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Article

Bat assemblages of protected areas in the state of Rio de Janeiro, Brazil

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ABSTRACT. We analyzed the bat assemblages found in protected areas in the state of Rio de Janeiro, Brazil, which is the best-sampled region of the Atlantic Forest. We selected 24 strict nature reserves and nine sustainable-use protected areas. We used data from inventories and complemented with data from the literature. We compared strict and sustainable-use protected areas, and tested whether the bat assemblages varied between habitat types. We tested the effect of geographic distance on the dissimilarity between bat assemblages, as well as the relationship between species composition and the size, mean altitude of the protected area, and capture effort. We compiled a total of 34,443 capture records, involving 67 species. Three species were captured only once, which raises cause for concern. Bat assemblages did not vary between protected area categories, but did vary among habitats with less than 1,000 captures. Assemblages were more similar to one another in geographically proximate areas. The size of the protected area and capture effort did not affect the composition of the bat assemblages, but altitude did influence this parameter. The Atlantic Forest is a priority biome for research and conservation, and reliable data on species distributions are essential for the development of conservation strategies.

KEYWORDS. Altitude, Atlantic Forest, Chiroptera, geographic distance, types of habitat.

RESUMO. Assembleias de morcegos em Unidades de Conservação no estado do Rio de Janeiro, Brasil. Analisamos as assembleias de morcegos encontradas em Unidades de Conservação (UCs) no estado do Rio de Janeiro, Brasil, que é a região melhor amostrada da Mata Atlântica. Selecionamos 24 UCs de Proteção Integral e nove de Uso Sustentável. Utilizamos dados de inventários e complementamos com dados da literatura. Comparamos as UCs de Proteção Integral e de Uso Sustentável e testamos se as assembleias de morcegos variavam entre os tipos de habitat. Testamos o efeito da distância geográfica na dissimilaridade entre as assembleias de morcegos, bem como a relação entre a composição das espécies e o tamanho, a altitude média das UCs e o esforço de captura. Compilamos um total de 34.443 registros de captura, de 67 espécies. Três espécies foram capturadas apenas uma vez, o que mostra motivos de preocupação. As assembleias de morcegos não variaram entre categorias das UCs, mas variaram entre habitats com menos de 1.000 capturas. As assembleias foram mais parecidas entre si em áreas geograficamente próximas. O tamanho da UC e o esforço de captura não afetaram a composição das assembleias de morcegos, mas a altitude influenciou esse parâmetro. A Mata Atlântica é um bioma prioritário para pesquisa e conservação, e dados confiáveis sobre a distribuição de espécies são essenciais para o desenvolvimento de estratégias de conservação.

PALAVRAS-CHAVE. Altitude, Mata Atlântica, Chiroptera, distância geográfica, tipos de habitat.

Actions for conservation and sustainable use of natural resources depend fundamentally on the availability of reliable data on biological diversity. These actions also depend on a minimum level of understanding of the systematics and occurrence of organisms and the ecosystems they inhabit (Santos, 2004). The adequate conservation of habitats can contribute to the maintenance of most of a region's diversity (Shaw, 1985).

One of the main strategies of nature conservation is the protected area model (Bernardo, 2007). Current Brazilian environmental legislation defines two types of protected areas: strict nature reserves and areas of sustainable use. The primary objective of strict nature reserves is to preserve natural resources, by permitting only indirect use, except in specific cases. By contrast, sustainable-use protected areas are intended to ensure conservation through the managed exploitation of natural resources (see Bernardo, 2007).

Understanding the variation in the abundance of species is an important prerequisite for the management and conservation of biological resources (Brown *et al.*, 1995). Reliable information on the occurrence and relative abundance of each species found within a protected area is fundamental to the definition of threats and conservation priorities (*e.g.*, Chiarello, 1995; Costa *et al.*, 2005). This type of data can also be used to infer which species will be able to survive in protected area over the long term

(Chiarello, 2000). A widely recurring pattern in ecology is the rarity of the majority of species, while only a few are abundant (Brown, 1984).

Human occupation changes natural environments, which threatens the survival of many species (Mickleburgh, 2002; Voigt & Kingston, 2016). However, some bat species are less vulnerable to habitat fragmentation than most other mammals due to their capacity to disperse between widely-separated fragments (Estrada & Coates-Estrada, 2002; Meyer & Kalko, 2008). In many cases, phyllostomid bats with insectivorous and carnivorous (Subfamily Phyllostominae) habits decrease in abundance and species richness in impacted habitats, whereas the abundance of frugivorous and nectarivorous species may increase in these habitats (Clarke *et al.*, 2005; Castro-Arellano *et al.*, 2007; Willig *et al.*, 2007; Bobrowiec & Gribel, 2010).

The bats of the Atlantic Forest are relatively well-studied in comparison with other Brazilian biomes (Bernard *et al.*, 2011). This biome has a long history of scientific inventory, due to the presence of a number of respected scientific institutions and a relatively high concentration of researchers (see Lewinsohn & Prado, 2005; Brito *et al.*, 2009). Although Rio de Janeiro is one of the best sampled Brazilian states in the Atlantic Forest biome (Bergallo *et al.*, 2003; Stevens, 2013), a number of gaps persist in the scientific understanding of the distribution of bats in this region (Dias *et al.*, 2010; Peracchi & Nogueira, 2010).

Despite the large number of inventories available for Rio de Janeiro, the state's bat fauna has yet to be analyzed systematically from the perspective of its network of protected areas. Given this, the present study aimed to (i) inventory the bat species that occur in the protected areas of the state of Rio de Janeiro and (ii) test the potential influence of the category protected area (strict nature reserve *vs.* sustainable use), habitat type, geographic distance, altitude, reserve size, and capture effort on the similarity of the local bat assemblages.

