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ARTICLE

Ilha Grande, one of the locations with the most records of bat species (Mammalia, Chiroptera) in Rio de Janeiro state: results of a long-term ecological study

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Abstract. Faunal inventories provide quantitative and qualitative data for different sites and are relevant sources of information for identifying areas of high species richness and endemism. Biological collections are important in this context for increasing the precision of species identification. The objectives of this study were to update the list of bat species of Ilha Grande by analyzing specimens in zoological collections as well as records obtained in areas where no such studies had been undertaken before; to compare five different studies conducted on Ilha Grande using mist net sampling; and to compare the results of studies on Ilha Grande with sampling results from other areas in Rio de Janeiro state. The occurrence of 36 bat species was confirmed for Ilha Grande. Five studies on Ilha Grande formerly conducted by the authors were compared with 34 fauna inventories in Rio de Janeiro state. The studies on Ilha Grande had distinct objectives and sampling techniques applied to different locations in the same area. Ilha Grande is one of the regions in Rio de Janeiro state with more bat records both in terms of abundance and number of species, as well as one of the areas of highest bat capture effort.

Keywords. Atlantic Forest; Inventory; RAPELD; Richness; Zoological collections.

INTRODUCTION

Knowledge on biological diversity is considered essential for planning conservation actions, as these depend on understanding species distribution and systematics as well as aspects related to *community ecology,* demography and natural history (Santos, 2003; Silveira *et al.,* 2010). Fauna inventories provide quantitative and qualitative data (Owen, 2000), therefore being relevant sources of information for identifying areas of high richness and endemism (Remsen, 1994; Blackburn & Gaston, 1998; Myers *et al.,* 2000). Species inventories form a substantial part of studies on mammals in Brazil (Brito *et al.,* 2009).

The Order Chiroptera represents the second most studied taxon among mammals in Brazil (Brito *et al.,* 2009). Bats are considered well studied in Atlantic Forest ecosystems (Bernard *et al.,* 2011). There is a long history of scientific inventories in the biome, a larger concentration of researchers and scientific institutions, and more financial resources compared with other regions in Brazil (see Lewinsohn & Prado, 2005; Brito *et al.,* 2009). Although survey gaps remain in several regions in the country, bats may be considered well

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studied in Rio de Janeiro state, in southeastern Brazil (Bergallo *et al.,* 2003; Peracchi & Nogueira, 2010; Stevens, 2013). Secondary studies in this region can therefore be useful to synthesize data in search of new evidence.

Different techniques may be used in chiropterofauna inventories. Capture methods used in inventories must be efficient in capturing the largest number of species. The method most commonly used in the Neotropical region for bat capture is to set mist nets in probable bat flight routes in the forest undergrowth (Kunz & Kurta, 1988; Estrada *et al.,* 2004). Mist nets are efficient for capturing bats in the Phyllostomidae family, especially for frugivore bats (Sipinski & Reis, 1995; Pedro & Taddei, 1997; Kalko, 1998). The efficiency of the method is low for insectivore bats in families Emballonuridae, Thyropteridae, Vespertilionidae, and Molossidae (Voss & Emmons, 1996; Simmons & Voss, 1998), as insectivore species tend to fly higher and avoid the nets by using echolocation (Kunz & Kurta, 1988; Voss & Emmons, 1996).

The selective quality of mist nets can be minimized by sampling design. Alternatives have been used in different studies to increase capture of insectivore bats or of bat species that fly above the forest undergrowth. Mist nets are set in the higher forest strata or above water (*e.g.,* Carvalho & Fabián, 2011; Costa *et al.,* 2012). Sampling design can also influence bat abundance, not only species richness, and be directed at certain species or groups of species. Mist nets set near fruit-bearing trees would increase capture of frugivorous species, for example (Kalko, 1998). Methodological variations can lead to detecting more species or capturing more bats in an area, but total local density may interfere with capture rates (*e.g.,* Fleming, 1988). Capture effort is another relevant variable for increasing the knowledge of species in an area, being strictly related to richness (Bergallo *et al.,* 2003).

Ilha Grande is recognized as one of the areas of highest bat richness and abundance in the state of Rio de Janeiro due to intensive capture efforts in different regions (see Bergallo *et al.,* 2003; Esbérard *et al.,* 2006). The first list of bat species of Ilha Grande, compiled in 1988, included seven species (Fernandez *et al.,* 1988). Later Esbérard *et al.* (2006) updated these records, listing 36 species. However, some areas on the island, especially in the forest interior and at elevations higher than 250 meters, had not been well studied before 2014 despite high capture efforts in other areas (Esbérard *et al.,* 2006). Additionally, new bat species have been described for Ilha Grande in recent years and taxonomic issues on Chiroptera in Brazil were resolved. For these reasons, a taxonomic review of bats of Ilha Grande was needed to provide a more precise estimate of bat diversity on the island. The objectives of this study were, therefore, to (i) compile an updated list of bat species of Ilha Grande by conducting studies in areas that had not been well studied and reviewing the taxonomic identification of voucher specimens; (ii) compare different studies formerly conducted on Ilha Grande; (iii) compare studies conducted on Ilha Grande with studies in other areas in Rio de Janeiro state.

