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Bat fauna from the Sooretama Biological Reserve, southeastern Brazil

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ABSTRACT. The Atlantic Forest is one of the world's hotspots of biodiversity, a heterogeneous biome encompassing tropical and subtropical vegetation formations. Its remnants in the state of Espírito Santo, southeastern Brazil, are mostly within state and federal Conservation Units. The largest Unit is the Sooretama Biological Reserve, which harbors several endemic occurrences of fauna and flora, and is the last refuge of some threatened animal species. Inventories of fauna are essential to know the community composition, and for the elaboration of preservation strategies. We conducted a survey focused on the bat fauna of the Sooretama Reserve, analyzing the trophic guilds and the conservation status of its species. We surveyed online taxonomic databases and the literature, resulting in 402 records from two different scientific collections. These records represent five families, 39 genera, and 57 species of bats, revealing that the Sooretama Biological Reserve has all known bat families in the Atlantic Forest biome. Phyllostomidae was the family with the highest number of species registered, and a majority of species belongs to the aerial insectivorous trophic guild. Four species are registered as "Vulnerable" in state and federal conservation books.

Keywords: atlantic forest remnant; chiroptera; inventory; phytophysiognomy.

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Introduction

The Atlantic Forest is the Brazilian biome with the greatest latitudinal extension, resulting in a high heterogeneity of its physiognomies and making it a biome of great interest to science (Tabarelli, Pinto, Silva, Hirota, & Bedê, 2005). The state of Espírito Santo, southeastern Brazil, is fully inserted in the Atlantic Forest. Once entirely covered by rainforest, today the state has only 10.5% of its original forest coverage still standing, concentrated in fragments within Conservation Units such as Biological Reserves and parks (Fundação SOS Mata Atlântica & INPE, 2021).

One of these units is the Sooretama Biological Reserve (RBS). Located in the northeastern region of Espírito Santo, RBS has 24,000 ha of native forest (ICMBIO, 2020). With the Vale Natural Reserve (RNV – 25,000 ha) and two other small private reserves (Mutum Preto and Antas Reserve), these constitute the largest portion (53,000 ha) of Atlantic Forest in the Rio de Janeiro - Bahia forest corridor (Instituto de Pesquisa da Mata Atlântica [IPEMA], 2005; Peixoto et al., 2008; Garbin, Saiter, Carrijo, & Peixoto, 2017). Due to its sheer size, the region preserves a large number of endemic species, both for fauna and flora (Peixoto et al., 2008, Galetti et al., 2009, Thomaz, 2010). Notably, it is the last refuge for the jaguar (*Panthera onca* (Linnaeus, 1758)), in Espírito Santo (Srbek-Araujo & Kierulff, 2016). In the surroundings of the RBS, there are areas of cattle raising and *Eucalyptus* production (Rolim, Jesus, Nascimento, Couto, & Chambers, 2005). Its eastern portion is crossed by the BR-101, a federal highway connecting the South and Northeast regions of Brazil. These anthropogenic changes impose strong pressure on the reserve's biodiversity.

The different phytophysiognomies within the RBS (Peixoto et al., 2008; Garbin et al., 2017) offer different types of shelter and food resources, essential for the maintenance of local fauna. Among the animals favored by this diversity are bats. These animals are natural bioindicators of disturbance because of their variety of feeding habits and shelter usage, which can inform the degree of perturbation of an area (Kunz, Torres, Bauer, Lobova, & Fleming, 2011).

There have been few publications reporting occurrences of bats in the RBS, mostly consisting of individual or small samples. Ruschi (1980) contains a list of 19 bat species, but with no clear methodology. Klippel et al.

(2015) has an inventory of 14 species, but specific to road-kill fauna identified through DNA barcode. Two are first reports for the Espírito Santo chiropterofauna, *Lonchophylla peracchii* (Pimenta, Machel, Fonseca, & Ditchfield, 2010) and *Molossus coibensis* (Pimenta, Hoppe, Fonseca, & Ditchfield, 2014). There are also two reports on ecologic interactions, one reporting the predation of *Nyctinomops laticaudatus* by *Chrotopterus auritus* (Borloti, Pimenta, & Ditchfield, 2019) and *Desmodus rotundus* feeding on the lowland tapir, *Tapirus terrestris* (Gnocchi & Srbek-Araújo, 2017). The gray literature has two theses concerning the echolocation of Molossidae, and another for resource segregation (documents deposited at the UFES academic collection). The latter has a clear methodology, describing sampling effort and locations, however no description of species identification. The majority of the collected specimens were ultimately housed at the *Coleção de Mamíferos* of the *Universidade Federal do Espírito Santo* (UFES-MAM).

