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Under blue wings: mammals of the Spix's Macaw Protected Areas, Northeastern Brazil

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Mammals can be used as indicators of relative biological integrity and environmental quality. Therefore, inventories of this taxon are fundamental for planning and evaluating conservation and management strategies such as the creation of protected areas. This study compared the medium- and large-sized mammalian species' diversity and composition before and after the establishment of the Spix's Macaw protected areas to assess its potential beneficial effects and to provide subsidies for the management and monitoring of the protected ecosystem. Mammal data were collected in two camera trapping surveys carried out in 2017 and between 2020 and 2021, totaling a sampling effort of 3,803 camera-trap days. We obtained a total of 1,141 records of 17 species of wild mammals, including 13 medium- and large-sized species and four small mammal species. We recorded four threatened species. Although species richness and composition were very similar between the periods before and after the establishment of the protected area, diversity was higher which is associated with having greater species evenness. *Cerdocyon thous*, *Euphractus sexcinctus*, and *Dasypus novemcinctus* were the most common wild mammals, while the rarest species were *Puma concolor*, *Procyon cancrivorus*, *Dicotyles tajacu,* and *Dasyprocta prymnolopha*. Seven domestic species were recorded, including the super-abundant *Capra hircus*. Therefore, conservation and habitat restoration strategies, such as the expansion of protected areas and the sustainable management of domestic species, must be reinforced and expanded to ensure the persistence of an important diversity of wild mammals, whose population trends should be monitored.

Keywords: Caatinga, camera trap, medium and large-sized mammals, threatened species, tropical dry forest.

Los mamíferos pueden utilizarse como indicadores de la integridad biológica relativa y la calidad ambiental. Por lo tanto, los inventarios de este taxón son fundamentales para la planificación y evaluación de estrategias de conservación y manejo como la creación de áreas protegidas. Este estudio comparó la diversidad y la composición de las especies de mamíferos de tamaño mediano y grande antes y después del establecimiento de las áreas protegidas del guacamayo de Spix para evaluar sus posibles efectos beneficiosos y proporcionar información para la gestión y el monitoreo del ecosistema protegido. Los datos de mamíferos se recolectaron en dos campañas de fototrampeo realizadas en 2017 y entre 2020 y 2021, totalizando 3,803 días-trampa. cámara Obtuvimos un total de 1,141 registros de 17 especies de mamíferos silvestres, incluyendo 13 especies de tamaño mediano y grande y cuatro especies de mamíferos pequeños. Registramos cuatro especies amenazadas. Aunque la riqueza y la composición de especies fueron muy similares entre los períodos anteriores y posteriores a la protección del hábitat, la diversidad fue mayor tras el establecimiento de áreas protegidas, cuando las poblaciones mostraron una mayor uniformidad. *Cerdocyon thous*, *Euphractus sexcinctus* y *Dasypus novemcinctus* fueron los mamíferos silvestres más comunes; mientras que las especies más raras fueron *Puma concolor*, *Procyon cancrivorus*, *Dicotyles tajacu* y *Dasyprocta prymnolopha*. Se registraron siete especies domésticas, incluyendo la superabundante *Capra hircus*. Por lo tanto, es necesario reforzar y ampliar las estrategias de conservación y restauración del hábitat, como la expansión de las áreas protegidas y el manejo sostenible de las especies domésticas, para asegurar la persistencia de una importante diversidad de mamíferos silvestres, cuyas tendencias poblacionales deben ser monitoreadas.

Palabras clave: Bosque seco tropical, Caatinga, cámara trampa, especies amenazadas, mamíferos medianos y grandes.

The presence of certain mammal species in an area is an indicator of relative biological integrity and environmental quality (Cheyne *et al.* 2016; Marques *et al.*, 2023). Species inventories, with adequate sampling design, can ensure detailed knowledge of the occurrence, diversity, and distribution of species in this group in a specific region, potentially generating data to be used for assessing the impacts of human actions on the biological community (Tobler *et al.* 2008; Marinho *et al.* 2018a). This type of knowledge is fundamental for planning and evaluating appropriate conservation and management strategies within and outside protected areas (Tobler *et al.* 2008; Falcão *et al.* 2025; Martins *et al.* 2025).

Among mammals, medium and large-sized mammals (*i.e.* > 1 kg) are particularly good indicators of environmental quality, as they generally require large areas, have low population density, and occupy high trophic levels, in the case of top predators (Chiarello 1999; Cardillo *et al.* 2005). Medium- and large-sized mammals are among the vertebrates most affected by hunting (Benítez-López *et al.* 2017) and by habitat loss, fragmentation, and degradation (Crooks *et al.* 2017). They play important ecological roles and provide strategic ecosystem services, such as controlling herbivore populations, modulating the nutrient cycle, and dispersing large seeds, being essential for the structuring and regeneration of tropical forests (Chiarello 1999; Terborgh *et al.* 2001; Cardillo *et al.* 2005; Galetti and Dirzo 2013; Sobral *et al.* 2017; Vale *et al.* 2023). Therefore, their population decline can cause numerous cascading effects on the ecosystem (Vanthomme *et al.* 2010; Gibson *et al.* 2011). Thus, medium- and large-sized mammals are an important target for conservation and systematic monitoring (Balmford *et al.* 2005; Dobson 2005; Silva *et al.* 2018).

On a global scale, the diversity of medium- and large-sized mammals is positively related to the coverage of protected areas (Chen *et al.* 2022). Protected areas represent one of the main strategies for biodiversity conservation (Silva *et al.* 2018; Magioli *et al.* 2021; Sonoda *et al.* 2021), generally harboring greater species richness, including those threatened with extinction (Magioli *et al.* 2021), in addition to protecting species from threats that are present outside their boundaries (Pacifici *et al.* 2020). The positive effect of habitat protection persists at regional scale, especially in tropical ecosystems characterized by high biodiversity and significant anthropogenic pressure (Magioli *et al.* 2021).