MATERIAL AND METHODS

Study area

Ilha Grande is located in Ilha Grande Bay, in the municipality of Angra dos Reis. It is the third largest island in Brazil (INEA, 2020), and the largest in Rio de Janeiro state. The shortest distance to the continent is approximately 2 km (Araújo & Oliveira, 1988). Protected areas are established on 156 km^2 (81% of the insular surface) of the total 193 km^2 of Ilha Grande (Ilha Grande State Park and Praia do Sul Biological Reserve, INEA, 2013) in the category of strict protection. The climate is tropical, hot and humid, subject to rainfall all year round, with higher concentration in the summer and lower in winter, and no dry season (INEA, 2013). The variation in average temperature is low throughout the year. July is the coldest month (20.2°C), and February, the hottest (26.4°C) (INEA, 2013). The forests on Ilha Grande are classified as Dense Ombrophilous Forest (Atlantic Forest) in the Brazilian Classification System (INEA, 2013). Dense secondary forests in intermediate and advanced stages of succession cover about 80% of the island. The remaining areas are forests in early successional stages, coastal scrub (restinga), vegetation on rock outcrops, and mangroves (INEA, 2013). Ilha Grande contains some of the best conserved remnants of the Atlantic Forest biome in Brazil, being therefore considered an ecological sanctuary. The relevance of local ecosystems led to the inclusion of Ilha Grande in the Atlantic Forest Biosphere Reserve in 1992 (INEA, 2020). It was more recently declared a UNESCO Natural Heritage Site on 05 July, 2019.

Data collection

Bat capture and data generation are results of different projects of the Mammal Ecology Lab (Laboratório de Ecologia de Mamíferos – LEMA) of the Rio de Janeiro State University (Universidade do Estado do Rio de Janeiro – UERJ). These five studies on bats conducted on Ilha Grande were not published independently in scientific journals. Some of the data gathered in studies 1, 2, 3, and 4 (described below) were included in the study by Esbérard *et al.* (2006). While other exclusive results by Esbérard *et al.* (2006) were not used in the present study, as they are not data from LEMA.

The bats captured in all studies were released on the same site of capture. Bats were initially identified in the field with the use of field guides and identification keys available in the scientific literature (mainly, Emmons & Feer, 1997; Gregorin & Taddei, 2002; Reis *et al.,* 2007; Gardner, 2008; Reis *et al.,* 2013). A few individuals of each species were collected for voucher material (see Table 1). Voucher specimens captured in studies 1, 2, 3, and 4 were deposited in the collection of the old Urban Bats Project (Projeto Morcegos Urbanos), currently the reference collection of the Bat Diversity Lab (Laboratório de Diversidade de Morcegos – LADIM) of the Federal Rural University of Rio de Janeiro (Processes 1785/89-IBAMA

Table 1. Updated list of bat species of Ilha Grande, Angra dos Reis, Rio de Janeiro state, Brazil, with reference to voucher specimens. Nomenclature and taxonomic arrangement according to Garbino *et al.* (2020).

TAXA	VOUCHER MATERIAL
Family Emballonuridae	
Peropteryx macrotis (Wagner, 1843)	LADIM 3836
Family Phyllostomidae	
Micronycteris microtis Miller, 1898	LADIM 3466, 4019; ALP 10843
Desmodus rotundus (É. Geoffroy, 1810)	ALP 10931
Chrotopterus auritus (Peters, 1856)	ALP 10842
Phyllostomus hastatus (Pallas, 1767)	LADIM 4045
Tonatia bidens (Spix, 1823)	ALP 10844, 10943
Trachops cirrhosus (Spix, 1823)	ALP 10580
Anoura caudifer (É. Geoffroy, 1818)	ALP 11026, 11045
Anoura geoffroyi Gray, 1838	ALP 10939
Glossophaga soricina (Pallas, 1766)	ALP 10923
Lonchophylla peracchii Dias, Esbérard e Moratelli, 2013	ALP 10924
Carollia perspicillata (Linnaeus, 1758)	ALP 10845, 11023
Glyphonycteris sylvestris Thomas, 1896*	ALP 10940
Artibeus cinereus (Gervais, 1856)	ALP 11038
Artibeus fimbriatus Gray, 1838	LADIM 3823, 4016, 4017; ALP 10840, 10851
Artibeus lituratus (Olfers, 1818)	LADIM 4031; ALP 10937
Artibeus obscurus Schinz, 1821	LADIM 3916, 3914, 3920,; ALP 10838, 10919
Chiroderma doriae Thomas, 1891	LADIM 3945; ALP 10852
Chiroderma villosum Peters, 1860	ALP 11039
Platyrrhinus lineatus (É. Geoffroy, 1810)	LADIM 3997, 4023; ALP 11052, 11053
Platyrrhinus recifinus (Thomas, 1901)*	LADIM 4229; ALP 10925, 10942
Pygoderma bilabiatum (Wagner, 1843)	ALP 11048
Sturnira lilium (É. Geoffroy, 1810)	ALP 10846
Sturnira tildae de la Torre, 1959	ALP 10848
Vampyressa pusilla (Wagner, 1843)	ALP 10928, 10944
Vampyrodes caraccioli (Thomas, 1889)*	ALP 10841
Family Noctilionidae	
Noctilio leporinus (Linnaeus, 1758)	LADIM 1072
Family Furipteridae	
Furipterus horrens (Cuvier, 1828)**	LADIM 3625
Family Molossidae	
Molossus fluminensis Lataste, 1891	LADIM 1011
Molossus molossus (Pallas, 1766)	ALP 11031
Nyctinomops laticaudata (É. Geoffroy, 1805)**	LADIM 3887; ALP 11056
Family Vespertilionidae	
Lasiurus ega (Gervais, 1856)**	LADIM 3679
Myotis albescens (É. Geoffroy, 1906)**	ALP 10918
Myotis izecksohni Moratelli, Peracchi, Dias & Oliveira, 2011*	ALP 11049
Myotis nigricans (Schinz, 1821)	LADIM 3704; ALP 11044, 11047
Myotis riparius Handley, 1960*	ALP 10839, 10847

* = Species added to the bat list of Ilha Grande.
** = Species registered by Esbérard *et al.* (2006) and not registered in the five studies detailed in the present study.
LADIM = Reference collection of the Bat Diversity Lab, Federal Rural University of Rio de Janeiro.
ALP = Reference collection of the Mastozoology Lab, Federal Rural University of Rio de Janeiro.

and SISBIO-10356-1). The voucher material of study 5 was deposited in the reference collection of the Mastozoology Lab (Laboratório de Mastozoologia Dr. Adriano Lúcio Peracchi – ALP) of the Federal Rural University of Rio de Janeiro (Universidade Federal Rural do Rio de Janeiro – UFRRJ) (Permanent IBAMA License Nº 12548 and Nº 10361; SISBIO Nº 45702-4; INEA Nº 63/2015; CEUA Nº 008/2018).