MATERIAL AND METHODS

Rio de Janeiro has 48 strict nature reserves and 53 sustainable-use reserves. Currently, 78 bat species are known to occur in the state (Peracchi & Nogueira 2010; Moratelli *et al.*, 2011; Dias *et al.*, 2013; Delciellos *et al.*, 2018). This state is good for study with bats, because it is the best-sampled region of the Atlantic Forest (Bergallo *et al.*, 2003; Bernard *et al.*, 2011).

We obtained data from the inventories conducted by the field team of the Laboratory of Bat Diversity of the *Universidade Federal Rural do Rio de Janeiro* (UFRRJ) between 1989 and 2013. We complemented our findings with published data, including papers, dissertations, and theses. We only selected studies that provided information on the total number of individuals captured (Appendix 1).

We searched the literature using the following databases: CAPES Theses Database (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), and Google Scholar (http://scholar.google.com). We also searched in "Revista Brasileira de Zoociências" and "Chiroptera Neotropical" that are not listed in the SciELO database and consulted the curricula of Brazilian chiropteran researchers available the Lattes online database (http://lattes.cnpq.br). We conducted the research in July 2013, using the keywords: "Chiroptera", "Quiróptero" (chiropteran),"Bat", "Morcego" (bat), and "Rio de Janeiro".

We verified the geographic coordinates of each study site (protected areas only) and plotted the localities in Quantum GIS 1.8.0. We only considered protected areas recognized by the Brazilian National System of Protected Areas (SNUC) that were available as shapefiles (shp, shx, or dbf). We selected 49 sites located within 33 protected areas (Tab. I, Fig. 1).

We transformed the capture data into relative abundance by dividing the number of captures of each species by the total number of individuals captured in each protected area. We used Non-Metric Multidimensional Scaling (NMDS) to verify the variation in the bat assemblages among protected areas. We obtained two NMDS axes based on Bray-Curtis distances (Jongman *et al.*, 1995), so that the first NMDS axis represents the different bat assemblages, which we related to the variables analysed (see below).

We assigned the protected areas to one of two categories: (i) strict nature reserve or (ii) sustainable-use protected areas. To define the type of habitat at each site, we classified the predominant type of vegetation cover as montane forest, *restinga*, submontane forest, pasture, secondary growth, urban, eucalypt or upper montane forest. Geographic distances between sites were measured by the linear distance between the central points of each pair of protected areas in Quantum GIS 1.8.0. We considered the total area of each protected area to analyze the size. We used the altitude of each study site to calculate the mean altitude of each protected area. We calculated capture effort ($h.m^2$) according to the approach of Straube & Bianconi (2002). Some of the studies identified in the literature did not provide information on the capture effort, and were thus not included in the analyses.

We compared the reserve categories (strict nature reserve *vs.* sustainable use) with the Mann-Whitney test, and applied the Kruskal-Wallis test to determine whether the bat assemblages varied significantly among habitat types. We then compiled a matrix of ecological and geographic distances to test the potential influence of distance on the dissimilarity between bat assemblages. For this, we applied the Mantel test (5,000 replications), based on Bray-Curtis distances for the matrix of bat assemblages (ecological distances), and the

Tab. I. Sampling sites, the protected areas surveyed in the state of Rio de Janeiro, and data sources. *See appendix 1[APA, Área de Proteção Ambiental (Environmental Protection Area); ARIE, Área de Relevante Interesse Ecológico (Area of Relevant Ecological Interest); EE, Estação Ecológica (Ecological Station); FLONA, Floresta Nacional (National Forest); PARNA, Parque Nacional (National Park); PE, Parque Estadual (State Park); PNM, Parque Natural Municipal (Natural Municipal Park); REBIO, Reserva Biológica (Biological Reserve); RESEC, Reserva Ecológica (Ecological Reserve)].

