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Bats (Mammalia: Chiroptera) in a cerrado landscape in São Carlos, southeastern Brazil

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Abstract: We studied bat assemblages in seven sampling sites in the rural zone of São Carlos, southeastern Brazil. The sampling sites were two riparian forests, two types of Brazilian savanna (*cerrado sensu stricto* and *cerradão*), a *Pinus* plantation, a semideciduous forest, and an open area. We sampled bats from January 2007 to December 2011 with mist nets, totalizing 100 capture nights and 38,587 m^{2}h of capture effort. We captured 523 individual bats of 23 species belonging to three families. *Sturnira lilium* was the most frequently captured species and represented 40% of all captures, followed by *Carollia perspicillata* (17%) and *Glossophaga soricina* (12%). The studied heterogeneous landscape harbors a rich bat fauna compared to other studies with similar effort in well-preserved savannas.

Introduction

Brazil has the second most diverse bat fauna in the world, with at least 174 species (Paglia *et al.* 2012). In the Brazilian Cerrado, a savanna biome, bats represent 41% of the mammalian fauna; furthermore, over 45% of the Brazilian bat species (77) are found in the Cerrado (Marinho-Filho 1996; Paglia *et al.* 2012).

The Cerrado has been reduced to only 20% of its original area due to human impacts (Myers *et al.* 2000). In the state of São Paulo, southeastern Brazil, only 0.81% of the Cerrado remains, and many of its remnants are located within or near urban areas (Kronka *et al.* 2005). Although it is known that several bat species are able to maintain viable populations in urban environments or near them (Esbérard 2003; Barros *et al.* 2006), bat population declines due to anthropogenic influences have been pointed out by several studies (Rydell *et al.* 2010; Sakanowicz and Wower 2013; Brosset *et al.* 1996).

In order to develop strategies for the conservation of the Cerrado in São Paulo, we need to better survey its biodiversity in order to fill considerable gaps of knowledge. The central region of São Paulo, in the region of São Carlos, represents one of these knowledge gaps in Brazil (Bernard *et al.* 2011). In the present study we aimed at fulfilling this gap by making the first assessment of bat diversity in a cerrado of São Carlos.

Materials and Methods

Study site

The study was carried out in the municipality of São Carlos, within the Area of Environment Protection of the Corumbataí River Basin, state of São Paulo, southeastern Brazil. This area represents a transition between Cerrado and Atlantic Forest. The regional climate is a transition between the types Aw (tropical wet and dry climate) and Cwa (humid subtropical), according to the Köppen classification (Tauk-Tornisielo and Esquierro 2009).

We captured bats in seven sampling sites (Figure 1) located in the private reserve of the Federal University of São Carlos (UFSCar, 21°96´ S, 47°87´ W) and in the Canchim Farm, which belongs to the Brazilian Agricultural Research Corporation (Embrapa, 21°58' S, 47°52' W). The study site was located approximately 8 km from the city. We mapped habitats within the study area based on a buffer with 2.5 km in radius (centered in the mass centroid among all sampling sites). The area comprises a mosaic of habitats (Figure 1) including remnants of cerrado (300 ha of total area), semideciduous forests (340 ha), riparian forests (5 ha), monocultures of *Pinus elliottii* and *Eucalyptus* sp. (171 ha), and 1768 ha of urban areas, crops and deforested areas. The *cerrado sensu stricto* habitat has an area of 50 ha and connects two areas delimited as legal reserves in a neighboring farm. In the Canchim Farm there are 112 ha of semideciduous forest, which did not suffer intense human pressures in the past four decades. Trees in this semideciduous forest are up to 30 m tall and the canopy is discontinuous (Primavesi *et al.* 1999).

Data collection

Fieldwork was carried out under a research permit (SISBIO 11093-2) and a permanent bat collection permit (SISBIO 19335-1, 11093-3) granted by the Chico Mendes Institute for Conservation and Biodiversity (ICMBio). We also got a permit from the Committee for Ethics in Animal Research of UFSCar (013/2007), and access to the study area was granted by the campus Administration of UFSCar and Embrapa (022/07 DISG/PU).