Despite constituting the largest and most diverse seasonally dry tropical forest in the Americas, the Caatinga is one of the least protected (Teixeira *et al.* 2021) and most degraded and fragmented ecosystems in Brazil (Antongiovanni *et al.* 2018, 2020). This ecosystem undergoes great pressure from a human population of over 28 million people and nine million goats raised extensively (Tabarelli *et al.* 2018). Moreover, climate change (Moura *et al.* 2023) and the recent advance of large renewable energy projects threaten this ecosystem (MAPBIOMAS 2024). With at least 183 recorded mammal species, 11 of which are endemic, the semiarid Brazilian Caatinga is rich in mammal diversity and endemism (Carmignotto and Astúa 2017). However, knowledge about the distribution and conservation status of mammals in the ecosystem is still scarce, even in protected areas (Marinho *et al.* 2018a; Campos *et al.* 2019).

Created in 2018, the Spix's Macaw protected areas encompass approximately 120,000 hectares of Caatinga ecosystem under different protection levels (Presidência da República do Brasil 2018). Their central objective is to protect natural habitats that are important to the life cycle of the Spix's Macaw (*Cyanopsitta spixii*) (Presidência da República do Brasil 2018), thereby ensuring conditions for the reintroduction of a psittacine species that is extinct in the wild. The region's entire biodiversity may benefit from the conservation and management actions implemented, with a focus on a charismatic bird considered a flagship and umbrella species that requires extensive areas to establish and survive (Simberloff 1998; Lugarini *et al.* 2021). However, studies characterizing the fauna possibly benefited by the protected areas implemented in the region are still incipient, especially for mammals. Therefore, this study aimed to describe the diversity and composition of the medium- and large-sized mammal assemblage (mammals, from now on) before and after the establishment of Blue Spix's Macaw protected areas in northeastern Brazil. We conducted an initial assessment of the effects of habitat protection on mammals to provide subsidies for the management and monitoring of the protected ecosystem.

Materials and methods

Study area. The study area comprises the Spix's Macaw Environmental Protection Area (EPA), with 89,996 hectares, and the Spix's Macaw Wildlife Refuge (WR), which has 29,986 hectares, in addition to a part of the immediate surroundings of these protected areas located in the municipalities of Curaçá and Juazeiro, in northern Bahia, Northeast Brazil (Presidência da República do Brasil 2018; Figure 1). The protected areas are located in the Caatinga morphoclimatic domain, where a hot and semiarid climate predominates (Velloso *et al.* 2002) with an average annual minimum temperature of 25°C and a maximum of 34°C, and an average annual rainfall of 429 mm, with more frequent rains between December and March (Junqueira *et al.* 2020). The phytophysiognomy of the area can be divided into three main formations: open shrubland, including flattened and rocky outcrop environments; dense arboreal vegetation in environments influenced by mountain ranges; and riparian forest, represented by floodplain and lowland environments in banks of temporary rivers and streams (Freitas *et al.* 2005). Human activities have historically degraded the region's vegetation and hampered its natural regeneration, such as excessive grazing pressure by goats, sheep and cattle (Juniper and Yamashita 1991), which reach high densities in the region (Magalhães *et al.* 2024).