To list the species of Chiroptera in the RBS, a survey was carried out on online scientific databases and the literature, followed by an analysis of the conservation situation of species. Our main goal is to provide an inventory of the bat biodiversity of the Sooretama Biological Reserve, analyze the trophic guilds present, and discuss the surrounding pressures over it. In addition, we are publishing a much-needed substrate for further studies – geographic occurrences – coming from graduation theses that otherwise would not be available.

Material and methods

Study area

The Sooretama Biological Reserve (RBS) is in northeastern Espírito Santo (coordinates: 18°33’ – 19°05’ S, 39°55’ - 40°15’ W), between the municipalities of Sooretama, Linhares, and Jaguaré (Figure 1). The region's climate is humid subtropical, with short dry winters and rainy hot summers (Aw and Cfa in Koppën’s classification) (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). The RBS is a 24,000 ha fragment belonging to the Mata de Tabuleiros ecoregion, a diversity and endemism center at the Atlantic Forest biome (ICMBIO, 2020). In the reserve, there is a unique open forest, called “muçununga”, formed by arboreal vegetation developed on sandy-textured acidic nutrient-poor soil (Simonelli, Souza, Peixoto, & Silva, 2008). The RBS harbors animal species categorized as Threatened, such as the giant armadillo (*Priodontes maximus* (Kerr, 1792), Anacleto et al., 2014), the lowland tapir (*Tapirus terrestris* (Linnaeus, 1758), Varela et al., 2019) (Vulnerable), and the red-billed curassow (*Crax blumenbachii* Spix, 1825, International Bird Life, 2016) (ICMBIO, 2020) (Endangered). The RBS is sectioned by BR-101, a federal highway that connects the Brazilian South and Northeast regions, a major anthropogenic pressure responsible for several run overs through its extension (Srbek-Araujo, Rocha, & Peracchi, 2015; Srbek-Araujo & Kierulff, 2016). The eastern portion of RBS makes a connection with the Vale Natural Reserve (RNV) that, along with two small private reserves (Mutum Preto, 370 ha, and Anta Reserve, 2,240 ha), forms the largest continuous remnant of Atlantic Forest on Espírito Santo State (53,000 ha) (Rolim, Menezes, & Srbek-Araujo, 2016).

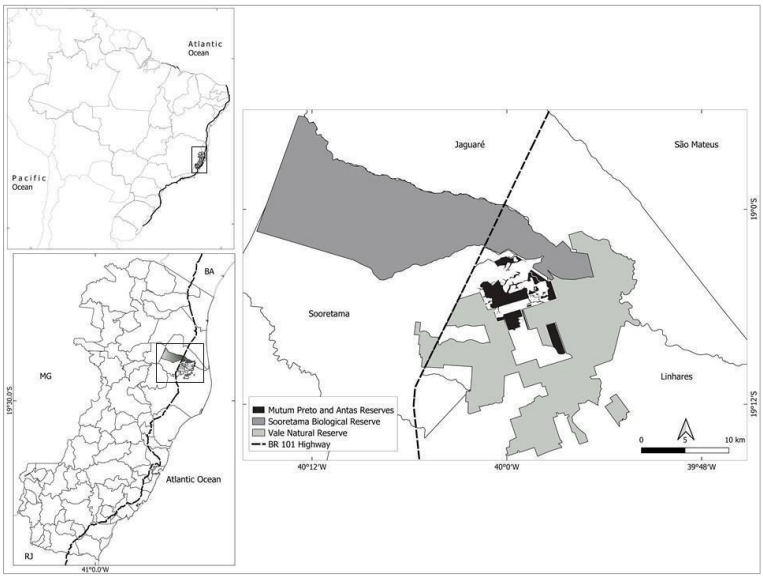

Figure 1. Location of the reserves Sooretama, Vale, Mutum Preto, and Antas in Espírito Santo State, Brazil.