We captured bats from January 2007 to December 2011 in seven sites (Figure 1): (1) open area; (2) *Pinus* grove; (3) semideciduous forest in Canchim Farm; (4) cerradão; (5) cerrado *sensu stricto*; and (6–7) riparian forests. The open area was a pasture with shrubs (mainly

Bauhinia hollophylla, Leguminosae). The vegetation of *cerrado sensu stricto* and *cerradão* are savanna formations. The *cerrado sensu stricto* is structurally an intermediate formation and the *cerradão* is a denser formation that looks like a forest, but with a lower canopy, up to 8 m tall (Coutinho 1978; Eiten 1979).

Bats were captured with mist nets (7 x 2.5 m; denier 70/2, mesh 16 x 16 mm, Ecotone Inc., Poland), set up from sunset to 24:00h. In 13 capture nights (area 1) we set up the nets from sunset to sunrise. We opened three nets per night, but in area 1 we used eight nets following the protocol of other studies carried out simultaneously to this inventory. We avoided opening nets in the same place in consecutive days. Our sampling effort was calculated following Straube and Bianconi (2002), by multiplying the area of each net (m^2) by the total number of nets opened each night and the total number of working hours. We carried out a total of 100 sampling nights, which resulted in a total capture effort of 38,587 m^2.h, with 13 nights of capture in area 1, 15 in area 2, 1 in area 3, 7 in area 4, 20 in area 5, 20 in area 6 and 24 in area 7. We performed only one night of capture in area 3 due to access limitations in Canchim Farm.

Bats were identified using taxonomic keys (Vizotto and Taddei 1973; Emmons and Feer 1997; Gardner 2008) and marked with metallic rings in the right forearm for individual identification (acronym 'MARM' followed by a four-digit number). Voucher specimens were deposited in the mammal collections of the Zoological Museum of São Paulo University, as well as in the reference collection of mammals in the Department of Ecology and Evolutionary Biology of UFSCar (Appendix 1).

Data Analysis

To estimate sampling completeness we built a species accumulation curve and calculated completeness by dividing the sampled total richness by the average of first- and second-order Jackknife estimates (following Magurran 2003) bootstrapped from the original dataset (999 iterations). We estimated taxonomic richness in R (R Development core team 2010) using the package vegan (Oskanen *et al.* 2010). The package gridBase (Murrell 2002) was used to plot the graphics. The map of study sites and area estimates were made based on a satellite image (Quickbird, resolution of 60 cm) analyzed in Quantum GIS 2.0.1 (QGIS) and mapped at 1:5.000 scale.

Results

We captured 533 bats of 23 species belonging to families: Phyllostomidae (16 species of five subfamilies), Molossidae (*Molossus molossus*), and Vespertilionidae (six species). Phyllostomids were the most frequently captured bats (Table 1).

The estimated richness was 33 species (first-order Jacknife, sd = 3.84). The species accumulation curve is presented in Figure 2 and sampling completeness was estimated as 71%. The richness among sampling sites is presented in Figure 3.

The most abundant species in the study area was *Sturnira lilium* with a total of 193 captures (36% of the total). The other most abundant species were also phyllostomids: *Carollia perspicillata* accounted for 93 captures (17% of the total) and *Glossophaga soricina* for 62 (12% of the total). The number of captures for each area was: 58 in riparian forest (6), 173 in riparian forest (7), 27 captures in open area, 48 in cerrado *sensu stricto*, 25 in cerradão, 121 in *Pinus* grove, and 81 in semideciduous forest.

Discussion

The species accumulation curve did not stabilize, which may be attributed to the relatively low effort. Despite