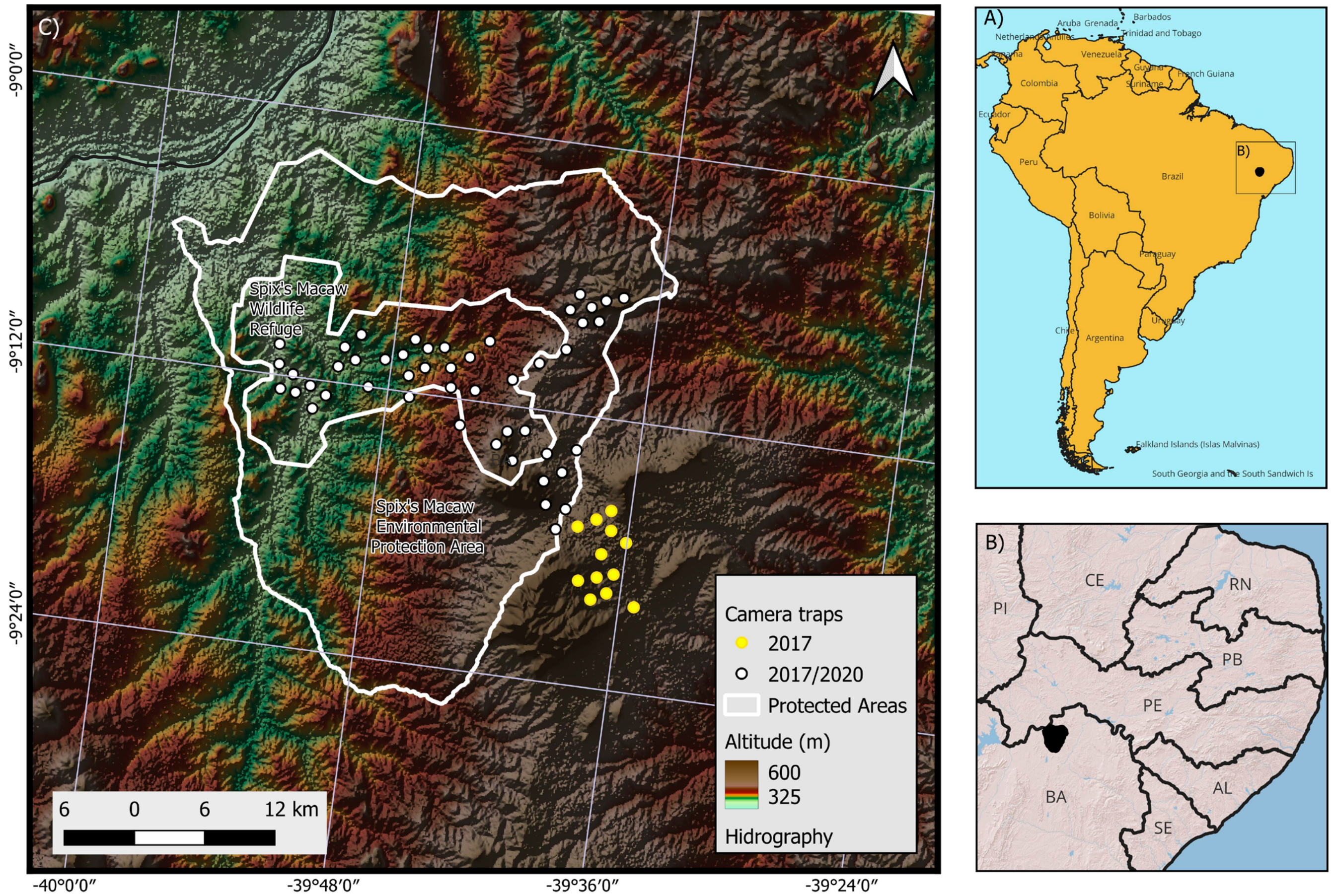

Figure 1. Study area and sampling points in the Spix's Macaw Protected Areas and their surroundings located in Northeastern Brazil (A), northern Bahia (B), between Curaçá and Juazeiro municipalities (C). Brazilian states: Rio Grande do Norte (RN), Ceará (CE), Paraíba (PB), Piauí (PI), Alagoas (AL), Sergipe (SE), and Bahia (BA). The topography presented is based on NASA Shuttle Radar Topography Mission (2013).

Data sampling. Data on mammals were collected in two campaigns conducted between 2017 and 2021, following an adaptation of the Tropical Ecology Assessment and Monitoring protocol (TEAM) (Ahumada *et al.* 2013). Both sampling campaigns followed the same field protocol, varying only in the number of sampling points. From September to November 2017, 60 points were sampled (before the creation of the protected areas) during the dry season. From October 2020 to January 2021, 48 of the 60 points from the first campaign were surveyed again, covering the dry season and the beginning of the rainy season. During this period, the traps were distributed exclusively within the protected areas, excluding the 12 sampled points that were outside the boundaries of the conservation units after their creation. All sampling points were preferably installed on pre-existing trails used by animals and people and established with a minimum distance of approximately 1.5 km between them, considering that the adopted protocol focused primarily on medium to large-sized mammals. We took care to consider the heterogeneity of the environments found in the area, as well as to encompass the altitudinal gradient, including areas from the lowest points to the mountain ranges. No bait was used.

At each sampling point, a Bushnell automatic camera trap (Essential E2 or Trophy Cam HD) activated by movement was installed. The cameras were programmed to take 2 or 3 pictures, with 5-minute resting intervals, and remained active 24 hours a day during the sampling period, for a minimum of 30 consecutive days, except for those that presented any problem. They were installed on pre-existing trails, in dry streambeds, and in riparian forests at 30-40 cm from the ground.

Data analysis. All analyses were conducted for medium- and large-sized mammals (>1 kg; Marinho *et al.* 2018a), while for small mammals only the number of records obtained is presented. We used the grouped records of the same species and site within one-hour periods to calculate the frequency of recording for each species (Marinho *et al.* 2018a). The frequency of recording was calculated as the ratio of the number of grouped records to the sampling effort, multiplied by 100 (O'Brien 2011). We built rank-abundance graphs (Cruz-Bazan *et al.* 2025), based on the recoding frequencies of medium- and large-sized mammal species for the 2017 and 2020 sampling seasons, as well as for the total data obtained from the 60 and 48 sample points, respectively.

Mammal diversity was assessed using alpha and beta diversity metrics calculated for the 2017 and 2020 sampling periods, as well as for the pooled dataset. We