Fieldwork for study 1 was conducted during three consecutive nights per month between January, 1998, and December, 1999, totaling 72 survey nights. Two to five mist nets were set every night (sizes varying from 6 × 3 meters to 12 × 3 meters) and deployed for a period of six hours. Capture effort was estimated at a minimum of 15,552 h.m² and a maximum of 77,760 h.m² (Straube & Bianconi, 2002), with an average of 46,656 h.m². The sampling sites (one per night) were the Caxadaço trail, Parnaioca trail and Dois Rios Village (Fig. 1). Sampling was carried out in well conserved habitats and under varied climatic conditions that included wind and rain, and covered all phases of the lunar cycle. Mist nets were set in areas with higher likelihood of bat capture according to recommendations by Kunz & Kurta (1988), such as close to the entrance of caves, over rivers, along trails, faults, rocky formations, tree hollows, and under flowering or fruit-bearing trees.

Fieldwork for study 2 was conducted between May, 2001, and April, 2002. Six field surveys were carried out, each one during one, three or four nights, totaling 19 survey nights. Two to five mist nets (sizes varying from 7 × 3 meters to 12 × 3 meters) were deployed between four and seven hours from twilight, totaling 17,518 h.m² of capture effort. The sampling sites were located in Dois Rios Village, Parnaioca Village, Abraão Village and on Praia Grande de Palmas (Fig. 1). The position of mist nets was defined using the same criteria as in study 1.

Fieldwork for study 3 was conducted between September, 2002, and August, 2005, with sampling undertaken in three consecutive nights, totaling 33 survey nights. Mist nets were set in the same position during the three nights of the survey. Six mist nets were deployed every night (12 × 3 meters) from twilight to dawn, totaling 85,536 h.m² of capture effort. Eleven areas were covered: Matariz Village, Saco do Céu, Enseada das Estrelas, Abraão Village, Praia Grande de Palmas, Farol dos Castelhanos, Praia de Lopes Mendes, Caxadaço, Dois Rios Village, Dois Rios Village trail – Parnaioca, Parnaioca

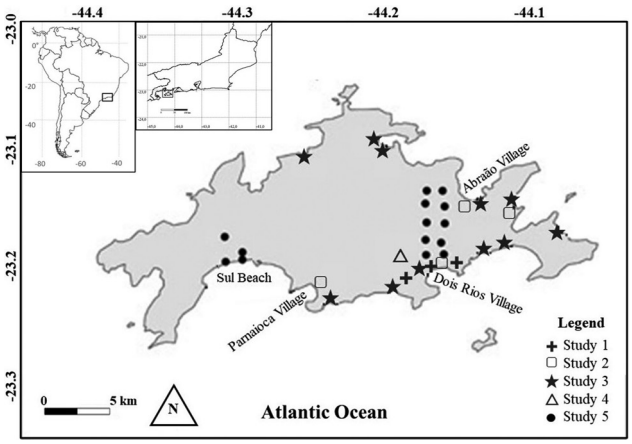

Figure 1. Map of Ilha Grande with sampling points of the five studies described in this paper, conducted between 1998 and 2018 on Ilha Grande, Angra dos Reis, Rio de Janeiro state, Brazil. A map of South America is shown, detailing the location of the state of Rio de Janeiro, in southeastern Brazil, while in the enlargement is shown the state of Rio de Janeiro detailing the location of Ilha Grande.

Village (Fig. 1). Sites were chosen by drawing sampling points at random on a virtual grid covering the entire area of Ilha Grande in order to generate data from various areas, not only from sites that favored bat flight routes. Mist nets were set in line as much as possible, with the center of the line on the coordinate of the sampling point. No phases of the lunar cycle were privileged in this study.

Fieldwork for study 4 was conducted between November, 2004 and January, 2007, totaling 31 survey nights. Mist nets were set in the tree canopy and in the understory. Nets were fastened in the canopy with a set of ropes and pulleys (Humphrey *et al.,* 1968; Vecchi & Alves, 2015), while nets in the understory were set underneath the ones above. The position of mist nets was not changed throughout the period of the survey. Three mist nets (12 × 3 meters) were deployed in the canopy and three in the understory every night, totaling a capture effort of 82,944 h.m^2, 40,176 h.m^2 in the canopy and 40,176 h.m^2 in the understory. All bats were individually marked with a colorful bead collar on a nylon string and a unique code, following our own methodology. The sampling site at the end of the Jararaca trail in Dois Rios Village (Fig. 1) was located at 240 meters altitude a.s.l. (Vecchi & Alves, 2015). Canopy height varied from 10 to 35 meters, or 23 meters on average (± 5.8 metros), although a few emergent trees reached 40 meters (Vecchi & Alves, 2015).

Fieldwork for study 5 was conducted between December, 2014, and August, 2018, totaling 56 survey nights. Bats were captured with 13 mist nets (10 × 3 meters, 19 mm mesh, Ecotone® 719/10) deployed before twilight and closed before dawn, totaling 257,790 h. m^2 of capture effort. Captured bats were marked with plastic collars with closed bands, each individual having a unique number. Small and young individuals were marked by piercing the dactylopatagium (Bonaccorso & Smythe, 1972) to facilitate identification in the short term in case of recapture. The methodology of uniform distribution plots (RAPELD – acronym in Portuguese for Rapid Assessment in Long-Term Ecological Research Sites) was adapted to long-term ecological research sites (Magnusson *et al.,* 2005). A total of 14 uniform distribution plots were assessed (Fig. 1), each 250 meters long along contour lines. Ten plots were located in the eastern part of the island, in Ilha Grande State Park, between Abraão and Dois Rios Villages, in Submontane and Montane Dense Ombrophilous Forest. Four plots were located in the western side of the island, in the Praia do Sul State Biological Reserve, in Submontane Ombrophilous Forest and coastal scrub forest (mata de restinga), between beaches Longa and Sul. Plots were located from sea level to 692 meters of altitude. No mist nets were set close to known refuges, neither over water bodies or near fruit-bearing plants. Sampling dates were defined regardless of lunar phases.