Data source

We conducted a survey of records at the main online taxonomic database that integrates primary data and information from collections, *Species Link* (CRIA, 2016) using the keywords "Reserva Biológica de Sooretama" (geographic information) and "Chiroptera" (taxonomic information). We also compiled data from the literature. After compiling the data, we classified each species by its trophic guild following Kalko, Handley, and Handley (1996).

Results

We found 476 records in the *Species Link* database for the RBS, with 12 duplicates. Vouchers are deposited at two different scientific collections at the *Universidade Federal do Espírito Santo* (UFES), 63 at UFES-CTA (Collection of Animal Tissues from the Department of Biological Sciences) and 396 at UFES-MAM (Collection of Mammals). Duplicates are from 12 individuals of six different species independently registered in the collections. Six of these registers were identified at genus level and were excluded from this inventory. The remaining six were accounted only for UFES-MAM and excluded from the CTA-UFES list at *Species Link*. Another 35 results were recovered by the literature survey. Although the collections do not offer information on the capture methods used, it is reasonable to consider that most captures were made using mist-nets, as it is the sampling method most used by researchers (Gilley & Kennedy, 2010). Other possible method is road-kill fauna (Klippel et al., 2015). Augusto Ruschi employed a range of methods, but his publications are not clear on what sampling methods were ultimately used. In addition, we note that most of these records are from academic studies either making inventories or using data collected in these inventories, and they largely relied on mist-netting.

Concerning the taxonomic identification, approximately 84% of records were at the species level (402 of 476 records). 59 individuals (15%) for UFES-CTA, representing 20 species; and 343 specimens (85%) for UFES-MAM, amounting to 54 species. The number of vouchers for each species in each collection is provided (Table 1). Records identified at genus level or above, as well as the duplicated records, were excluded from the study. Species were initially classified according to Díaz, Solari, Aguirre, Aguiar, and Barquez (2016), and subsequently reevaluated by Prof. Dr. Albert Ditchfield (the head of the Laboratory of Chiropteran Studies at UFES) before being incorporated into the collection.

The 402 valid records represent 57 species, complemented by seven more from the literature, totaling 7 families, 44 genera, and 64 species of Chiroptera. Phyllostomidae had the highest species richness, representing 64% of the records (41 species), followed by Vespertilionidade (9 spp., 14%), Molossidae (6 spp., 9%), Emballonuridae (5 spp., 7.8%), Natalidae, Noctilionidae, and Thyropteridae (1 species, 1.7% each). The majority of species belongs to the aerial insectivorous trophic guild, with 22 species (34.4%), followed by gleaning frugivorous with 15 species (23.4%), gleaning insectivorous with 14 species (21.8%), gleaning nectarivorous with five species (7.8%), gleaning sanguivorous with three species (4.7%) gleaning omnivorous with two species (3.1%), and only one gleaning carnivorous species (1.6 %) (Table 1).

The "Brazilian Red Book of Extinction Threatened Fauna" (ICMBIO, 2018) lists *Lonchorhina aurita* Tomes, 1863 as Vulnerable, while the "Endangered Fauna and Flora in the State of Espírito Santo Book" (Fraga, Formigoni, & Chave, 2019) classifies *Choeroniscus minor* (Peters, 1868), *Diaemus youngii* (Jentink, 1893), and *Lonchorhina aurita* Tomes, 1863 as Vulnerable.

Table 1. List of species for Sooretama Biological Reserve, indicating the trophic guild (TG) and the number of preserved specimens registered by scientific collection. (CTA) - UFES-CTA: Collection of Animal Tissues from the Department of Biological Sciences at Federal University of Espírito Santo; (MAM) - UFES-MAM: Collection of Mammals of the Federal University of Espírito Santo.