#	Locality	Protected area	Source*
1	Parque Estadual do Desengano	PE do Desengano	1, This Study
2	Restinga de Jurubatiba	PARNA Restinga de Jurubatiba	2, 3, This Study
3	REBIO União	REBIO União	4, This Study
4	Morro de São João	APA da Bacia do Rio São João - Mico Leão	5
5	REBIO Poço das Antas	REBIO de Poço das Antas	6, 7, This Study
6	Santa Helena e Haras Harmonia	APA da Bacia do Rio São João - Mico Leão	This Study
7	Fazenda Rio Vermelho	APA da Bacia do Rio São João - Mico Leão	4
8	Reserva Ecológica de Guapiaçu	PE dos Três Picos	8, This Study
9	Centro de Primatologia	EE do Paraíso	This Study
10	Parque Estadual da Serra do Tiririca	PE Serra do Tiririca	9
11	Parque Nacional da Serra dos Órgãos	PARNA da Serra dos Órgãos	10, 11
12	Fazenda Santa Inês	APA Suruí	This Study
13	REBIO Araras	REBIO de Araras	12, This Study
14	Parque Henrique Lage	PARNA da Tijuca	This Study
15	Parque da Catacumba	PNM da Catacumba	This Study
16	Reserva dos Trapicheiros	PARNA da Tijuca	This Study
17	Penhasco Dois Irmãos	PNM Penhasco Dois Irmãos – Arquiteto Sérgio Bernardes	This Study
18	Parque da Gávea	PNM da Cidade	This Study
19	Parque Estadual do Grajaú	PE Grajaú	This Study
20	Parque Nacional da Tijuca	PARNA da Tijuca	This Study
21	Bosque da Barra	PNM Bosque da Barra	13
22	Parque Chico Mendes	PNM Chico Mendes	This Study
23	Parque Natural Municipal da Prainha	PNM da Prainha	14
24	Parque Estadual da Pedra Branca	PE Pedra Branca	15
25	Parque Natural Municipal do Mendanha	APA de Gericinó/Mendanha	16
26	Reserva Biológica do Tinguá	REBIO do Tinguá	11, 17
27	Instituto Zoobotânico de Morro Azul	APA Guandu	18, 19
28	Parque do Curió	PNM do Curió	20
29	Ponte Coberta	APA Guandu	21, This Study
30	Belvedere	APA Guandu	21, This Study
31	Floresta Nacional Mario Xavier	FLONA Mario Xavier	22
32	Cacaria	APA Guandu	21, This Study
33	Ilha de Itacuruçá	APA de Mangaratiba	This Study
34	Ilha de Jaguanum	APA de Mangaratiba	This Study
35	Ilha da Marambaia	APA de Mangaratiba	23, 24, This Study
36	Muriqui	APA de Mangaratiba	21, This Study
37	Santa Bárbara	APA de Mangaratiba	21, This Study
38	Sahy	APA de Mangaratiba	21, This Study
39	Hotel Portobello	APA de Mangaratiba	This Study
40	Conceição de Jacareí	APA de Mangaratiba	21, This Study
41	Reserva Rio das Pedras	APA de Mangaratiba	25
42	Ilha Grande	PE da Ilha Grande	26
43	Ilha da Gipóia	APA de Tamoios	27, This Study
44	Ilha do Capítulo	APA de Tamoios	This Study
45	Floresta da Cicuta	ARIE Floresta da Cicuta	This Study
46	Fazenda Santa Cecília do Ingá	PNM Fazenda Santa Cecília do Ingá	28

Tab. I. Cont.

#	Locality	Protected area	Source*
47	Fazenda Marimbondo	APA Serra da Mantiqueira	29
48	Parque Nacional do Itatiaia	PARNA do Itatiaia	18, 30
49	Praia do Sono	RESEC de Juatinga	This Study

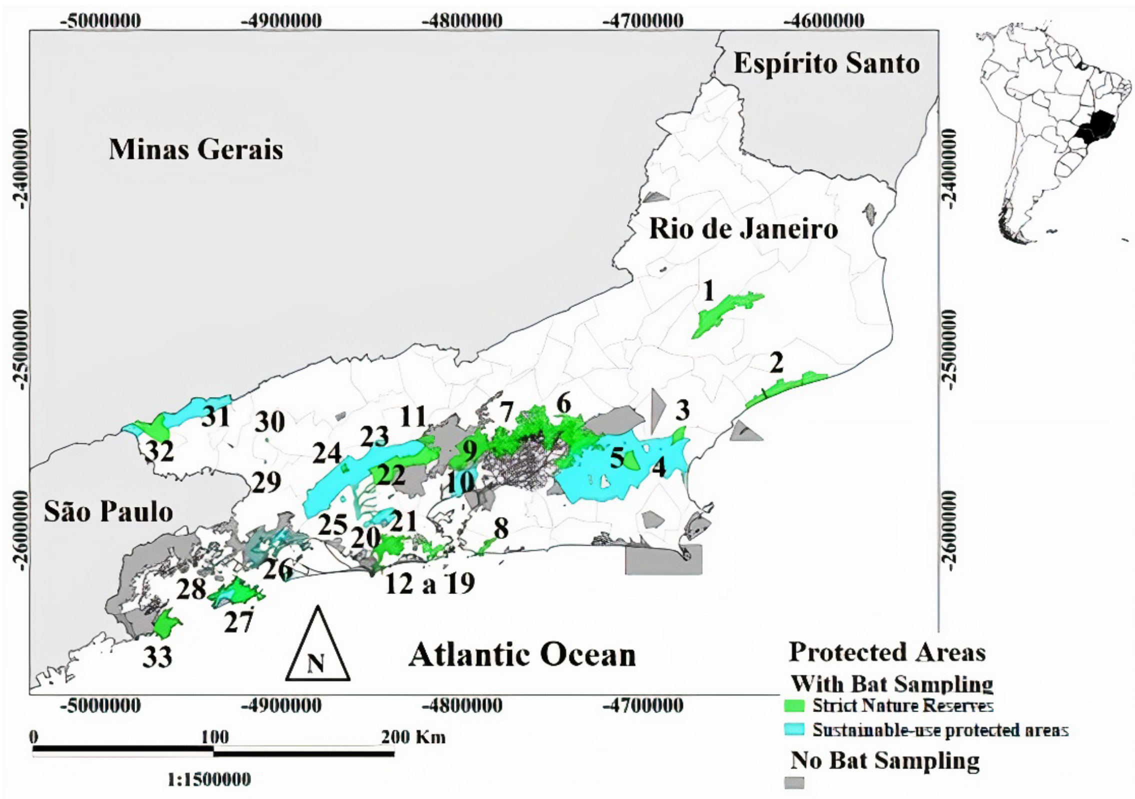

Fig. 1. Protected areas in the state of Rio de Janeiro in which bat inventories have been conducted. The inset shows the location of Southeast Brazil in South America (the numbers correspond to those in Table III).

Euclidean distance for the matrix of geographic distances. We used a multiple regression to test the relationships between the composition of the bat assemblages and the size of the protected area, its mean altitude, and capture effort. We conducted this analysis on the entire dataset, and repeated the procedure for the adequately-sampled (more than 1,000 captures) and the insufficiently-sampled (less than 1,000 captures) subsets. This criterion was based on the findings of BERGALLO *et al.* (2003), who considered 1,000 captures to be the minimally-adequate threshold for bat inventories in the region. To make the altitude chart we determined classes following the Sturge rule using the formula k = 1 + 3,322(log n), where "k" represents the number of frequency classes and "n" the total of samples.