A species accumulation curve was built for each of the studies to plot the accumulated number of captures (X axis) per accumulated species richness (Y axis). The Jaccard Similarity Index was calculated with the Past 2.1 software (Hammer *et al.,* 2001) to compare the five studies conducted on Ilha Grande.

Comparison between studies on Ilha Grande and other studies in Rio de Janeiro state

The following sources were consulted in our literature review: CAPES database of non-published studies (http://www.capes.gov.br/servicos/banco-de-teses), Scientific Electronic Library Online (SciELO, http://www.scielo.org), Web of Science (WoS, http://www.webofknowledge.com), Google Scholar (https://scholar.google.com.br), and specialized journals not indexed in Scielo or Web of Science. The literature search was concluded in January, 2019. The following keywords were used in the search: "Chiroptera Rio de Janeiro", "quiróptero Rio de Janeiro", "morcego Rio de Janeiro" and "bat Rio de Janeiro".

Only studies that provide species lists with respective numbers of captured individuals were selected. We considered abundance as the sum of capture and recapture because some of the studies did not provide separate data. As not all studies discriminate the numbers of captures near refuges, captures in refuges were not excluded from the analyses, but the studies that mention this method of capture were marked. Inventories that did not use standardized capture methods according to Straube & Bianconi (2002) (h.m^2) were not used in the analysis of capture efforts.

In order to compare richness, capture number and capture effort between studies conducted on Ilha Grande and other studies in Rio de Janeiro state, only data of species in the family Phyllostomidae were used because capturing bats with mist nets in the understory is more efficient for this family (Sipinski & Reis, 1995; Pedro & Taddei, 1997; Kalko, 1998). Two simple linear regression analyses were performed, the first to compare Phyllostomidae richness with number of captures in different studies in Rio de Janeiro state; and the second to compare Phyllostomidae richness and capture effort between the different studies. The program Systat 13.0 was used for these analyses.

RESULTS

Updated list of bat species and capture results from five different studies of Ilha Grande

We confirmed the occurrence of 36 bat species on Ilha Grande (Table 1). We add five species to the Ilha Grande bat list: *Glyphonycteris sylvestris, Platyrrhinus recifinus, Vampyrodes caraccioli, Myotis izecksohni,* and *M. riparius.* We removed seven species from the previous list: *Artibeus planirostris, Lonchophylla mordax, Lonchophylla bokermanni, Micronycteris minuta, Micronycteris megalotis, Uroderma magnirostrum,* and *Nyctinomops macrotis.*

Considering the five studies together, a total of 2,763 individuals of 32 species in 23 genera and five families were captured. The most abundant species on the island

Table 2. Bat abundance in five studies conducted between 1998 and 2018 on Ilha Grande, Angra dos Reis, Rio de Janeiro state, Brazil. In parentheses, number of recaptures in studies that cite this data. Total capture number includes recapture.

Taxa	Study 1 (1998-1999)	Study 2 (2001-2002)	Study 3 (2002-2005)	Study 4 (2004-2007)	Study 5 (2014-2018)	TOTAL
Family Emballonuridae						
Peropteryx macrotis	0	0	1	0	0	**1**
Family Phyllostomidae						
Micronycteris microtis	2	0	3	0	13	**18**
Desmodus rotundus	13	2	16	0	3	**34**
Chrotopterus auritus	0	0	0	1	5	**6**
Phyllostomus hastatus	4	0	25	0	0	**29**
Tonatia bidens	16	7	9	2	12	**46**
Trachops cirrhosus	4	3	8	0	16	**31**
Anoura caudifer	19	6	9	1	6 (1)	**42**
Anoura geoffroyi	0	0	0	0	6	**6**
Glossophaga soricina	16	0	4	1	4	**25**
Lonchophylla peracchii	8	2	4	3	7	**24**
Carollia perspicillata	225	65	161	18	239 (27)	**735**
Glyphonycteris sylvestris	0	0	0	0	2	**2**
Artibeus cinereus	0	0	0	2	4	**6**
Artibeus fimbriatus	203	25	81	84 (8)	80 (4)	**485**
Artibeus lituratus	33	3	31	23 (1)	25	**116**
Artibeus obscurus	139	46	99	32 (3)	148 (6)	**473**
Artibeus spp.	41	4	8	17 (1)	0	**71**
Chiroderma doriae	3	1	7	7	4	**22**
Chiroderma villosum	1	0	2	0	2	**5**
Platyrrhinus lineatus	13	5	9	3	8	**38**
Platyrrhinus recifinus	0	0	0	3	8	**11**
Pygoderma bilabiatum	1	0	1	10	0	**12**
Sturnira lilium	161	33	76	11	4	**285**
Sturnira tildae	0	0	0	2	5	**7**
Vampyressa pusilla	0	4	7	2	4	**17**
Vampyrodes caraccioli	0	0	0	0	3	**3**
Family Noctilionidae						
Noctilio leporinus	1	33	42	0	0	**76**
Family Molossidae						
Molossus fluminensis	0	2	2	0	0	**4**
Molossus molossus	4	16	42	0	0	**62**
Family Vespertilionidae						
Myotis izecksohni	0	0	0	0	1	**1**
Myotis nigricans	12	10	18	4	1	**45**
Myotis riparius	0	0	0	0	25	**25**
Total capture	**919**	**267**	**665**	**226 (13)**	**635 (38)**	**2.763**
Accumulated capture	**919**	**1.186**	**1.851**	**2.090**	**2.763**	—
Total species	**20**	**17**	**23**	**18**	**26**	**32**
Accumulated species	**20**	**22**	**23**	**27**	**32**	—
Exclusive species	**0**	**0**	**1**	**0**	**5**	—
Capture effort (h.m^2)	**46.656**	**17.518**	**85.536**	**82.944**	**257.790**	**490.444**
Capture efficiency*	**0,020**	**0,015**	**0,008**	**0,003**	**0,003**	**0,006**

* = Total capture divided by capture effort.

were *C. perspicillata,* with 735 captures, and *A. fimbriatus*, with 485 captures. Bats of two species were only captured once, *P. macrotis* and *M. izecksohni*. Eleven species were common to the five studies: *C. perspicillata, A. fimbriatus, Sturnira lilium, A. obscurus, Artibeus lituratus, A. caudifer, T. bidens, Platyrrhinus lineatus, M. nigricans, Lonchophylla peracchii,* and *C. doriae* (Table 2).