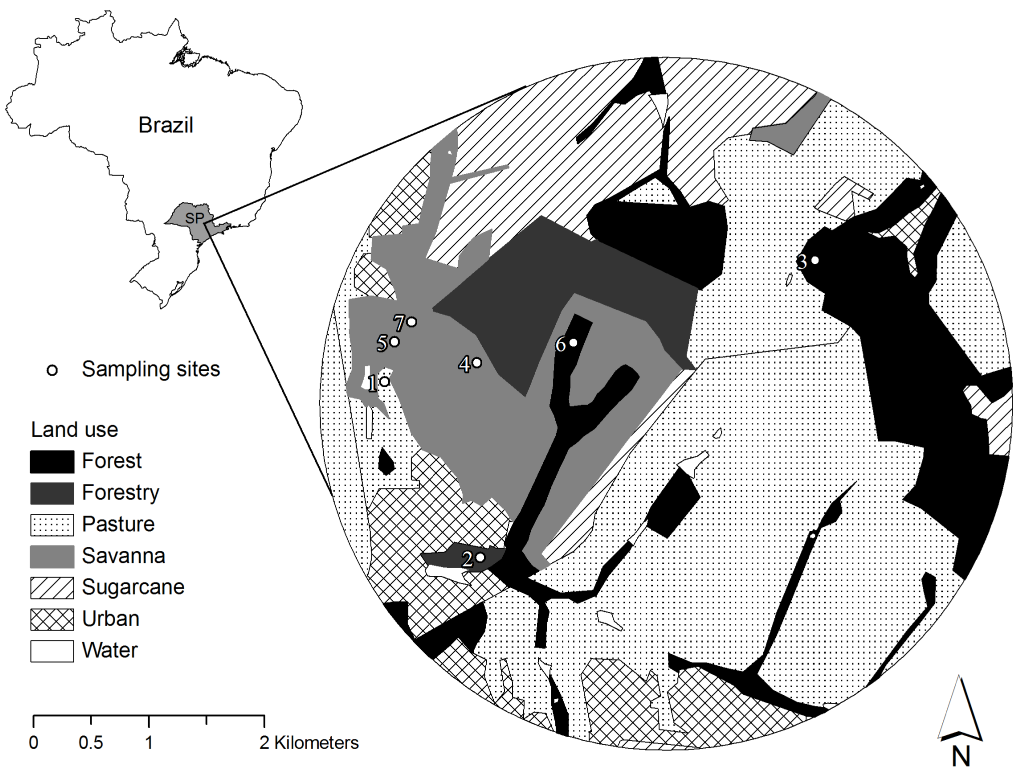

Figure 1. Map of Brazil with study area in detail (São Carlos municipality). The center of the circle is the mass centroid of the seven sampled sites.

this low capture effort, our results are consistent with other results obtained in cerrado and dry forest mosaics (e.g. Cunha *et al.* 2011; Avilla-Cabadilla *et al.* 2014). Our sampling was based only in mist netting, so other non-phyllostomid bat species that may occur in the area might have passed undetected, since mist nets are selective (Kunz and Parsons 2009).

To make a more complete inventory of the bat fauna in the study area additional bat surveys are needed. For instance, Bergallo *et al.* (2003) recommended at least 1,000 captures to inventory bats in the Atlantic Forest. Several factors influence the necessary effort to achieve sample completeness and, in a recent meta-analysis, the roles of latitude and type of forest have been considered important to determine the minimum acceptable sampling effort (Stevens 2013) in the Atlantic Forest. No similar estimates were made for the Brazilian Cerrado.

Dry forests and cerrados are intensively used by bats. In this first assessment we aimed at recording the "first-captured species" of the study area, such as *Sturnira lilium*, *Glossophaga soricina*, and other very common bats in the Neotropics (Kunz and Parsons 2009). Therefore, despite the lack of sampling completeness, our results are consistent, since detecting common species results in little loss of information in analyses of general biodiversity patterns (Vellend *et al.* 2008).

The sampled richness was 23 species, suggesting that we recorded a considerable richness in the study area compared to inventories made in well-preserved cerrados. For example, 25 species were recorded in a well-preserved cerrado in Central Brazil, with 60 nights of capture and 4 working hours a night (Zortéa and Alho 2008). However, the authors obtained a larger number of captures (758) in their study.

Our study recorded a larger number of species than other studies with similar effort (e.g., 18 species in the Sonora savanna, Cunha *et al.* 2011) and in well-preserved cerrados (Zortéa and Alho 2008). A possible explanation for that may be our distribution of the sampling effort over seven different kinds of habitat. Most of our sampling was done in cerrado areas but a single capture night in a semi-deciduous forest accounted for two additional species, *Desmodus rotundus* and *Anoura geoffroyi*. Despite being a typical cerrado area, the study area is located within a cerrado-semideciduous forest transition. This heterogeneity of the area may facilitate the capture of different species.

The sampling sites with highest richness were the riparian forests, probably due to higher roost availability (Rogeri 2011) and bat detectability, as these areas represent flight routes that connect landscape elements in the study. The bats prefer to roost inside forests in the study area (Rogeri 2011), so forests play a key role in bat biodiversity maintenance (Grindal *et al.* 1999; Galindo-Gonzáles and Sosa 2003; Ober and Hayes 2008).