RESULTS

We compiled data collected at 24 strict nature reserves and nine sustainable-use protected areas (Fig. 1), where a total of 67 bat species were recorded in 34,443 captures (Tab. II). Between four and 44 species ($\bar{x}$ = 20.84 ± 9.20 species) were collected in each protected area (Tab. III), with between 27 and 7,624 captures ($\bar{x}$ = 1,043.72 ± 1,497.19 captures; median = 509 captures; 1st quartile = 203 and 3rd quartile = 1,211) per protected area (Tab.III). Eleven protected areas were considered well sampled (more than 1,000 captures), while the other 22 were considered to have been insufficiently sampled, with less than 1,000 captures (Tab. III).

Tab. II. List of the bat species recorded in the state of Rio de Janeiro, Brazil between 1989 and 2013, and the total number of captures recorded in strict nature reserves and sustainable-use protected areas.

Species	Number of captures by type of protected area:		
	Strict Nature Reserve	Sustainable Use	TOTAL
Eptesicus diminutus Osgood, 1915	1	-	1
Macrophyllum macrophyllum (Schinz, 1821)	-	1	1
Molossops neglectus Williams e Genoways, 1980	-	1	1
Furipterus horrens (F. Cuvier, 1828)	2	-	2
Glyphonycteris sylvestris Thomas, 1896	1	1	2
Micronycteris hirsuta (Peters, 1869)	2	-	2
Myotis albescens (E. Geoffroy, 1806)	2	-	2
Eumops glaucinus (Wagner, 1843)	-	3	3
Lasiurus cinereus (Palisot de Beauvois, 1796)	3	-	3
Lophostoma brasiliense Peters, 1867	3	-	3
Thyroptera tricolor Spix, 1823	1	2	3
Carollia brevicauda (Schinz, 1821)	5	-	5
Uroderma magnirostrum Davis, 1968	5	-	5
Diaemus youngi (Jentink, 1893)	1	5	6
Phylloderma stenops Peters, 1865	2	4	6
Peropteryx macrotis (Wagner, 1843)	2	5	7
Mimon bennettii (Gray, 1838)	8	-	8
Lasiurus blossevillii (Lesson, 1826)	6	3	9
Mimon crenulatum (E. Geoffroy, 1806)	9	1	10
Saccopteryx leptura (Schreber, 1774)	2	8	10
Myotis levis (I. Geoffroy, 1806)	10	2	12
Histiotus velatus (E. Geoffroy, 1806)	8	5	13
Micronycteris microtis Miller, 1898	11	3	14
Phyllostomus discolor (Wagner, 1843)	-	14	14
Myotis izecksohni Moratelli, Peracchi, Dias & Oliveira, 2011	13	2	15
Myotis ruber (E. Geoffroy, 1806)	16	-	16
Nyctinomops macrotis (Gray, 1839)	14	2	16
Vampyrodes caraccioli (Thomas, 1889)	-	16	16
Lasiurus ega (Gervais, 1856)	14	4	18
Sturnira tildae de la Torre, 1959	11	7	18
Chrotopterus auritus (Peters, 1856)	11	8	19
Tadarida brasiliensis (I. Geoffroy, 1806)	19	-	19
Eumops auripendulus (Shaw, 1800)	21	-	21
Lonchorhina aurita Tomes, 1863	13	14	27
Chiroderma villosum Peters, 1860	16	14	30
Cynomops abrasus (Temmink, 1826)	29	2	31
Micronycteris minuta (Gervais, 1856)	18	13	31
Nyctinomops laticaudatus (E. Geoffroy, 1806)	4	27	31
Dermanura cinerea Gervais, 1856	35	5	40
Diphylla ecaudata Spix, 1823	22	19	41
Eptesicus furinalis (d'Orbigny & Gervais, 1847)	21	33	54
Trachops cirrhosus (Spix, 1823)	28	30	58
Pygoderma bilabiatum (Wagner, 1843)	52	14	66
Micronycteris megalotis (Gray, 1842)	41	30	71
Chiroderma doriae Thomas, 1891	73	21	94
Eptesicus brasiliensis (Desmarest, 1819)	86	9	95

Tab. II. Cont.

Species	Number of captures by type of protected area:		
	Strict Nature Reserve	Sustainable Use	TOTAL
Lonchophylla peracchii Dias, Esbérard & Moratelli, 2013	75	41	116
Vampyressa pusilla (Wagner, 1843)	97	68	165
Tonatia bidens (Spix, 1823)	101	79	180
Anoura geoffroyi Gray, 1838	56	164	220
Platyrrhinus recifinus (Thomas, 1901)	120	180	300
Myotis riparius Handley, 1960	158	180	338
Noctilio leporinus (Linnaeus, 1758)	89	347	436
Platyrrhinus lineatus (E. Geoffroy, 1810)	327	278	605
Anoura caudifer (E. Geoffroy, 1810)	330	314	644
Glossophaga soricina (Pallas, 1766)	276	395	671
Myotis nigricans (Schinz, 1821)	497	189	686
Desmodus rotundus (E. Geoffroy, 1810)	342	527	869
Phyllostomus hastatus (Pallas, 1767)	261	616	877
Artibeus planirostris (Spix, 1823)	527	539	1,066
Molossus rufus E. Geoffroy, 1806	759	319	1,078
Artibeus obscurus (Schinz, 1821)	911	681	1,592
Sturnira lilium (E. Geoffroy, 1810)	2,065	789	2,854
Molossus molossus (Pallas, 1766)	1,532	1,597	3,129
Artibeus fimbriatus Gray, 1838	2,490	773	3,263
Artibeus lituratus (Olfers, 1818)	3,094	3,139	6,233
Carollia perspicillata (Linnaeus, 1758)	5,180	2,972	8,152
TOTAL	19,928 captures	14,515 captures	34,443 captures

Tab. III. Protected areas of state of Rio de Janeiro, Brazil included in the present study (the numbers correspond to those in Figure 1) and details of the bat inventories.

