is the first from the Cerrado. This species is rare throughout its range and has two disjunct populations: one from Costa Rica to the Amazon basin, occupying areas east of the Andes, Venezuela, Colombia, French Guiana, Suriname, Peru, and Trinidad and Tobago, and another population occurring in the Atlantic Forest in southeastern Brazil (Williams and Genoways 2008). However, our record of this species from Aurora do Tocantins, in a deciduous forest area inserted into the Cerrado, is midway between the two populations. More studies are needed to determine if the population of G. sylvestris found in Aurora do Tocantins is relictual and has no functional connection with other populations. However, the incipient distributional information about G. sylvestris may result from misidentifications.

Table 4. Bats captured in two caves in Aurora do Tocantins, northern Brazil: presence (X) and absence (–).

<table>
<thead>
<tr>
<th>Species</th>
<th>Mouro Cave</th>
<th>Urso Cave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peropycterx macrotis</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Glossophaga soricina</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Linycteris spurrelli</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Lonchophylla dekeyseri</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Desmodus rotundus</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Diphylla ecaudata</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Carollia perspicillata</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chrotomops auritus</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Glyphonycteris sylvestris</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Microcyon cerberus</td>
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</tr>
<tr>
<td>Microcyon schmidtorum</td>
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<td>Mimon bennetti</td>
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<td>X</td>
</tr>
<tr>
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<td>Furipterus herrens</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Noctilio leporinus</td>
<td>X</td>
<td>–</td>
</tr>
<tr>
<td>Pteronotus parnellii</td>
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<tr>
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Table 3. Occurrences of Glyphonycteris sylvestris in South America.

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<td>Salazar Trace, Trinidad and Tobago</td>
<td>10°07’N, 61°47’W</td>
<td>Goodwin and Greenhall (1961)</td>
</tr>
<tr>
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<td>05°00’N, 54°59’W</td>
<td>Williams and Genoways (1980)</td>
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<tr>
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<td>05°16’N, 52°55’W</td>
<td>Simmons and Voss (1998)</td>
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<tr>
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<td>03°38’N, 53°13’W</td>
<td>Brosset and Dubost (1968)</td>
</tr>
<tr>
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<td>04°32’N, 59°05’W</td>
<td>Lim and Engstrom (2001)</td>
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<td>Not mentioned</td>
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<tr>
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Table 4. Bats captured in two caves in Aurora do Tocantins, northern Brazil: presence (X) and absence (–).
to Nogueira et al. (2007), this species can be misidentified as bats of the genera *Carollia* and *Trinecteris*. Therefore, it is possible that taxonomic review of museum collections of *Gyponycteris*, *Carollia*, and *Trinecteris* specimens may yield new occurrence data for *G. sylvestrus*.

We recorded other rare species, including *Micronycteris schmitzorum* Sanborn, 1935, *Phylloderma stenops* Peters, 1865, and *Lonicaophylla dekeyser* Taddei, Vizotto & Sazima, 1983. The last species is endemic to the Cerrado and Caatinga ecoregions of South America and is classified as Near Threatened (Sampaio et al. 2008). This shows the importance of conservation of the caves and the surrounding savanna and forest habitats of the Aurora do Tocantins region for the maintenance of bat diversity.

Caves surveys

Studies on bats in caves are rare throughout the Neotropics, precluding a robust data comparison. However, according to our results, Gruta dos Moura, with 21 species, has the highest richness of bat species of any cave in the Neotropical region. Surveys in Brazil revealed species richness ranged from one to 17 species of bats per cave (e.g., Esbérard et al. 1998; Trajano and Gimenez 1998; Bredt et al. 1999; Esbérard et al. 2005). Studies in other Neotropical countries indicate a maximum 12 species per cave (Appendix, Table A2). Arita (1996) found from one to 12 species per cave in a survey conducted in 36 caves in Mexico. Also in Mexico, Brunet and Medellin (2001) studied bat diversity of 20 caves recorded from zero to 11 species per cave. Molinari et al. (2012) found from four to five species in four Venezuelan caves. Siles et al. (2007) reported six to seven species in three caves in Bolivia. In Colombia, one to 10 species were reported in 13 different caves (Muñoz-Saba et al. 1999; Pérez-Torres et al. 2015). Two caves in Honduras had their richnesses estimated from three to five species (Divoll and Buc 2013), and from a cave in Cuba six species were recorded (Mora et al. 2002).