Chronologically, 20 species were registered in the first study; two species added from the second study, and only one species from the third study. Four more species were added from study 4, with *C. auritus, Artibeus cinereus,* and *P. recifinus* captured exclusively in mist nets in the canopy, and *Sturnira tildae* only in a mist net at ground level. Five other species were added from study 5. All five studies have therefore contributed species for the bat list of Ilha Grande (Table 2).

The Jaccard Similarity Index between the five studies on Ilha Grande demonstrated a variation of Cj = 0.48 to 0.87. Studies 1 and 3 had more similar results (87%), followed by studies 2 and 3 (74%) (Table 3).

Table 3. Jaccard Similarity Index between five different studies conducted between 1998 and 2018 on Ilha Grande, Angra dos Reis, Rio de Janeiro state, Brazil.

	Study 1	Study 2	Study 3	Study 4	Study 5
Study 1	1.00				
Study 2	0.68	1.00			
Study 3	0.87	0.74	1.00		
Study 4	0.52	0.52	0.52	1.00	
Study 5	0.53	0.48	0.53	0.63	1.00

Comparison between studies on Ilha Grande and other studies in Rio de Janeiro state

A total of 39 studies containing lists of bat species in Rio de Janeiro state were reviewed (Table 4 and Fig. 2). The best studied location was Maciço da Tijuca, with six sampling sites. Five studies conducted on Ilha Grande were assessed. Two studies conducted at different periods in time were found for each of the locations Pedra Branca State Park and Tinguá Biological Reserve. One single inventory was found for each of the other locations.

The highest number of Phyllostomidae bat species was registered in the Tinguá Biological Reserve, with 25 species in the family (Table 4, Figs. 3A and 3B). At the same time, it accounted for the highest capture effort of all studies (268,473 h.m^2) (Table 4, Figs. 3A and 3B). Study 5 on Ilha Grande is among the richest in Phyllostomidae, with 23 species (Table 4, Figs. 3A and 3B). The study with highest capture success was conducted at Quinta da Boa Vista, with 2,994 captures (Table 4, Fig. 3A). The linear regression between capture number and species richness was significant ($r^2 = 0.337$; $F = 4.732$; $p = 0.036$), but the best fit was generated from a quadratic model ($r^2 = 0.648$ – Fig. 3A). The linear regression between capture effort and richness was also significant, as well as positive ($r^2 = 0.546$; $F = 24.078$; $p < 0.001$, Fig. 3B). This confirmed that the higher the number of captures and capture effort, the higher the richness encountered.

DISCUSSION

The confirmation that 36 bat species occur on Ilha Grande implies that the island hosts 18% of the bat species known in Brazil (Garbino *et al.,* 2020), 37% of the species in the Atlantic Forest (Muylaert *et al.,* 2017), and 46% of the species known in Rio de Janeiro state (Peracchi & Nogueira, 2010; Moratelli *et al.,* 2011; Dias *et al.,* 2013; Delciellos *et al.,* 2018).

Species lists must be regularly updated because new species are continually described and recorded in Brazil due to taxonomic revisions (*e.g.,* Moratelli *et al.,* 2011; Dias *et al.,* 2013; Garbino *et al.,* 2020). In addition, there are species that are difficult to identify and can be confused with other species such as *G. sylvestris* (Nogueira *et al.,* 2007) and species of the genus *Myotis* (López-González *et al.,* 2001; Moratelli *et al.,* 2011).

Myotis izecksohni was described after publication of the first list of bat species of Ilha Grande (Esbérard *et al.,* 2006). Records of *M. izecksohni* have shown that it occurs between 600 and 1,300 meters a.s.l. (Moratelli *et al.,* 2011; Reis *et al.,* 2013; Dias *et al.,* 2015). Bats of this species were captured during study 5 on Ilha Grande at 408 meters a.s.l., which indicates that it can occur at lower altitudes than formerly stated.

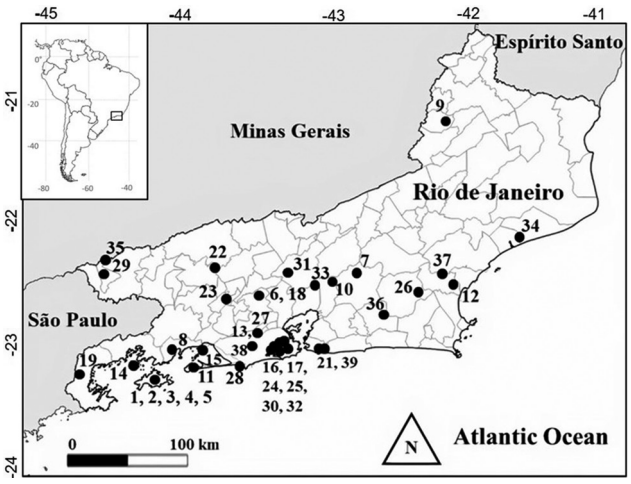

Figure 2. Locations in Rio de Janeiro state where bat inventories have been conducted. Numbers correspond to locations in Table 4. A map of South America is shown, detailing the location of the state of Rio de Janeiro in southeastern Brazil.