N	Protected Area	Captures	Species richness	Sampling effort (h.m²)	Sampling nights	Altitude (m a.s.l.)	Area (ha)
1	Parque Estadual do Desengano	114	16	15,510	7	1,240	22,400
2	Parque Nacional da Restinga de Jurubatiba	211	15	33,559	24	5	14,860
3	Reserva Biológica União	267	12	4,515	8	60	2,930
4	Área de Proteção Ambiental da Bacia do Rio São João - Mico Leão	1,756	30	64,022	109	40	150,373
5	Reserva Biológica Nacional de Poço das Antas	3,514	20	130,497	100	50	5,000
6	Parque Estadual dos Três Picos	1,153	15	13,597	51	300	46,350
7	Estação Ecológica Paraíso	1,518	30	81,326	37	90	4,920
8	Parque Estadual da Serra do Tiririca	271	19	.	.	250	2,400
9	Parque Nacional da Serra dos Órgãos	203	17	8,172	.	750	10,527
10	Área de Proteção Ambiental Suruí	27	4	3,990	2	5	14,146
11	Reserva Biológica de Araras	1,211	23	66,297	52	1,100	2,131
12	Parque Nacional da Tijuca	2,282	36	124,127	82	150	3,958
13	Parque Natural Municipal da Catacumba	111	7	5,250	3	30	30
14	Parque Natural Municipal do Penhasco Dois Irmãos – Arquiteto Sérgio Bernardes	767	22	42,323	20	70	39
15	Parque Natural Municipal da Cidade	1,020	32	44,064	40	100	47
16	Parque Estadual do Grajaú	533	23	10,812	15	60	61
17	Parque Natural Municipal Bosque da Barra	116	8	77,760	12	5	54
18	Parque Natural Municipal Chico Mendes	139	15	9,345	11	5	43

Tab. III. Cont.

N	Protected Area	Captures	Species richness	Sampling effort (h.m²)	Sampling nights	Altitude (m a.s.l.)	Area (ha)
19	Parque Natural Municipal da Prainha	402	19	15,900	23	30	147
20	Parque Estadual da Pedra Branca	682	24	.	45	250	12,400
21	Área de Proteção Ambiental do Gericinó-Mendanha	509	17	63,000	25	500	8,000
22	Reserva Biológica do Tinguá	655	29	.	31	670	24,900
23	Área de Proteção Ambiental do Guandu	1,654	29	144,420	53	190	74,300
24	Parque Natural Municipal do Curió	745	18	51,840	12	150	915
25	Floresta Nacional Mario Xavier	150	9	.	35	40	495
26	Área de Proteção Ambiental de Mangaratiba	7,624	44	512,325	245	50	23,000
27	Parque Estadual da Ilha Grande	3,480	37	.	.	50	12,000
28	Área de Proteção Ambiental de Tamoios	2,121	29	104,227	38	5	90,000
29	Área de Relevante Interesse Ecológico Floresta da Cicuta	470	20	79,200	24	400	125
30	Parque Natural Municipal Fazenda Santa Cecília do Ingá	96	15	16,515	7	430	211
31	Área de Proteção Ambiental da Serra da Mantiqueira	204	13	10,135	7	1,550	27,763
32	Parque Nacional do Itatiaia	268	23	33,195	23	1,400	12,778
33	Reserva Ecológica de Juatinga	170	18	2,940	2	30	8,000

Three species – *Eptesicus diminutus* Osgood, 1915, *Macrophyllum macrophyllum* (Schinz, 1821), and *Molossops neglectus* Williams & Genoways, 1980 – were recorded only once in the inventories (Tab. II). One of these species, *E. diminutus*, was captured in the Grajaú State Park, a strict nature reserve in the municipality of Rio de Janeiro, whereas the other two were captured in sustainable-use protected areas. *Macrophyllum macrophyllum* was captured in the Tamoios Environmental Protection Area (APA de Tamoios), in the municipality of Angra dos Reis, while *Molossops neglectus* was recorded in the Floresta da Cicuta Area of Relevant Ecological Interest (ARIE Floresta da Cicuta) in Volta Redonda. The species most frequently captured was *Carollia perspicillata* (Linnaeus, 1758), with 8,152 records (23.67% of the total). The next most common species was *Artibeus lituratus* (Olfers, 1818), with 6,233, that is, 18.09% of the total captures (Tab. II). More than half of the captures (19,928) were recorded in the strict nature reserves, where 62 species occurred, while only 14,515 captures and 55 species were recorded in the sustainable-use protected areas (Tab. II). The NMDS distorted the original distances in a minor way, with the stress of the final configuration being 0.160, and $r^2 = 0.840$ (Fig. 2). But no significant relationship was found between the first NMDS axis, which represents the distances among bat assemblages, and the protected area category, based on the Mann-Whitney test (Tab. IV, Fig. 2).