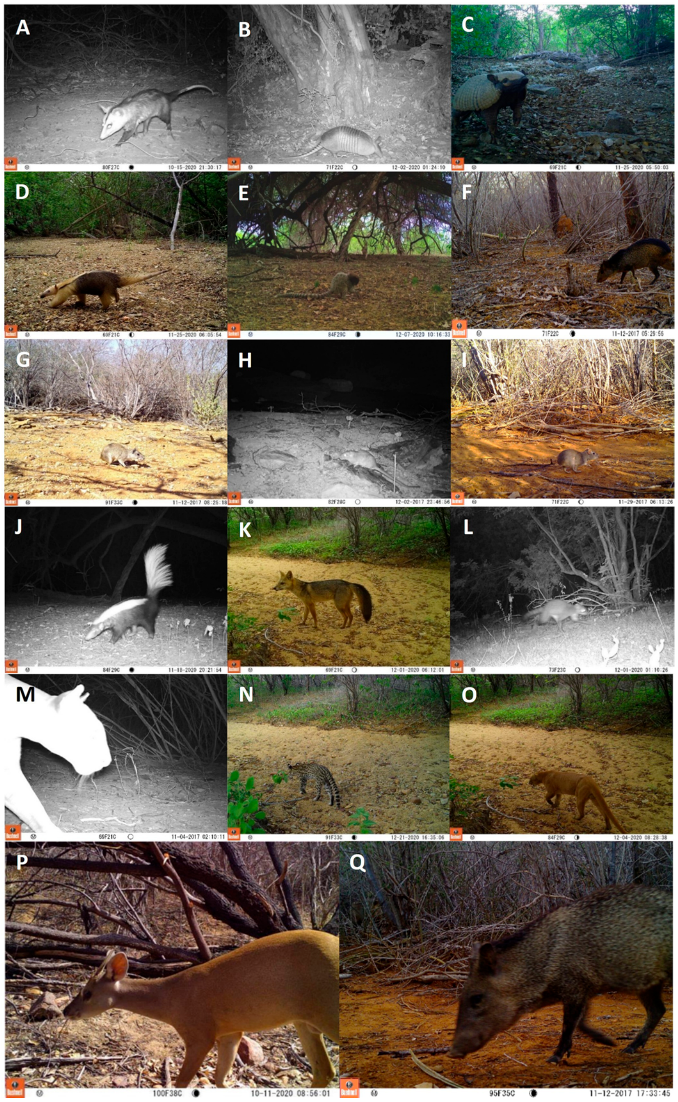

Figure 2. Mammals recorded between 2017 and 2021 in the Spix's Macaw protected areas and their surroundings, Bahia, northeast Brazil. A) *Didelphis albiventris*, B) *Dasypus novemcinctus*, C) *Euphractus sexcinctus*, D) *Tamandua tetradactyla*, E) *Callithrix penicillata*, F) *Dasyprocta prymnolopha*, G) *Kerodon rupestris*, H) *Galea spixii*, I) *Thricomys laurentius*, J) *Conepatus semistriatus*, K) *Cerdocyon thous*, L) *Procyon cancrivorus*, M) *Puma concolor*, N) *Leopardus emiliae*, O) *Herpailurus yagouaroundi*, P) *Subulo gouazoubira*, and Q) *Dicotyles tajacu*.

generated a rarefaction (interpolation) and extrapolation (prediction) curve based on Hill numbers (q = 0 [richness], q = 1 [Shannon], and q = 2 [Simpson]) using abundance data (number of records) from all sampling points across both periods. This method allows for robust comparisons between samples with differing sampling efforts (Cruz-Bazan *et al.* 2025). A curve based on Hill numbers also provides sample coverage through rarefaction and extrapolation curves, which can indicate the degree of completeness of the mammal inventory. On the other hand, we considered only the 48 points sampled during the two sampling periods to estimate the Shannon diversity index (H') and Simpson diversity index (D), as well as Pielou's evenness (J'). Similarly, we estimated Sørensen beta diversity (βsor) between the two sampling periods (2017 and 2020) to assess potential changes in species composition. Diversity indices were obtained using the vegan package (Oksanen *et al.* 2026), and rarefaction and extrapolation curves were constructed using the iNEXT package (Hsieh *et al.* 2016). Statistically significant differences were based on a significance threshold of α = 0.05. All analyses were performed using R software (R Core Team 2026).

Finally, we conducted an assessment of the habitats in which each species was recorded, through assessments of the vegetation at each field point and its comparison with the habitat type classification adapted from Freitas *et al.* (2005), as follows: open shrub vegetation (including flat and rocky outcrop environments; 22 sampling points), riparian forest vegetation (including lowland and floodplain; 22 points), and dense arboreal vegetation (mountain range; 16 points). There was no standardization in the number of points per habitat, so we once again used rarefaction and extrapolation curves in the iNEXT package to compare mammal diversity based on data from the entire sample while accounting for unequal sampling effort.

Species identification was carried out using image guides of potential species and consultation with specialists. The taxonomic classification of the species followed Abreu *et al.* (2025), and the conservation status was based on the red lists of Bahia (Cassano *et al.* 2017; SEMA 2017), Brazil (MMA 2026), and the IUCN (2025). In turn, the classification of species according to trophic guilds followed Paglia *et al.* (2012). Data collection was authorized by the Biodiversity Authorization and Information System of ICMBio (SISBIO Nº75795), and data tabulation and organization were performed using the CamtrapR package (Niedballa *et al.* 2016).

Results

The 2017 and 2020-2021 surveys accumulated a total sampling effort of 3,803 camera-days. There were 2,250 camera-days in 2017, with the cameras remaining active for an average of 37.5 days (SD = ± 2.9), and 1,553 camera-days in 2020-2021, with the cameras remaining in the field for an average of 33 days (SD = ± 5).

We obtained a total of 1,141 grouped records of wild mammals in the two samplings (642 records in 2017 and 499 records in 2020-2021). Based on these records, we obtained a total richness of 17 species of wild mammals (15 species in each sampling season) distributed across seven orders and 13 families, including 13 medium- and large-sized species and four small mammal species, including three rodents and one arboreal primate species (Figure 2; Table 1). Four of the recorded species are considered threatened with extinction at different levels: *Kerodon rupestris* (Bahia), *Herpailurus yagouaroundi* (Bahia and Brazil), *Puma concolor* (Bahia), and *Leopardus emiliae* (Bahia, Brazil and IUCN) (Table 1). In addition to native species, we recorded seven species of domesticated mammals (Table 1).

The richness rarefaction curves (q = 0) for both sampling periods and the pooled data did not tend toward stabilization, indicating that more species would be recorded with increased sampling effort; however, the sample coverage

Table 1. Wild and domesticated mammals recorded in the Spix's Macaw protected areas and their surroundings between 2017 and 2021, using camera trapping, in the municipalities of Curaçá and Juazeiro, Bahia, northeastern Brazil. Recording location: EPA (Environmental Protection Area), WRE (Wildlife Refuge), SUR (surroundings of the two protected areas). Conservation status in Bahia (BA), Brazil (BR) and IUCN (global): VU (Vulnerable), EN (Endangered), NT (Near Threatened). Habitat types: dense arboreal vegetation (DA), open shrubby vegetation (OS) and riparian forest vegetation (RF). Guild: fr (frugivore), om (omnivore), in (insectivore), hb (herbivore), ca (carnivore), according to Paglia *et al.* (2012). Small mammals are marked with one asterisk (*). Exotic/domesticated species are marked with two asterisks (**).