Based on taxonomic reviews of bat voucher material collected in studies by Esbérard *et al.* (2006), the occurrence of seven species was not confirmed on Ilha Grande. They were therefore removed from our list. Some species, such as *A. planirostris, M. minuta, N. macrotis* and *U. magnirostrum,* are reported for the Costa Verde region, in the municipalities of Mangaratiba or Angra dos Reis (Bolzan *et al.,* 2010; Delciellos *et al.,* 2018). Specimens registered by Esbérard *et al.* (2006) as *M. megalotis* correspond to *M. microtis.* Specimens formerly identified on the island as *L. mordax* and *L. bokermanni* correspond to *L. peracchii,* the only species of Lonchophyllinae registered in the state of Rio de Janeiro (see Dias *et al.,* 2013).

The five studies conducted by the authors on Ilha Grande and described in this paper amount to a total capture effort of 490,444 h.m^2, one of the largest ever applied to a single area in Rio de Janeiro state. Considering all five studies, the species more often captured were *C. perspicillata* and *A. fimbriatus*, which together represented almost half the total captures (44,15%). These two most abundant species on Ilha Grande are also among the most frequent and most captured bat species in the Atlantic Forest domain (Muylaert *et al.,* 2017). As Esbérard *et al.* (2006) had already observed, the record of *A. fimbriatus* as the second most abundant species differs from other locations surveyed in Rio de Janeiro state, where *A. lituratus* is most often more abundant (*e.g.,* Dias *et al.,* 2002; Luz *et al.,* 2011a; Esbérard *et al.,* 2013; Lourenço *et al.,* 2014; Souza *et al.,* 2015).

Although the five studies conducted on the island were based on the use of mist nets, the sampling points and some criteria for defining the location of these points differed. In studies 1 and 2, mist nets were set in probable bat flight routes (Kunz & Kurta, 1988), resulting

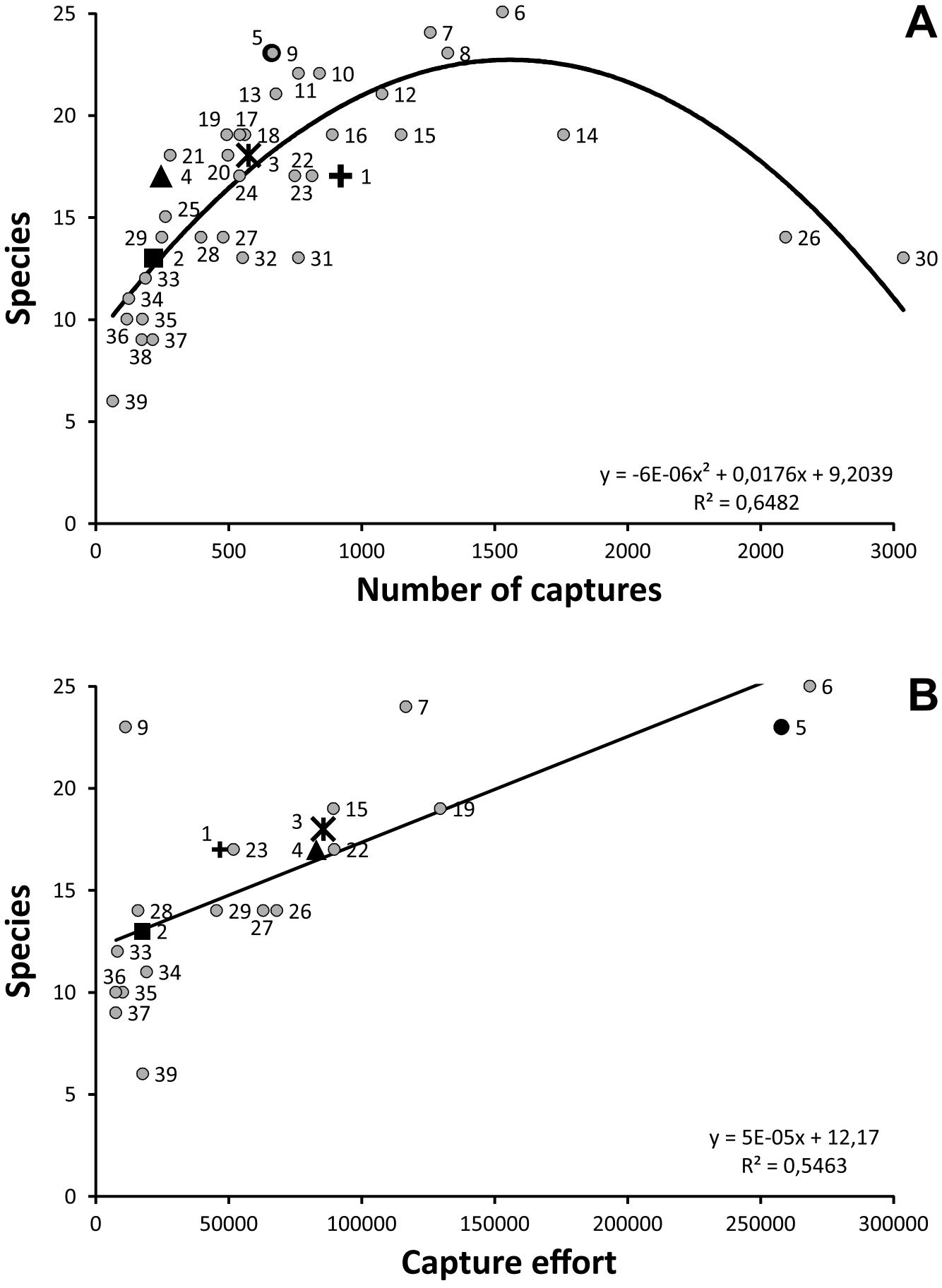

Figure 3. Relationship between number of species in the Phyllostomidae family (A) and number of captures in the Phyllostomidae family, (B) and capture effort (h.m^2) in bat inventories in Rio de Janeiro state. Numbers correspond to locations listed in Table IV. Dots: cross = study 1 on Ilha Grande; square = study 2 on Ilha Grande; star = study 3 on Ilha Grande; triangle = study 4 on Ilha Grande; black circle = study 5 on Ilha Grande; grey circle = other studies in Rio de Janeiro state.