The protected areas analyzed in the present study were located in eight different types of habitat. We classified five areas as montane forest, two as *restinga*, nine as submontane forest, three as pasture, six as secondary growth, five as urban, two as eucalypt stands, and one as upper-montane forest. Once again, however, no significant variation (Kruskal-Wallis test) was found in the data in relation to the type of habitat (Tab. IV, Fig. 3), although significant variation was detected when only the data on the insufficiently sampled areas (less than 1,000 captures) were considered (Tab. IV).

The Restinga de Jurubatiba National Park and the Juatinga Ecological Reserve were the two areas furthest apart (approximately 370 km), whereas the Penhasco Dois Irmãos Natural Municipal Park and the Rio de Janeiro City Natural Municipal Park are only 2 km apart. We observed a positive relationship between geographic distance and the dissimilarity of the bat assemblages of protected areas at distances of up to 150 km (Tab. IV, Fig. 4).

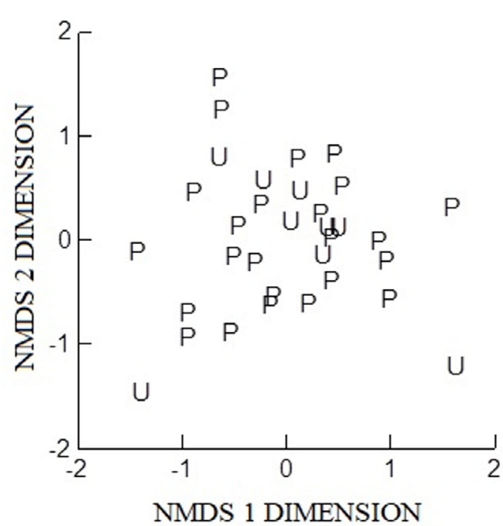

Fig. 2. Non-metric multidimensional scaling (NMDS) of the Bray-Curtis distance matrix, showing the dissimilarities between the strict nature reserves (P) and the sustainable-use protected areas (U) in the state of Rio de Janeiro, Brazil surveyed between 1989 and 2013.

Tab. IV. Results of the statistical analyses, considering all protected areas combined, only protected areas with less than 1,000 captures and only those with more than 1,000 captures.

	All protected areas	Protected areas with less than 1,000 captures	Protected areas with more than 1,000 captures
Categories	U = 98.000; p = 0.686	U = 38.000; p = 0.724	U = 9.000; p = 0.893
Habitat types	U = 13.302; p = 0.065	U = 15.978; p = **0.025**	U = 4.682; p = 0.322
Geographic distance	r = 0.679; p <**0.001**	r = 0.586; p <**0.001**	r = 0.355; p = **0.026**
Model	$r^2 = 0.284; F_{3,24} = 3.180$; p = **0.042**	$r^2 = 0.621; F_{3,14} = 7.660$; p = **0.003**	$r^2 = 0.248; F_{3,6} = 0.659; p = 0.606$
Area of reserve	0.288	0.241	0.475
Mean altitude	**0.007**	**0.002**	0.456
Capture effort	0.698	0.128	0.256

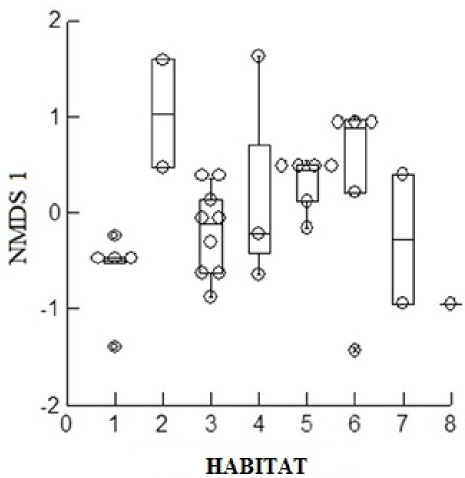

Fig. 3. Box plot of the first axis of the Non-Metric Multidimensional Scaling (NMDS1) representing the bat assemblages and different types of habitat of each protected area sampled in the state of Rio de Janeiro, Brazil between 1989 and 2013:1, Montane Forest; 2, Restinga; 3, Submontane Forest; 4, Pasture; 5, Secondary growth Vegetation; 6, Urban; 7, Eucalypt; 8, Upper-montane Forest. Each circle represents one of the protected areas sampled.

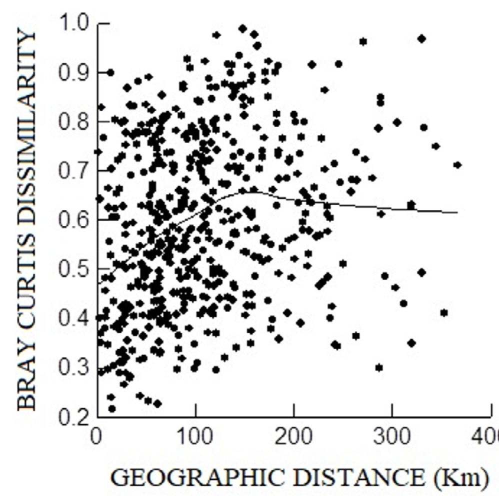

Fig. 4. Relationship between the geographic distance between each pair of protected areas and their Bray-Curtis dissimilarity in the quantitative composition of bat assemblages in the state of Rio de Janeiro, Brazil in surveys conducted between 1989 and 2013.

The Bacia do Rio São João - Mico Leão Environmental Protection Area was the largest protected area sampled (150,373 ha), and was home to 30 bat species recorded in 1,756 captures derived from a capture effort of 64,022 h.m² over 109 sampling nights. The smallest protected area surveyed was the Catacumba Natural Municipal Park, where seven species were recorded in 111 captures, with a capture effort of 5,250 h.m² over only three sampling nights.