Phyllostomids are the most frequently captured bats in mist netting-based inventories (Kunz and Parsons 2009). Phyllostomid bats are also dominant in other Neotropical biomes (Gorrensen and Willig 2004; Stevens 2013). Among phyllostomids, we already expected that *Sturnira lilium* would be one of the most frequently captured bats in the study area, since Solanaceae, its main food-plants, are very abundant in the area (Muylaert *et al.* 2013). We also captured the phyllostomid bats *Pygoderma bilabiatum*, *Vampyressa pussilla*, *Chiroderma doriae*, *Sturnira tildae*, and *Uroderma bilobatum* only in cerradão areas. These bats are usually rare (Cunto and Bernard 2012) and some of them are considered data deficient by IUCN (IUCN 2013), so these records contribute to the knowledge on these species' geographic distribution.

Species of other families, such as Vespertilionidae and Molossidae, tend to fly very high, so they are usually less frequently captured with mist nets (Arita 1993; Pedro and Taddei 1997). Nevertheless, we captured vespertilionid bats in different habitats within the study area. *Histiotus velatus* was captured in *Pinus elliottii* stands. The monospecific pine stands in the area have open canopy and form large corridors (up to 5 m wide) where some bats, such as aerial insectivores (Kalko *et al.* 2008), may hunt their prey. *Eptesicus furinalis*, *Lasiurus ega*, and *Lasiurus blossevillii* were captured only in *cerradão* areas. *Myotis nigricans*, a broadly distributed species (Wilson and Reeder 2005), was captured in five different areas.

In the Cerrado, most studies recorded between 10 and 26 bat species when mist nets were the single sampling method used (Ferreira *et al.* 2010; Cunha *et al.* 2009; Zortéa and Alho 2008; Aguirre 2002). Even in a better

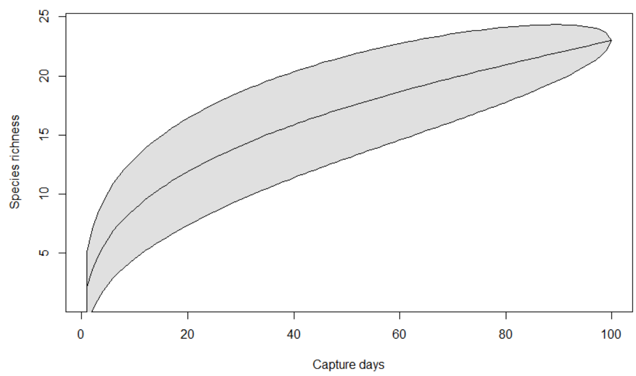

Figure 2. Species accumulation curve for bats captured in São Carlos municipality, between 2006 and 2011 (gray area represents the 95% confidence intervals).

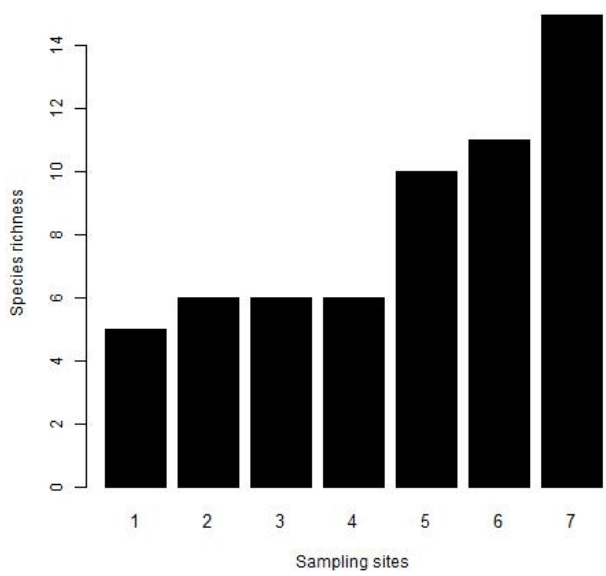

Figure 3. Species richness in seven sampling sites in São Carlos municipality, between 2006 and 2011.

sampled biome such as the Atlantic Forest, most studies found local richness values below 30 species (Stevens 2013), but it is known that the biome harbors much more species than that (Paglia *et al.* 2012). Detectability differs largely among bat species (Meyer *et al.* 2011), mainly when a single sampling method is used. Thus, a combination of mist netting and additional sampling methods such as bioacoustic monitoring would probably increase the recorded richness in the area (as in Sampaio *et al.* 2003). For example, phytophagous bats commonly have higher detectability than animalivorous bats, and this difference should be taken into account when interpreting results of short-term studies (Cunto and Bernard 2012).