Table 4. Bat studies in Rio de Janeiro state, number of species and number of captures in the family Phyllostomidae, capture effort (according to Straube & Bianconi, 2002), latitude and longitude of each site, and respective references.

Nº	Inventories	Nº species Phyllostomidae	Capture	Effort (h.m^2)	Latitude	Longitude	Reference
1	Ilha Grande (Study 1)	17	902	46.656	-23.148417	-44.246978	This study
2	Ilha Grande (Study 2)	13	206	17.518	-23.148417	-44.246978	This study
3	Ilha Grande (Study 3)	18	560	85.536	-23.148417	-44.246978	This study
4	Ilha Grande (Study 4)	17	235	82.944	-23.148417	-44.246978	This study
5	Ilha Grande (Study 5)	23	646	257.790	-23.148417	-44.246978	This study
6	Tinguá Biological Reserve	25	1.504	268.473	-22.596153	-43.495839	Lourenço *et al.,* 2014
7	Guapiaçu Ecological Reserve	24	1.236	116.640	-22.400000	-42.733333	Souza *et al.,* 2015
8	Rio das Pedras Ecological Reserve	23	1.301	—	-22.988928	-44.104261	Luz *et al.,* 2011a
9	Paraíso do Tobias*	23	650	11.232	-21.404500	-42.067683	Esbérard *et al.,* 2010
10	Paraíso State Ecological Station	22	824	—	-22.489500	-42.913972	Esbérard, 2007
11	Marambaia Island	22	746	—	-22.939444	-43.610556	Lourenço *et al.,* 2010
12	Morro de São João*	21	1.056	—	-22.538417	-42.012472	Esbérard *et al.,* 2013
13	Pedra Branca State Park	21	662	—	-22.940556	-43.480556	Dias *et al.,* 2002, 2003
14	Gipóia Island	19	1.731	—	-23.039058	-44.353239	Carvalho *et al.,* 2011
15	Itacuruçá Island*	19	1.128	89.400	-22.940278	-43.894444	Gomes & Esbérard, 2017
16	Rio de Janeiro Botanical Garden	19	872	—	-22.967683	-43.223858	Esbérard, 2003
17	Grajaú State Park	19	547	—	-22.923611	-43.268333	Esbérard, 2003
18	Tinguá Biological Reserve	19	528	—	-22.596153	-43.495839	Dias & Peracchi, 2008
19	Serra da Bocaina National Park	19	480	129.600	-23.205277	-44.838055	Delciellos *et al.,* 2018
20	Açude da Solidão	18	484	—	-22.961111	-43.300277	Esbérard, 2003
21	Serra da Tiririca State Park	18	269	—	-22.951147	-43.008333	Teixeira & Peracchi, 1996
22	Morro Azul*	17	796	89.700	-22.484114	-43.566667	Pereira, 2013
23	Curió Natural Municipal Park	17	732	51.840	-22.596944	-43.705833	Gomes *et al.,* 2015
24	Penhasco Dois Irmãos Natural Municipal Park	17	527	—	-22.989069	-43.233997	Esbérard, 2003
25	Gávea Park	15	252	—	-23.985555	-43.248333	Esbérard, 2003
26	Poço das Antas Biological Reserve	14	2.557	68.040	-22.554833	-42.279883	Mello, 2009
27	Mendanha Mountain Range	14	466	63.000	-22.825217	-43.527389	Menezes-Júnior, 2008
28	Prainha Natural Municipal Park	14	384	15.900	-23.033386	-43.502700	Pinto, 2008
29	Itatiaia National Park	14	238	45.450	-22.453917	-44.605539	Martins *et al.,* 2015
30	Quinta da Boa Vista*	13	2.994	—	-22.905556	-43.221222	Esbérard *et al.,* 2014
31	Araras Bological Reserve*	13	746	—	-22.445011	-43.261539	Esbérard *et al.,* 1996
32	Trapicheiros Reserve	13	538	—	-22.941203	-43.236022	Esbérard, 2003
33	Serra dos Órgãos National Park*	12	177	8.172	-22.491136	-43.043772	Moratelli & Peracchi, 2007
34	Restinga de Jurubatiba National Park	11	115	19.140	-22.204053	-41.528261	Luz *et al.,* 2011b
35	Visconde de Mauá	10	166	10.135	-22.363056	-44.596519	Luz *et al.,* 2013
36	Rio Vermelho Farm	10	108	7.560	-22.721944	-42.550833	Mello & Schittini, 2005
37	União Biological Reserve	9	204	7.560	-22.452678	-42.041825	Mello & Schittini, 2005
38	Pedra Branca State Park	9	164	—	-22.940556	-43.480556	Almeida *et al.,* 2011
39	Maricá Environmental Protection Area	6	56	17.640	-22.956111	-42.882222	Gomes *et al.,* 2016

* = Inventories with capture in refuges.
— = Capture efforts in h.m^2 not available in publications.

in the surveys with highest capture efficiency. In studies 3, 4, and 5, we did not choose specific points to set the mist nets. In study 3, the nets were set systematically, while in study 5 we used the method of uniform distribution plots. Only study 4 included sampling efforts in the tree canopy.