Family	Species	TG*	CTA	MAM	Literature
Emballonuridae					
	Centronycteris maximiliani (J.Fischer, 1829)	A	2	6	-
	Diclidurus albus (Wied-Neuwied, 1820)	A		1	-
	Rhynchonycteris naso (Wied-Neuwied, 1820)	A		3	Ruschi (1980)
	Saccopteryx bilineata (Temminck, 1838)	A	3	7	Klippel et al. (2015)
	Saccopteryx leptura (Schreber, 1774)	A		10	-
Molossidae					
	Eumops auripendulus (Shaw, 1800)	A			Ruschi (1980)
	Molossus coibensis (J.A.Allen, 1904)	A		10	Pimenta et al. (2014)
	Molossus molossus (Pallas, 1766)	A	20	9	Klippel et al. (2015)
	Molossus rufus (É. Geoffroy, 1805)	A	1	6	Ruschi (1980)

Nyctinomops laticaudatus (É. Geoffroy, 1805)	A	1		Borloti et al. (2019)
Promops nasutus (Spix, 1823)	A	2		Klippel et al. (2015)
Natalidae				
Natalus macrourus (Gervais, 1856)	A			Ruschi (1980)
Noctilionidae				
Noctilio leporinus (Linnaeus, 1758)	T			Ruschi (1980)
Phyllostomidae				
Subfamily Carolliinae				
Carollia perspicillata (Linnaeus, 1758)	Gf	1		Klippel et al. (2015)
Rhinophyllinae				
Rhinophylla pumilio (Peters, 1865)	Gf	1	14	Klippel et al. (2015)
Desmodontinae				
Desmodus rotundus (É. Geoffroy, 1810)	Gs	5	12	Ruschi (1980)
Diaemus youngii (Jentink, 1893)	Gs		1	-
Diphylla ecaudata (Spix, 1823)	Gs			Ruschi (1980)
Glossophaginae				
Anoura geoffroyi (Gray, 1838)	Gi	2	25	Ruschi (1980)
Choeroniscus minor (Peters, 1868)	Gn		1	-
Dryadonycteris capixaba (Nogueira, Lima, Peracchi & Simmons, 2012)	Gn		2	-
Glossophaga soricina (Pallas, 1766)	Gn	7	27	Ruschi (1980)
Lonchophyllinae				
Lonchophylla peracchii (Dias, Esbérard, & Moratelli, 2013)	Gn	1	16	Pimenta et al. (2010)
Micronycterinae				
Lampronycteris brachyotis (Dobson, 1879)	Go		1	Klippel et al. (2015)
Micronycteris hirsuta (Peters, 1869)	Gi		8	-
Micronycteris megalotis (Gray, 1842)	Gi			Ruschi (1980)
Micronycteris minuta (Gervais, 1856)	Gi	1	3	Klippel et al. (2015)
Micronycteris schmidtorum (Sanborn, 1935)	Gi		3	-
Lonchorhininae				
Lonchorhina aurita (Tomes, 1863)	Gi		4	-
Phyllostominae				
Chrotopterus auritus (Peters, 1856)	Gc		5	Borloti et al. (2019)
Gardnerycteris crenulatum (É. Geoffroy, 1803)	Gi		11	-
Lophostoma brasiliense (Peters, 1867)	Gi	1	4	Ruschi (1980)
Macrophyllum macrophyllum (Schinz, 1821)	Gi			Ruschi (1980)
Phyllostomus discolor (Wagner, 1843)	Gn		4	-
Phyllostomus hastatus (Pallas, 1767)	Go	4	8	Ruschi (1980)
Tonatia bidens (Spix, 1823)	Gi		3	-
Tonatia saurophila (Koopman & Williams, 1951)	Gi		3	-
Trachops cirrhosus (Spix, 1823)	Gi	2	27	Klippel et al. (2015)
Glyphonycterinae				
Glyphonycteris daviesi (Hill, 1964)	Gi		1	-
Glyphonycteris sylvestris (Thomas, 1896)	Gi		1	-
Trinycteris nicefori (Sanborn, 1949)	Gi		4	-
Stenodermatinae–Ectophyllini-Stenodermatini				
Artibeus fimbriatus (Gray, 1838)	Gf		7	-
Artibeus lituratus (Olfers, 1818)	Gf		12	Ruschi (1980)
Artibeus obscurus (Schinz, 1821)	Gf	1	13	-
Artibeus planirostris (Spix, 1823)	Gf		1	-
Chiroderma villosum (Peters, 1860)	Gf	2	1	Klippel et al. (2015)
Dermanura cinerea (Gervais, 1856)	Gf		6	-
Dermanura gnoma (Handley, 1987)	Gf		11	Klippel et al. (2015)
Platyrrhinus lineatus (É. Geoffroy, 1810)	Gf		4	Ruschi (1980)
Platyrrhinus recifinus (Thomas, 1901)	Gf		5	-
Uroderma magnirostrum (Davis, 1968)	Gf		2	-
Vampyressa pusilla (Wagner, 1843)	Gf	1	3	Klippel et al. (2015)
Stenodermatinae – Sturnirini				
Sturnira lilium (É. Geoffroy, 1810)	Gf		6	-
Sturnira tildae (de la Torre, 1959)	Gf		3	-
Thyropteridae				
Thyroptera wynneae (Velazco, Gregorin, Voss, & Simmons, 2014)	A		1	Hoppe et al. (2014)
Vespertilionidae				
Eptesicus brasiliensis (Desmarest, 1819)	A			Ruschi (1980)