Taxon	Number of records			Status	Local	Habitat	Guild
	2017	2020-21	Total				
Didelphimorphia							
Didelphis albiventris	1	18	19		EPA, WRE	DA, OS, RF	fr/om
Cingulata							
Dasypus novemcinctus	85	82	167		EPA, WRE, SUR	DA, OS, RF	in/om
Euphractus sexcinctus	66	113	179		EPA, WRE, SUR	DA, OS, RF	in/om
Pilosa							
Tamandua tetradactyla	18	12	30		EPA, WRE, SUR	DA, OS, RF	in
Primates							
*Callithrix penicillata**	0	4	4		WRE	RF	on
Rodentia							
*Galea spixii**	33	1	34		EPA, WRE, SUR	DA, OS	hb
*Kerodon rupestris**	25	55	80	VU (BA)	EPA, WRE, SUR	DA, OS, RF	hb
Dasyprocta prymnolopha	2	0	2		SUR	DA	fr
*Thrichomys laurentius**	7	16	23		EPA, WRE, SUR	DA, OS	fr/hb
Cetartiodactyla							
Subulo gouazoubira	17	4	21		EPA, SUR	DA, OS	fr/hb
Dicotyles tajacu	1	1	2	NT (BA)	EPA, SUR	DA	fr/hb
*Bos taurus***	0	35	35		EPA e WRE	DA, OS, RF	
*Capra hircus***	1745	1018	2763			DA, OS, RF	
*Ovis aries***	512	289	801			DA, OS, RF	
Carnivora							
*Canis lupus familiaris***	12	5	17		EPA, WRE, SUR	OS, DA	
Cerdocyon thous	317	127	444		EPA, WRE	DA, OS, RF	in/on
Conepatus semistriatus	11	35	46		EPA, WRE	DA, OS, RF	in/on
Procyon cancrivorus	0	1	1		WRE	RF	fr/on
*Felis catus***	1	9	10		WRE	DA, OS, RF	
Herpailurus yagouaroundi	7	3	10	VU (BA, BR)	WRE, SUR	DA, OS, RF	ca
Leopardus emiliae	40	27	67	VU (BA), EN (BR), VU (IUCN)	EPA, WRE, SUR	DA, OS, RF	ca
Puma concolor	1	0	1	VU (BA), NT (BR)	SUR	DA	ca
Perissodactyla							
*Equus asinus***	59	68	127		EPA, WRE, SUR	DA, OS, RF	
*Equus caballus***	10	6	16		EPA e WRE	DA, OS, RF	

curves suggest a high level of representativeness and that the majority of the species present were recorded (Supplementary Data SD1). The species richness of wild medium- and large-sized mammals in the 2017 and 2020-21 surveys was very similar, with no significant differences between mammal surveys as demonstrated by the overlap of the 95% confidence intervals (Figure 3). Regarding Hill numbers, while richness (q = 0) was virtually identical given the same sampling effort (11 species with nearly 400 individuals recorded in both samples) (Figure 1A), the significantly higher values for q1 (Shannon) and q2 (Simpson) in the second survey suggest greater diversity and evenness in 2020 compared to 2017 (Figures 3B and 3C).

This result is reinforced by the diversity indices calculated from data obtained at the 48 sampling points investigated in 2017 and 2020 (Table 2). Species richness also did not show a statistically significant difference (Supplementary Data SD2), even though 2020 yielded two more species of the medium- and large-sized mammals (11 species) than 2017 (9 species) across the 48 sampling points (Table 2). On the other hand, both diversity indices (Shannon and Simpson) were significantly higher in 2020 (Supplementary Data SD2; Table 2), as was Pielou's evenness index (Table 2). Despite the difference in alpha diversity, the low value of