Comparisons between studies are of high relevance to science, contributing to the understanding of patterns of habitat use or even functioning as parameters of efficiency, especially when different methods are used. Setting mist nets in the forest canopy, the method used in study 4, is an alternative to survey bat species not easily captured in nets set at ground level (*e.g.,* Carvalho & Fabián, 2011). Knowledge on the use of the canopy by bats is still incipient in Brazil (Scultori *et al.,* 2008), where most studies of the kind have been conducted in the Amazon, often leading to the addition of exclusive species only registered when this method is applied (*e.g.,* Kalko & Handley, 2001; Bernard, 2001). Considering the chronology of studies on Ilha Grande, positioning mist nets at canopy height led to the addition of three species. Although the capture rates of *C. auritus, A. cinereus* and *P. recifinus* were low, these species are often captured at ground level, as in study 5. Setting mist nets in the canopy increased the capture rate of species that might otherwise have been considered rare if surveys had been restricted to ground level (Esbérard *et al.,* 2006; Bolzan *et al.,* 2010).

Even if capture rate was already high in former years, study 5, the most recent one (from 2014 to 2018),

contributed more species records to the list of Ilha Grande. The RAPELD methodology used in this study (Magnusson *et al.,* 2005) recommends sampling to be carried out in areas away from human settlements or roads (where research is often conducted), removing the bias of where researchers believe capture rate will be higher. Adoption of this methodology directed sampling to be performed in areas not considered in former studies (Esbérard *et al.,* 2006), as well as at higher altitudes.

Areas in the Atlantic Forest where records of bats varied from 20 to 40 species and more than 1,000 Phyllostomidae individuals were captured may be considered well studied (*e.g.,* Esbérard, 2003; Bergallo *et al.,* 2003). By applying these parameters to the studies assessed in this paper, we found that more than 20 species were only registered in nine studies in Rio de Janeiro state, while more than 1,000 Phyllostomidae bats were captured only in three of these nine studies (Lourenço *et al.,* 2014; Souza *et al.,* 2015; Luz *et al.,* 2011a). Capture rate may be related to local bat density, but it can also be influenced by the methods used (Fleming, 1988; Kunz & Kurta, 1988; Esbérard, 2006, 2007, 2009).

Long capture efforts are required to assess the real richness of a location (Voss & Emmons, 1996; Bergallo *et al.,* 2003). A large effort may be represented by the increase of survey nights and/or capture hours, or by the number and surface area of mist nets (Morrison, 1978, 1980,; Straube & Bianconi, 2002). The two studies in Rio de Janeiro state that stand out due to a capture effort of more than 200,000 h.m^2 are among the richest (25 and 23 species) (Lourenço *et al.,* 2014; study 5 on Ilha Grande). Short inventories most often do not include species that are difficult to capture or that are considered rare; such species may be captured in long-term ecological studies or when higher capture efforts than usual are applied (Esbérard, 2009).

So that more consistent data for conservation studies are obtained (see Bernard *et al.,* 2011), it is important that the lists are updated regularly, as new species are being described and registered as a result of taxonomic reviews and new inventories. (*e.g.,* Moratelli *et al.,* 2011; Nogueira *et al.,* 2012; Dias *et al.,* 2013; Nascimento *et al.,* 2013; Delciellos *et al.,* 2018). Lists of species that provide the capture quantity are important, as variation in abundance has been applied in species management and conservation biology (Brown *et al.,* 1995).

CONCLUSIONS

Given the results of our study, we reiterate the relevance of specimen collection for vouchers in zoological collections. The analysis and confirmation of taxonomic identification of specimens *a posteriori* in the light of current knowledge depends on voucher specimens and is essential to increase the knowledge of species diversity in different areas. Bats captured on Ilha Grande and deposited in zoological collections allowed us to review the identification of specimens as well as to remove species whose identification had not been confirmed from the list of bat species of Ilha Grande.

Complementarily, Ilha Grande is a location with a long history of research with logistical support by the Center for Environmental Studies and Sustainable Development (CEADS, acronym in Portuguese) of the State University of Rio de Janeiro (UERJ, acronym in Portuguese), located in Dois Rios Village. This explains the number of studies conducted by different coordinators with various objectives described in this paper. It has also contributed to the fact that Ilha Grande is one of the areas in the state of Rio de Janeiro with more bat records in terms of abundance and species richness, as well as one of the areas with highest capture effort.

The use of capture effort measures may be considered efficient to compare species richness in the Phyllostomidae family. For comparisons between studies, however, the use of this variable alone may be a problem because the sampling design of the surveys will influence the total richness registered at the sampling site. When studies on Ilha Grande were compared with others in the state, we noticed variations in richness and in abundance due to the methods used, with some species exclusive to certain studies. Besides, several publications do not include capture effort data, or calculate capture effort differently from the recommendation by Straube & Bianconi (2002), used in this study.

Implementation of the RAPELD methodology and taxonomic identification supported by voucher specimens in zoological collections made it possible to add new species records for Ilha Grande. Still, other new species records may be expected for the island, once sampling of bat species not commonly captured in mist nets has not been intensive. A methodology for insectivore bats, such as the use of bioacoustics, may increase the richness of bat species on Ilha Grande even more. In addition to the 36 species confirmed in this study, other four species for which voucher specimens were not available may be considered for Ilha Grande based on spatial distribution data.

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AUTHORS' CONTRIBUTIONS

Each author made a relevant contribution to the present manuscript, performed a critical revision, and approved the final version. L.M.C.: Fieldwork (in charge of study 5 on Ilha Grande); organization, analysis and data interpretation; manuscript development. E.C.L.: Fieldwork (study 5 on Ilha Grande); organization, data analysis and interpretation; manuscript development. D.A.D.J.: Fieldwork (study 5 on Ilha Grande); organization, analysis and data interpretation; manuscript development. D.D.: Taxonomic identification of voucher specimens; manuscript development. C.E.L.E.: Fieldwork (studies 1 and 2 on Ilha Grande); manuscript development. T.J.-N.: Fieldwork (study 3 and in charge of study 4 on Ilha Grande); organization of data. G.M.: Fieldwork (in charge of studies 1, 2, and 3 on Ilha Grande); organization of data. H.G.: Fieldwork (studies 1 and 2 on Ilha Grande); data analysis and interpretation; manuscript development.

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