Eptesicus diminutus (Osgood, 1915)	A		3	-
Eptesicus furinalis (d'Orbigny, 1847)	A		4	-
Histiotus velatus (I. Geoffroy, 1824)	A		1	-
Lasiurus ega (Gervais, 1856)	A		2	Klippel et al. (2015)
Myotis albescens (É. Geoffroy, 1806)	A		1	-
Myotis levis (I. Geoffroy, 1824)	A		1	-
Myotis nigricans (Schinz, 1821)	A		13	Ruschi (1980)
Myotis riparius (Handley, 1960)	A	1	3	Klippel et al. (2015)

*Trophic Guild: A: Aerial insectivorous; Gf: Gleaning frugivorous; Gs: Gleaning sanguivorous; Gi: Gleaning insectivorous; Gn: Gleaning nectivorous; Gc: Gleaning carnivorous; Go: Gleaning omnivorous; T: Trawler.

Discussion

The Sooretama Biological Reserve has an important role as an Atlantic Forest fragment and biodiversity Conservation Unit in the state of Espírito Santo. Its unique combination of different phytophysiognomies promotes an odd aggregation of species, several endemic to the area. This checklist highlighted the representativeness of bat fauna that can be found at the reserve, even considering that these specimens were collected mainly with mist-nets, resulting in a heavily biased species list (Gardner, 2008; Peracchi, Nogueira, & Lima, 2011). Nevertheless, checklists are very important for conservation actions taken by decision-makers, as indicated by Moreira, Coutinho, and Mendes (2008) and Mendes et al. (2010).

The RBS bat species richness represents 72.7% of registered species for the state (88 species, Vela-Ulian, Ditchfield, & Srbek-Araujo, 2023) and 52.5% of all bat species known for Atlantic Forest (122 species, Figueiredo et al., 2021). Comparison with other surveys in the Atlantic Forest - with similar altitudes and vegetation — shows that RBS has one of the largest numbers of bat species (Table 2).

The checklist carried out in the south of Bahia by Faria, Soares-Santos, and Sampaio (2006) (Table 2) over 16 years of research listed 59 species. This sampling success was due to the use of different collection methods, such as mist-nets, and making active searches for shelters and caves. This comparison highlights the likelihood that the bat diversity of RBS is likely even higher and employing other sampling methods will reveal a yet unknown chiropterofauna. Bioacoustic surveys, for example, can register bats that can avoid mist-nets, or fly too high to be caught by them (Miller, 2001).

Table 2. Similar fragments of Atlantic Forest used to compare species richness. States: BA: Bahia, ES: Espírito Santo, RJ: Rio de Janeiro, and SE: Sergipe.

Conservation Unit	Area (ha)	Species richness	Reference
Linhares Experimental Station (ES)	1,611 ha	38	Peracchi and Albuquerque (1993)
Vale Natural Reserve (ES)	21,787 ha		
Gavea Park (RJ)	47 ha	40	Esbérard (2003)
Trapicheiros Reserve (RJ)	-		
Rio de Janeiro Botanical Garden (RJ)	137 ha		
Grajaú Reserve (RJ)	55 ha		
Tijuca National Park (RJ)	3,330 ha		
Penhasco Dois Irmãos Park (RJ)	40 ha		
Tinguá Biological Reserve (BA)	26,000 ha	59	Dias, Esbérard, and Peracchi (2008)
Rio das Ostras Reserve (RJ)	1,361 ha	30	Luz, Costa, Lourenço, and Esbérard (2011)
Vale Natural Reserve (ES)	22,000 ha	30	Peracchi et al. (2011)
Fazenda Santana Reserve (SE)	600 ha	18	Pedroso et al. (2020)
Caju Private Natural Heritage Reserve (SE)	763 ha	13	Bezerra and Bocchiglieri (2021)