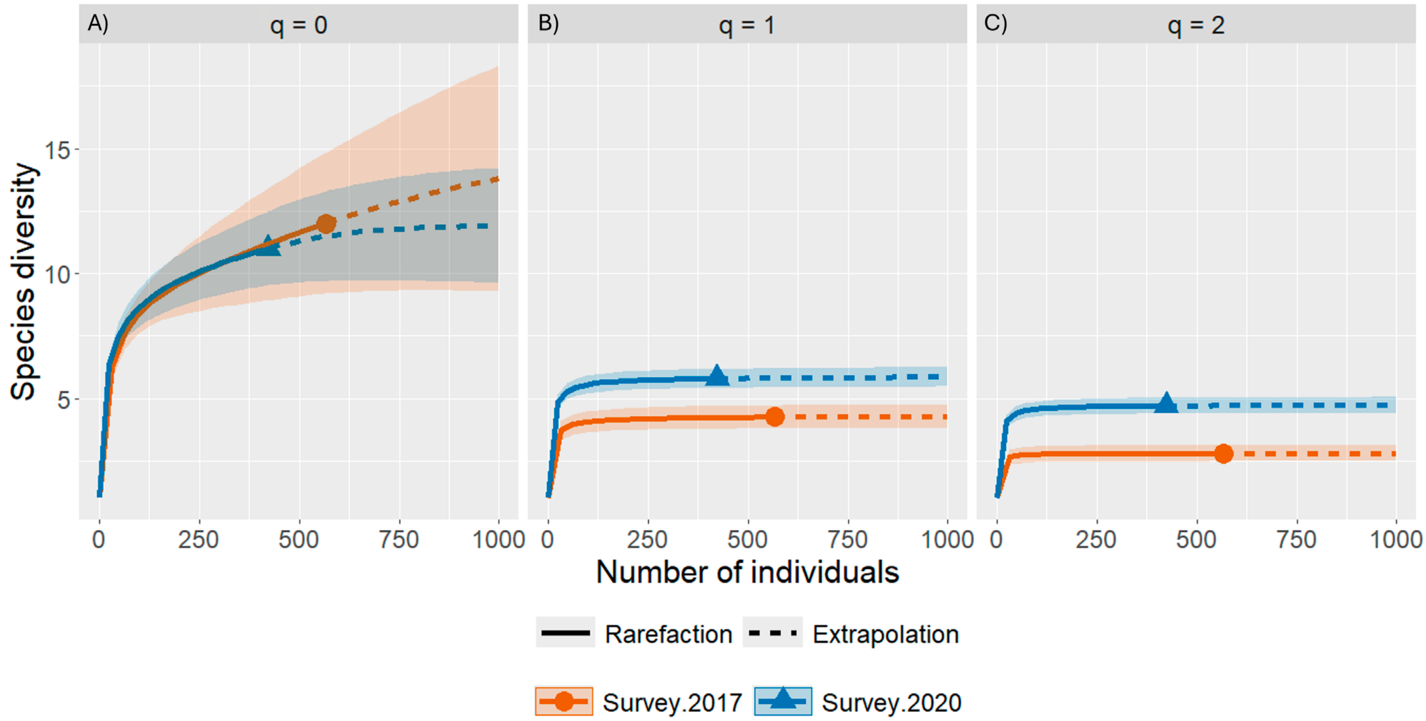

Figure 3. Species diversity curves according to Hill numbers (q = 0, richness [A]; q = 1, Shannon [B]; and q = 2, Simpson [C]) based on number of records (individuals) of wild medium- and large-sized mammals detected in 2017 (orange curve) and 2020-2021 (blue curve) in the Spix's Macaw protected areas and their surroundings, northeastern Brazil.

Table 2. Diversity, evenness, and dissimilarity (beta diversity) indices calculated based on medium- and large-sized mammals recorded at 48 sampling points in 2017 and 2020 in the protected areas of the Spix's Macaw, northeastern Brazil.

Survey	Richness (S)	Shannon (H')	Simpson (D)	Pielou (J')	Sørensen (βsor)
2017	9	1.41	0.66	0.64	
2020	11	1.76	0.79	0.73	
Total/Comparative	12	1.65	0.75	0.66	0.20

the estimated Sørensen beta diversity index (0.20) suggests low species turnover (0.11) and nestedness (0.09) between 2017 and 2020 surveys (Table 2).

In terms of the composition of the mammal assemblage, *P. concolor* and *Dasyprocta prymnolopha* were recorded only in 2017, while *Procyon cancrivorus* was recorded only in 2020 (Table 1). However, considering the data collected only within protected areas, *Didelphis albiventris*, *Dicotyles tajacu*, and *P. cancrivorus* were recorded only in 2020, whereas *P. concolor* was recorded only in 2017, and *D. prymnolopha* was never recorded in the protected areas (Table 1). All other species were recorded in both campaigns.

The species with the highest frequency of records, considered the most common species in both sample periods, was *Cerdocyon thous*, which dominated mainly the first sampling period, followed by *Euphractus sexcinctus* and *Dasypus novemcinctus* (Figure 4). On the other hand, among the species that showed the lowest number of records were *P. concolor*, *P. cancrivorus*, *D. tajacu* and *D. prymnolopha* (Figure 4).

There were many records of domestic animals. The seven species detected by the camera traps are divided into four families and three orders (Table 1). The goat (*Capra hircus*) was the most abundant species with 2,763 records, considering both samplings; followed by sheep (*Ovies aries*) with 801 records, donkey (*Equus asinus*) with 127 records, cow (*Bos taurus*) with 35 records, dog (*Canis lupus familiaris*) with 17 records, horse (*Equus caballus*) with 16 records, and cat (*Felis catus*) with 10 records.

Regarding the habitat types where the species were recorded, *P. cancrivorus* was recorded in a single riparian forest point; while *D. prymnolopha*, *D. tajacu*, and *P. concolor* were recorded only in arboreal vegetation associated with mountain ranges; and *Subulo gouazoubira* were recorded in areas with arboreal and shrubby vegetation, but not in riparian forest (Table 1). The rest of the wild mammals and almost all domesticated exotic species were recorded in all habitats, except for *C. lupus familiaris*, which was not recorded in riparian forest (Table 1). Despite the apparent differences between the habitats, the analysis of rarefaction and extrapolation curves suggests no significant difference in wild mammal richness (q = 0) or diversity (q = 1 or q = 2) between the environments (Supplementary Data SD3).

Discussion

The 17 species of mammals recorded in the Spix's Macaw protected areas and their surroundings, especially the 13 medium- and large-sized species, reinforce the biological importance of the region, which harbors just over 18% of the wild mammal species expected for the entire Caatinga biome (Carmignotto and Astúa 2017). Considering only the medium- and large-sized species, the richness found corresponds to 27% of the 45 mammal species weighing more than 1 kg expected for the Brazilian dry tropical forest (Carmignotto and Astúa 2017). Studies conducted in