The Serra da Mantiqueira Environmental Protection Area was the protected area at the highest altitude, at a mean of 1,555 m above sea level, and 13 species were recorded in this area (Tab. III). Five of the protected areas surveyed were at sea level, and had between four and 29 species, with a mean of 14.20 ± 9.52 species (Tab. III). The Mangaratiba Environmental Protection Area was the taxonomically richest area, with 44 species, and also the best sampled, with a capture effort of 512,325 h.m² (Tab. III). By contrast, the Juatinga Ecological Reserve had the lowest capture effort (2,940 h.m²), over only two sampling nights, although this did result in the identification of 18 species in 170 captures. No capture effort data were available for five protected areas, and the number of sampling nights was not known for two areas (Tab. III). The multiple regressions between the first NMDS axis and site area, mean altitude, and capture effort was significant for the full dataset and protected areas with less than 1,000 captures (Tab. IV). However, mean altitude was the only variable that explained a significant component of the variation after the removal effects of the other variables (Tab. III, Fig. 5). The model was not significant when the protected areas with more than 1,000 captures were considered.

DISCUSSION

Three species – *E. diminutus*, *Macrophyllum macrophyllum* and *Molossops neglectus* – were recorded only once in the protected areas of Rio de Janeiro state. Although none of these three species is considered to be threatened in any way in either Brazil (ICMBIO, 2018) or Rio de Janeiro (BERGALLO *et al.*, 2000), the evidence indicates that they may be extremely rare or infrequent in the state, a situation that clearly demands attention. Rarity in bats

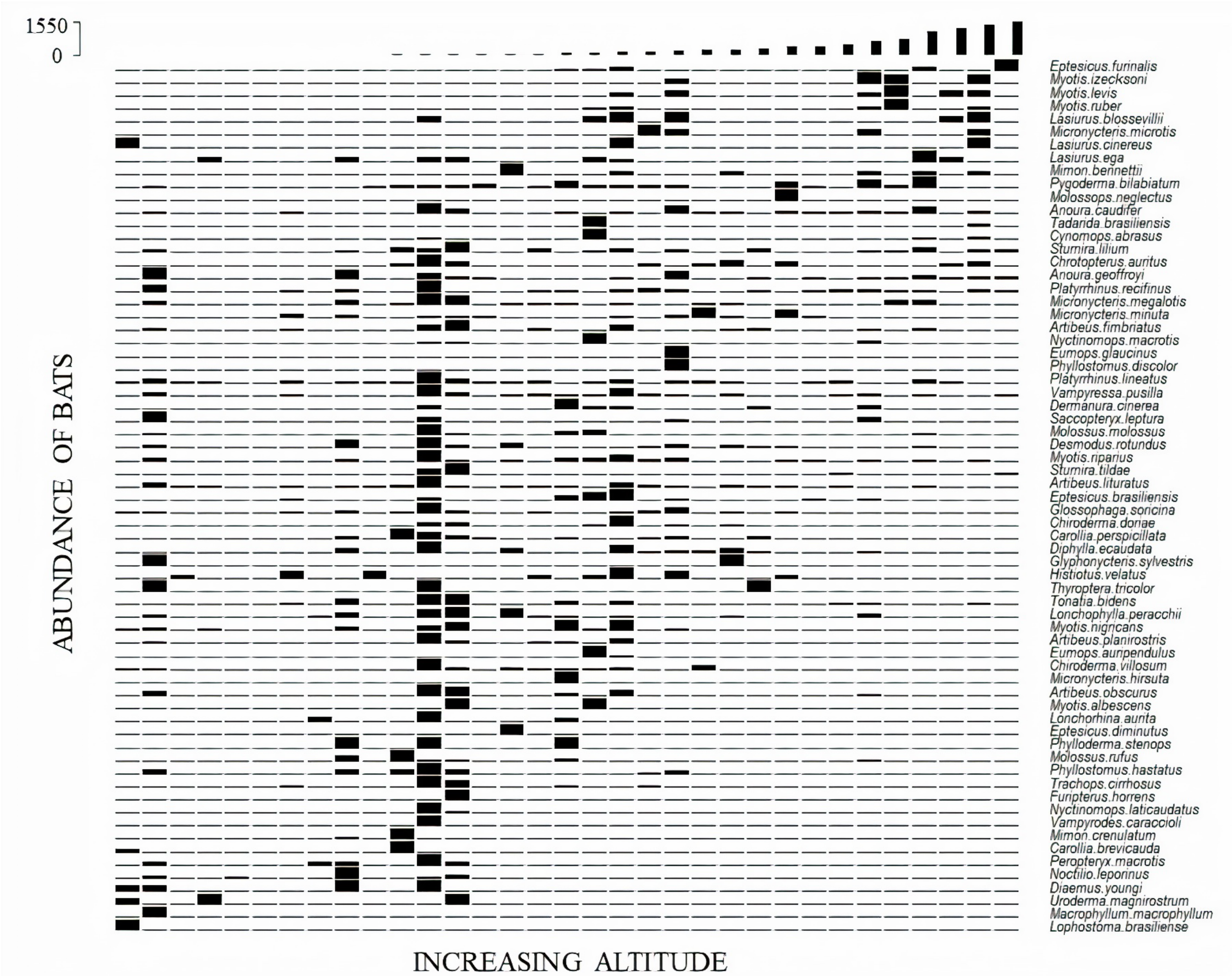

Fig. 5. Distribution of species captured in Protected Areas represented by the mean altitude categories of the sites surveyed in the state of Rio de Janeiro, Brazil between 1989 and 2013.

tends to be related to three main factors –low population density, a restricted distribution or difficulties in the capture of individuals (*e.g.*, ARITA, 1993).