Phyllostomidae was the most predominant family, a result consistent with previous research (see Table 2 referenced papers). This is a common result for this type of survey because of the aforementioned prevalence of mist-net usage. This collection method prioritizes species that fly in the subcanopy space, feeding on fruits, nectar, blood, insects perched on leaves, or small animals on the forest floor (Marques, Ramos Pereira, & Palmeirim, 2016). Phyllostomidae is recognized as the most diverse family in the Neotropical region in terms of eating and foraging habits (Reis, Peracchi, Batista, Lima, & Pereira, 2017). This diversity of diets makes phyllostomids efficient indicators of habit disturbance, especially the gleaning omnivores (i.e., the Phyllostominae *sensu latu* Belwood, 1988; Fenton et al., 1992), which feed mainly on mobile animals and need an undisturbed biodiverse habitat. Generalist species usually hail from groups with frugivorous adaptations, such as Carolliinae and Stenodermatinae. They are more resilient to changes in the landscape because their

food source are mainly fruits usually produced by pioneer plants, such as *Cecropia*, *Piper*, and *Solanum* (Fenton et al., 1992; Wilson, Ascorra, & Solari, 1996; Medellín, Equihua, & Amin, 2000). At this RBS checklist, we listed specimens of both groups, as expected in an area that has different landscapes, including undisturbed and disturbed habitats, the latter mostly due to the edge effect promoted by the proximity with pastures and *Eucalyptus* plantations (Rolim et al., 2005).

The presence of Molossidae, Vespertilionidae, Emballonuridae, and Thyropteridae probably happened by chance, with mist-nets placed close to shelters, by active search of shelters, or the result of a runover (Hoppe et al., 2014; Damásio et al., 2021). They access different layers of vertical wide-open spaces to hunt and feed, mainly because they have different body and wing characteristics that allow them high-speed flight, but lower maneuverability (Marques et al., 2016). The variety of RBS phytophysiognomies, including short and tall trees, open areas, and watercourses, also attracts several types of arthropods, providing a more diverse food resource (Brehm, Colwell, & Kluge, 2007; Magnago, Rocha, Meyer, Martins, & Meira-Neto, 2015). For insectivorous bats (e.g., *Myotis riparius*, *Saccopteryx bilineata*, and *S. leptura*), the wide gaps formed by the height difference between trees contribute to exploiting these subcanopy areas (Marques et al., 2016).

There are several private farming units surrounding the RBS that add one more pressure by building artesian wells to irrigate their cultures, which increases the dispute for water and reduces the forest fragment capacity to support water dependent fauna and flora (ICMBIO, 2020). Emballonuridae species forage insects over watercourses, and Noctilionidae are trawlers, fishing prey in or near the water surface. The reduction in volume or even the unavailability of water can affect the survival of these species. Although Noctilionidae bats were not recorded, there are records for the Vale Natural Reserve, a contiguous area, suggesting that the family also occurs at RBS (Peracchi et al., 2011).

Another stressful anthropic issue is the BR-101 highway, that crosses the RBS near its middle (Figure 1), being responsible for several run overs of wild animals trying to cross it, including bats (Hoppe et al., 2014; Srbek-Araujo et al., 2015; Ramalho & Aguiar, 2020; Damásio et al., 2021). As noted in the collection record, RBS is a habitat for bat species considered vulnerable on federal and state conservation lists. Although not the aim of this work, we strongly advise the need for greater care and inspection over the RBS borders, enlarge the fragment, and creation of green corridors for the fauna. However, those are mitigant actions at best, and from an ecological point of view, the best-case scenario is to divert the BR-101 altogether, completely suppressing its ever-present threat to this world hotspot of biodiversity.

Conclusion

All Atlantic Forest bat families occur at Sooretama Biological Reserve. The Phyllostomidae were the most abundant, with a very high diversity for of Atlantic Forest biome fragment. Our results demonstrate the importance of permanent conservation and better attention to the impact of BR-101 crossing this reserve.

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