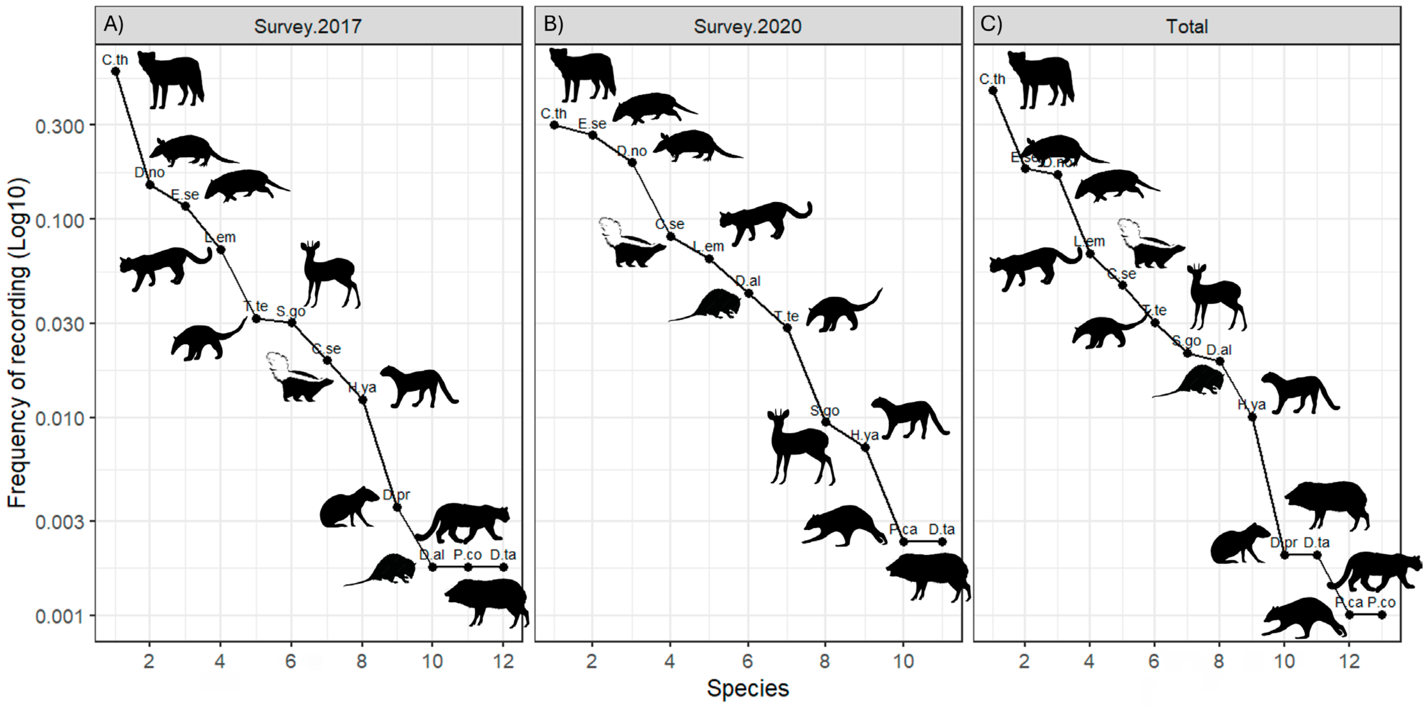

Figure 4. Rank abundance graphs based in frequency of recording of wild medium- and large-sized mammals recorded during 2017 (A), 2020-2021 (B), and considering the total data (C) in the Spix's Macaw protected areas and their surroundings, northeastern Brazil. D.al: *Didelphis albiventris*, D.no: *Dasypus novemcinctus*, E.se: *Euphractus sexcinctus*, T.te: *Tamandua tetradactyla*, D.pr: *Dasyprocta prymnolopha*, C.se: *Conepatus semistriatus*, C.th: *Cerdocyon thous*, P.ca: *Procyon cancrivorus*, P.co: *Puma concolor*, L.em: *Leopardus emiliae*, H.ya: *Herpailurus yagouaroundi*, S.go: *Subulo gouazoubira*, and D.ta: *Dicotyles tajacu*. Source of the mammal illustrations: https://www.phylopic.org/.

other protected areas of the Caatinga have found varying levels of mammal species richness. A survey carried out in the Boqueirão da Onça protected areas, including the National Park and the Environmental Protection Area, also located in northern Bahia, recorded 22 species of wild non-flying mammals using camera traps, including species likely extinct in our study area such as *Panthera onca* and *Myrmecophaga tridactyla* (Campos *et al.* 2019). In contrast, in the Catimbau National Park, in Pernambuco state, only eight species of wild non-flying mammals were found, in addition to seven exotic species that are very abundant in the area (Alves *et al.* 2020). The differences in species richness recorded in these areas and in the present study are related to the conservation status and environmental heterogeneity of the study areas, but also to the sampling effort employed.

The establishment of the Spix's Macaw Environmental Protection Area and Wildlife Refuge in 2018 appears to have benefited the mammals, resulting in a more diverse assemblage characterized by more equitable species abundances. Management actions, habitat restoration, environmental law enforcement and education initiatives, which emerged or were strengthened following the formalization of protected status (Lugarini *et al.* 2021; Vercillo *et al.* 2025), may have facilitated the recovery of mammal species with stricter habitat requirements or those subject to intense hunting pressure, such as *D. tajacu* (Alves *et al.* 2016). However, these results should be interpreted with caution, given the short timeframe since the creation of the EPA and WR. Furthermore, in 2020, the region was recovering from the most severe drought of the last century in the Caatinga that lasted from 2012 to 2017 (Silva *et al.* 2018), which likely also contributed to the recovery of populations most affected by the extended period of resource scarcity. *Procyon cancrivorus*, for example, was not recorded in 2017 and was recorded only once in 2020, possibly affected by scarcity of aquatic environments in the area, especially during the first sampling season, given its strong relationship with this type of habitat (Cheida *et al.* 2013).

The most generalist species in terms of habitat use and diet were the most frequently recorded among wild mammals. The omnivorous *C. thous* was the most common species, especially in the 2017 survey, following the pattern found in other areas of the Caatinga (Dias and Bocchiglieri 2016; Marinho *et al.* 2018a; Dias *et al.* 2019; Santos *et al.* 2024). The two armadillo species detected (*E. sexcinctus* and *D. novemcinctus*) are also considered common in the area. However, they are subjected to hunting in this ecosystem (Alves *et al.* 2016), which can reduce population levels or cause local extinctions in certain areas, especially in the case of *D. novemcinctus* (Bezerra *et al.* 2014; Marinho *et al.* 2018a).