We conclude that the cerrado remnants in São Carlos municipality harbor considerable bat richness, with most diversity concentrated in riparian forests. The study area offers good opportunities for studies on bat ecology and diversity.

Figure 1. List of bat species captured in São Carlos, SP, Brazil. Status according to IUCN (2013), LC = Least concern; DD = Data deficient. Areas Oa = open area, Pg = Pinus grove, C = cerradão, Css = cerrado sensu stricto, Sd = semideciduous forest, Rf = riparian forest.

SPECIES	CAPTURES	INDIVIDUALS	RECAPTURE (%)	SITES	STATUS
Molossidae					
Molossus molossus (Pallas, 1766)	1	1	0	Pg	LC
Phyllostomidae – Carolliinae					
Carollia perspicillata (Linnaeus, 1758)	93	90	6.5	Rf, Oa, C, Css, Sd	LC
Phyllostomidae – Desmodontinae					
Desmodus rotundus (É. Geoffroy St.-Hilaire, 1810)	2	2	0	Sd	LC
Phyllostomidae – Glossophaginae					
Anoura caudifer (É. Geoffroy St.-Hilaire, 1818)	8	8	0	Oa, Pg, C, Css	LC
Anoura geoffroyi Gray, 1838	1	1	0	Sd	LC
Glossophaga soricina (Pallas, 1766)	62	60	3.2	Oa, Pg, C, Css	LC
Phyllostomidae – Phyllostominae					
Phyllostomus discolor (Wagner, 1843)	37	36	2.7	Sd, Css	LC
Chrotopterus auritus (Peters, 1865)	1	1	0	Pg	LC
Phyllostomidae – Stenodermatinae					
Artibeus fimbriatus Gray, 1838	4	4	0	Pg, C, Sd	LC
Artibeus lituratus (Olfers, 1818)	47	47	0	Pg, C, Sd, Css	LC
Chiroderma doriae Thomas, 1891	1	1	0	C	LC
Platyrrhinus lineatus (É. Geoffroy St.-Hilaire, 1810)	24	24	0	C, Pg, Css, Sd	LC
Pygoderma bilabiatum (Wagner, 1843)	1	1	0	Rf, Oa, C, Css, Sd, Pg	LC
Sturnira lilium (É. Geoffroy St.-Hilaire, 1810)	213	209	1.9	C, Pg, Css, Sd, Rf	LC
Sturnira tildae de la Torre, 1959	5	5	0	C	LC
Uroderma bilobatum Peters, 1866	1	1	0	C	LC
Vampyressa pusilla (Wagner, 1843)	1	1	0	C	DD
Vespertilionidae					
Eptesicus furinalis (d'Orbigny & Gervais, 1847)	1	1	0	C	LC
Histiotus velatus (I. Geoffroy St.-Hilaire, 1824)	4	4	0	Pg	DD
Lasiurus blossevillii [Lesson, 1826]	7	7	0	C	LC
Lasiurus ega (Gervais, 1856)	2	2	0	C	LC
Myotis nigricans (Schinz, 1821)	11	11	0	Css, Rf, C, Sd, Pg	LC
Myotis albescens (É. Geoffroy St.-Hilaire, 1806)	6	6	0	Css	LC
Total	**533**	**523**	**14.3**	**-**	**-**

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Appendix 1. Institutional catalogue number of the vouchers (LES= Laboratório de estudos subterrâneos, UFSCar São Carlos) collected by this study.
Anoura caudifer (LES-10780), *Artibeus fimbriatus* (LES-1232007), *Artibeus lituratus* (LES-27786), *Carollia perspicillata* (LES-1232007), *Chiroderma doriae* (LES-1012008), *Desmodus rotundus* (LES-7102006), *Eptesicus furinalis* (LES-10102010), *Glossophaga soricina* (LES-10380), *Lasiurus blossevillii* (LES-17281), *Molossus molossus* (LES-207984), *Myotis nigricans* (LES-2992007), *Phyllostomus discolor* (LES-17012008), *Platyrrhinus lineatus* (LES-3062008), *Pygoderma bilabiatum* (LES-1172011), *Sturnira lilium* (LES-722007).