Despite the little knowledge on bat fauna in caves, some studies suggest a trend of positive correlation between the size of the cave and the number of species (Arita 1996; Brunet and Medellin 2001). Probably, this species–area relationship, where larger caves tend to have greater species richness of bats, is explained by greater humidity values and the presence of speleothems and cavities (Brunet and Medellin 2001).

Conservation considerations

Decree 6,640 of 7 November 2008 relaxed the laws to protect Brazilian caves. It represents a retreat in the legislation that protects the natural heritage and allows for the complete destruction of caves that have economic interest. The most plausible result of this loss of protection is an increase in the rate of biodiversity loss (Novaes 2012; Trajano 2013). Moreover, the Gruta dos Moura cave and the surrounding savanna vegetation are within in an area of intensive agricultural activity and not protected by conservation units. Therefore, although it has the highest richness of bat species found in a single cave in Neotropics, this cave is susceptible on anthropogenic exploration, which may cause its complete destruction. Some caves of this karstic complex already have signs of anthropogenic disturbance, such as damaged speleothems and dumped garbage in the cave entrances. We also found signs of hunting (ammunition for firearms) at the entrance to Gruta do Urso.

Considering the expansiveness of the karstic complex of Aurora do Tocantins, we believe that the richness and abundance of bats may be greater than that reported here. Bats contribute in a crucial way to the maintenance of essential ecological services, such as seed dispersal and insect population control (Wilson 1973; Kalka et al. 2008; Kunz et al. 2013; Puig-Montserrat et al. 2015).

In Aurora do Tocantins, the destruction of caves and their surrounding vegetation may do damage to local agriculture by the loss of pest-control bat species (see Boyles et al. 2011). The loss of these caves and their bats would be a serious setback for the conservation of the remaining Cerrado and its biodiversity. Paleontological studies have shown the importance of these caves for the fossil record (Oliveira et al. 2011; Castro et al. 2013; Rodrigues et al. 2014; Soibelzon et al. 2015).

With the exception of this first study of bats from Aurora do Tocantins, there is no other information about the extant wildlife found in the municipality, making it difficult to build a case for classifying the area as a priority for conservation, which would allow its legal protection as a conservation unit.

ACKNOWLEDGEMENTS

Cristal Sauwen, Gabriella Pego contributed to the fieldwork; UNIRIO provided logistical support. We appreciate all technical and logistic support provided during expeditions by Prefeitura de Aurora de Tocantins, Mr. Wagner Moura and the Sociedade Brasileira de Espeleologia. We thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (401812/2010-3, Edital MCT/CNPq No. 32/2010–Fortalecimento da Paleontologia Nacional/Edital 32/2010–Paixa B and 552975/2011, Apoio a Projetos de Pesquisa /Chamada MCT/CNPq No. 23/2011–Apoio Técnico para Fortalecimento da Paleontologia Nacional); the Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) for the MSc and PhD studentship awarded to S. Felix and R.F. Souza, respectively; and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the MSc studentship to R.L.M. Novaes.
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Author contributions: SF, RLMN and RFS collected the data; SF, RLMN and LSA delineated the study, RLMN and RFS made analysis, all authors wrote the text.

Received: 2 June 2016
Accepted: 12 October 2016

Academic editor: Sergio Solari
### APPENDIX

#### Table A1. Vouchers of bats from Aurora Tocantins deposited in the Museu Nacional, Universidade Federal do Rio de Janeiro, Brazil (MN).

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<td></td>
<td>Lhionycteris spurrelli</td>
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<td>Lonchophylla dekeyseri</td>
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#### Table A2. Caves compiled by literature review, including species richness of bats and author of the record.

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