Large mammals such as *D. tajacu* and *P. concolor* are among the species most impacted by habitat degradation and hunting. These species are intensely hunted and persecuted in the Caatinga for their meat or due to conflicts with livestock farmers, respectively (Alves *et al.* 2016), which explains their current absence in much of the biome (Marinho *et al.* 2019). *D. prymnolopha* is another very rare frugivore in the area, recorded infrequently and only in dense arboreal vegetation environments outside protected areas. This is concerning in terms of maintaining ecosystem services primarily performed by these species, such as the dispersal of large seeds (Vale *et al.* 2023). In turn, *P. concolor* may be affected by the low availability of prey and retaliatory killing (Alves *et al.* 2016; Borges *et al.* 2017; Zanin *et al.* 2020), especially in a region where extensive goat and sheep farming is so economically important. These factors, combined with the extensive home range and low densities of *P. concolor*, may explain why the species was recorded only once during the entire study.

In addition to species with low abundances, some species expected for the region and not detected in this study are also likely to be affected by anthropogenic and climatic impacts. Among them is *Leopardus pardalis*, a mesopredator that naturally exhibits low population densities and that seems to be related to more preserved environments in the Brazilian semiarid region (Penido *et al.* 2016; Dias *et al.* 2017; Campos *et al.* 2019). Among the armadillos with predicted distribution in the region is the threatened *Tolypeutes tricinctus* (Feijó *et al.* 2015). If it still occurs in the region, the population must also be at very low density and restricted to more protected environments. *Galictis cuja* is another carnivore that should also occur in the area but was not detected, a pattern that is repeated in other studies in the biome (Falcão *et al.* 2025; Marinho *et al.* 2018a). Regarding small mammals, *Wiedomys pyrrhorhinos*, *Gracilinanus agilis*, and *Monodelphis domestica* are species known to the area (Freitas *et al.* 2005), thus increasing to 20 the number of confirmed wild mammal species of the protected areas of the Spix's Macaw.

In the Caatinga biome, deforestation and degradation are mainly caused by agriculture and livestock farming, which, along with hunting, represents one of the main threats to wild species (ICMBio 2018). Large herds of goats and sheep, which together exceeded the number of wild mammal records in the present study, compete with wild animals for resources that are commonly scarce in the semiarid Caatinga (Marinho *et al.* 2016). These domestic animals were recorded in all types of habitats. Therefore, it is necessary to reduce their impact by protecting sensitive habitats, limiting access by domestic mammals, restoring degraded areas, and promoting more sustainable herd management strategies (Alves *et al.* 2020).

Indeed, the Caatinga consists of a mosaic of vegetation types shaped by environmental and anthropogenic factors that can determine the availability of resources and refuges for mammals (Freitas *et al.* 2005; Marinho *et al.* 2018b). Although our analysis did not detect significant variations in mammal richness or diversity among the different habitats studied, environments with arboreal vegetation showed a trend toward higher diversity, a pattern recognized in the literature (Marinho 2020). Therefore, future research should further investigate this issue using more appropriate sampling designs to identify priority habitats for enhanced protection or restoration.

The species recorded here reinforce the biological importance of the Spix's macaw protected areas for the conservation of non-flying mammal fauna in the Caatinga. Wild mammals have benefited from conservation and management strategies linked to the reintroduction process of *C. spixii* into the wild (Purchase *et al.* 2024), including the management of protected areas that guarantee the presence of rare and threatened species, as well as large mammals considered keystone species for the health of Brazilian semiarid ecosystems. However, it is important that long-term research investigates the population trends and potential recovery of the mammal assemblage, since the data presented here were collected a few years after the establishment of the protected areas. Actions for managing domestic species and conserving and restoring habitats should be reinforced and expanded to ensure the persistence of threatened and large wild mammals. For instance, records of threatened and rare species in the Caatinga biome obtained only in areas outside or on the periphery of reserves suggest the need to expand protection, as initially planned by the Institute of Environment and Water Resources of the State of Bahia (INEMA 2013), especially considering large-scale projects that may impact the landscape and biodiversity of the region (Bourscheit 2022).

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Declaration of Artificial Intelligence use

We declare that the authors have not used any Artificial Intelligence in the elaboration of this paper.

Author contributions

Thais Pereira dos Santos: Conceptualization, methodology, data curation, formal analysis, writing - original draft & writing - review and editing; Camile Lugarini: conceptualization, methodology, writing - original draft, writing - review and editing & funding; Eduardo Martins Venticinque:

conceptualization, formal analysis, writing - original draft & writing - review and editing; Paulo Henrique Dantas Marinho: conceptualization, methodology, data curation, formal analysis, writing - original draft & writing - review and editing.

Supplementary data

SD1. Diversity rarefaction and extrapolation (R/E) curves (q = 0) (A), sample completeness curves (B), and coverage-based R/E sampling curves (C) for wild medium- and large-sized mammals recorded in Spix's Macaw protected areas during 2017 (survey 2017) and 2020 (survey 2020) samplings and for the whole sample (total), considering 60 points sampled unevenly between 2017 and 2020.

SD2. Species diversity curves according to Hill numbers (q = 0, richness [A]; q = 1, Shannon [B]; and q = 2, Simpson [C]) representing wild medium- and large-sized mammals detected at 48 sampling points in 2017 (orange curve) and 2020-2021 (blue curve) in the Spix's Macaw protected areas, northeastern Brazil.

SD3. Species diversity curves according to Hill numbers (q = 0, richness [A]; q = 1, Shannon [B]; and q = 2, Simpson [C]) representing wild medium- and large-sized mammals detected in different habitat types (dense arboreal vegetation, riparian forest, and open shrub vegetation) of the Spix's Macaw protected areas and their surroundings, Bahia, northeastern Brazil, considering 60 points sampled unevenly between 2017 and 2020.

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