Carollia perspicillata and *A. lituratus* were the most common species, which was as expected. These bats were considered to be the most abundant species in many of the studies in Rio de Janeiro (*e.g.*, TEIXEIRA & PERACCHI, 1996; BAPTISTA & MELLO, 2001; DIAS *et al.*, 2002; ESBÉRARD, 2003, 2009; DIAS & PERACCHI, 2008; CARVALHO *et al.*, 2011; LUZ *et al.*, 2011a; GOMES *et al.*, 2015). These species adapt readily to many different types of habitat, given that they are not only generalists, but also consume the fruit of pioneer plant species found in the understory (FARIA, 2006), as well as being able to exploit exotic plants found in orchards and urban gardens, such as banana, mango, avocado, sea almond, and almond.

While we expected to find differences, the composition of the bat assemblages did not vary significantly between strict nature reserves and sustainable-use protected areas. This is at least partly due to the considerable heterogeneity of environments found in both types of protected area, including urban and rural settings, and a range of habitat types. Disturbed areas tend to have reduced species evenness, given the marked predominance of a small number of species, and the reduced contribution of the phyllostomines (FENTON *et al.*, 1992; MEDELLÍN *et al.*, 2000). The Phyllostominae is a good indicator of habitat quality, given that its species typically depend on relatively well-preserved environments (COSSON *et al.*, 1999; MEDELLÍN *et al.*, 2000; GORRENSEN & WILLIG, 2004; PETERS *et al.*, 2006).

The data indicated variation in the bat assemblages among the different types of habitat. As the substrate changes, the characteristics of the vegetation will shift, and associated shifts in the composition of the fauna will also be expected. These changes are linked primarily to food availability and roost quality, which are fundamental resources for bats (REMMERT, 1982; WILSON, 1997; RICKLEFS, 2001). Bats have different feeding habits and locals with availability and diversity of food such as fruits (frugivores) and flowers (nectarivores), small vertebrates (carnivores and piscivores), insects (insectivores) and terrestrial vertebrates such as birds and mammals (sanguinivores) (BONACCORSO, 1979), the locality can present large richness of bats. The active search for roots in a locality can affect richness estimates (Trajano, 1984; Fenton, 1997; Luz *et al.*, 2011b), and these roots can be natural or artificial. The structural characteristics of the vegetation tend to affect local abundance patterns in Neotropical bats (Medellín *et al.*, 2000; Caras & Korine, 2009).

We observed that the bat assemblages of geographically proximate areas were more similar to one another, which was as expected, given that the association between assemblage composition and geographic proximity is a common pattern in Ecology (Gauch, 1973; Nekola & White, 1999; Poulin, 2003). With increasing geographic distance, environments will tend to vary more, as will the response of the assemblages at each site (Tuomisto *et al.*, 2003).

The relationship between species richness and habitat fragment size is one of the most consistent patterns in ecology (MacArthur &Wilson, 1963, 1967). In the present study, however, the size of the protected area did not affect the composition of the bat assemblage. This may be accounted for by the fact that some of the protected areas surveyed, in particular the Environmental Protection Areas (EPAs), are not a single, continuous fragment of forest. In fact, the EPAs are often formed by heterogeneous, degraded forests interspersed with farmland.

The bat assemblages did vary by altitude, with protected areas at higher altitudes being similar to one another, and distinct from those at lower altitudes. In the state of Rio de Janeiro, the proportion of plant cover is greater at higher altitudes, where there is less deforestation (Costa *et al.*, 2009). At higher altitudes, vespertilionids tend to be more common, while phyllostomids are scarcer (Graham, 1983; Soriano, 2000; Martins *et al.*, 2015), resulting in a shift in the composition of the bat assemblages. Higher species richness has been recorded at intermediate altitudes (200–800 m a.s.l.; *e.g.*, Dias *et al.*, 2008; Bordignon & França, 2009), although in general, there is a decrease in richness at increasing altitude (*e.g.*, Gorrensen & Willig, 2004; Martins *et al.*, 2015).

Sampling effort did not affect the data on the bat assemblages. In the Atlantic Forest, however, Bergallo *et al.* (2003) and Lourenço *et al.* (2010) considered localities with 20–40 species or 1,000 phyllostomid captures to be well sampled. Less than half of the protected areas surveyed in the present study can be considered to be well inventoried. Given the intrinsic rarity of most species, reliable estimate of the species richness of a given locality tend to require prolonged capture effort (Voss & Emmons, 1996; Stevens, 2013).

The composition of the bat assemblies vary considerably among the protected areas of the state of Rio de Janeiro, with this variation being influenced primarily by the type of habitat, geographic distance, and altitude. Bats use a variety of environments for refuge and foraging and this could influence the difference in the assemblies of these organisms.

The Atlantic Forest is an important priority for conservation, management, and research (Moreira *et al.*, 2008), and understanding how its biological systems function will be essential for the development of effective conservation programs (Rocha *et al.*, 2003). The demarcation of protected areas is considered to be an effective strategy for the conservation of biodiversity (Bruner *et al.*, 2001; Hockings, 2003; Naughton-Treves *et al.*, 2005; Bernardo, 2007), and many studies focus on protected areas because they are considered well-preserved, tend to have appropriate infrastructure and good security, and support research. However, only a few of the studies conducted in the protected areas of the state of Rio de Janeiro have been based on adequate sampling effort. Adequate knowledge of species distributions is essential for the implementation of effective conservation strategies.

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Appendix 1. List of references available from Table I with sampling sites.

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