INTERACTIONS OF FOUR TEIID LIZARDS WITH GIANT ARMADILLO BURROWS AND RANGE EXTENSION FOR TWO ENDEMIC CERRADO SPECIES

INTERAÇÕES DE QUATRO LAGARTOS TEIÍDEOS COM TOCAS DE TATU-CANASTRA E EXTENSÃO DE DISTRIBUIÇÃO PARA DUAS ESPÉCIES ENDÊMICAS DO CERRADO

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Abstract.— The Neotropical genera *Tupinambis* and *Salvator* are large heliothermic lizards belonging to the teiid family with a wide distribution throughout South America. However, two species of these genera (*T. quadrilineatus* and *S. duseni*) have more limited distributions, being endemic to the Cerrado savanna. Giant armadillos build burrows that are used by a variety of species. In this study, we describe observations of interactions of four teiid species with giant armadillo burrows, report new distribution records of *T. quadrilineatus* and *S. duseni* within the Cerrado, and provide insights into the habitat requirements of these species. Our results highlight the importance of preserving threatened species to maintain ecological interactions and emphasize the need to protect the Cerrado savanna.

Key words.— Ecological interactions, ecosystem engineering, savanna, Squamata, camera-trap.

Resumo.— Os gêneros de lagartos heliotérmicos *Tupinambis* e *Salvator*, encontrados na região neotropical, pertencem à família Teiidae e são de grande porte. Eles possuem ampla distribuição em toda a América do Sul. No entanto, existem duas exceções em relação à sua distribuição, as quais *T. quadrilineatus* e *S. duseni* que são endêmicos do Cerrado. Os tatu-canastra, a maior espécie de tatu, constroem tocas que são usadas por várias espécies. Neste estudo, descrevemos observações de interações de quatro espécies de teídeos com tocas de tatu-canastra, relatamos novos registros de distribuição de *T. quadrilineatus* e *S. duseni* dentro do Cerrado, e discutimos sobre os requisitos de habitat dessas espécies. Nossos resultados destacam a importância de preservar espécies ameaçadas para manter as interações ecológicas e enfatizam a necessidade de proteger Cerrado.

Key words.— Interações ecológicas, engenheiro de ecossistemas, savana, Squamata, camera-trap.

South America harbors a great diversity of Teiidae lizards (Harvey et al., 2012). They are known for their general terrestrial ecology, with some exceptions of semi-aquatic species (Ávila-Pires, 1995). The distribution of these lizards is wide, with representatives occurring in several regions of South America, including the Amazon, Caatinga, Cerrado, and Atlantic Forest biomes. Although many species of Teiidae are relatively common and abundant in certain areas (e.g., *Ameiva ameiva*, *Ameivula ocellifera*, and *Salvator merianae*; Guedes et al., 2023), a few other species of the family can be rare or even face the threat of extinction in other regions (e.g., *Ameivula nativo* and *Tupinambis longilineus*; Ávila-Pires, 1995; Costa et al., 2008; Rocha et al., 1997; Vitt, 1991). Like many other reptiles, teiids are ectothermic animals, which means the external environment determines their body temperature (Huey, 1982). They are known to be agile and highly adaptable animals, enabling them to explore different habitats and feed on various prey.

Tupinambis Daudin, 1802 and *Salvator* Duméril & Bibron, 1839 are large diurnal teiid lizards that are heliothermic and

are known for being active foragers (Ávila-Pires, 1995; Harvey et al., 2012). Species within both genera inhabit habitats ranging from forested to open areas, with most of them occurring in at least two or more ecoregions throughout South America, making them widespread species (Silva et al., 2018). However, *T. quadrilineatus* Manzani & Abe, 1997 and *S. duseni* (Lönnberg in Lönnberg & Andersson, 1910) are endemic species to the Cerrado savanna (Drummond et al., 2014; Oliveira & Costa, 2022), which is the richest savanna in the world and a biodiversity hotspot, a megadiverse area with many endemic species that are severely threatened (Klink & Machado, 2005).

In the Cerrado savanna, *T. quadrilineatus* has already been recorded in the Brazilian states of Tocantins, Minas Gerais, Bahia, Piauí, Maranhão, Pará, Mato Grosso, Goiás, and Distrito Federal, with Mato Grosso do Sul being the only state in the Midwest region of Brazil without a record for the species (Oliveira & Costa, 2022). This species is mainly characterized in its external morphology by the upper lateral stripe well-defined along the flanks, whereas in other species, it is indistinct or absent (Avila-Pires, 1995; Colli et al., 1998; Manzani & Abe, 1997). *Salvator duseni* is one of the largest members of the genus and is strongly associated with the Cerrado. It was described based on a specimen collected from an unknown location in the Paraná state, probably in Cerrado areas in the northern parts of that state (Drummond et al., 2014; Lönnberg & Andersson, 1910). However, this large teiid has only been recorded in Cerrado areas, confirming its endemicity to this ecoregion (Drummond et al., 2014). Besides, it is characterized by scales on the nape that are distinctly larger than the dorsal ones, as well as convex dorsal scales, and its overall distinct coloration (Péres & Colli, 2004).

As ectothermic animals, Teiid lizards can adopt several behavioral strategies for thermoregulation. These strategies are especially important for species that live in savanna habitats, which are covered by less dense vegetation and are subject to wide temperature variation. Lizards can choose to shelter during hot hours of the day or bask in areas more exposed to the sun to optimize their thermoregulation at colder temperatures (Pianka, 2017). Hence, microhabitat that provides opportunities for behavioral thermoregulation is paramount for the survival of lizards in savanna habitats.

Armadillo burrows are conspicuous features in the Cerrado landscape that can provide microhabitats suitable as thermal shelters (inside the burrow) and for basking (in the sand mound formed in front of burrows as a result of soil displacement during digging). The largest armadillo burrows found in the Neotropics are excavated by the giant armadillo, *Priodontes maximus* (Kerr, 1792), a semi-fossorial mammal that can reach a body length of 1.5 m and weigh between 30 and 50 kg (Carter et al., 2016; Desbiez et al., 2019). These burrows measure on average 35 cm in diameter and up to five meters in depth and are used as a refuge by a high diversity of vertebrate species, including reptiles (Desbiez & Kluyber, 2013; Desbiez & Attias, 2021). The species is considered an ecosystem engineer due to the physical changes in the soil caused by its excavations that influence several other species (Aya-Cuero et al., 2017; Desbiez & Kluyber, 2013; Di Blanco et al., 2020; Fontes et al., 2020; Massocato & Desbiez, 2017).

In this study, we describe observations of four teiids species, *A. ameiva* (Linnaeus, 1758), *T. quadrilineatus*, *S. duseni*, and *S. merianae* Duméril & Bibron, 1839 interacting with giant armadillo burrows, and provide new insights into the potential ecological interactions of these lizards. We also provide new information on the distribution of *T. quadrilineatus* and *S. duseni*, with the first records of these species in the Cerrado of Mato Grosso do Sul state.

This study took place in the Parque Natural Municipal do Pombo (PNMP), located in the municipality of Três Lagoas, Mato Grosso do Sul state (20°21'S, 52°38'W). This is one of the few protected fragments of Cerrado habitat in Mato Grosso do Sul where the giant armadillo has been recorded (Ferraz et. al., 2021; Massocato & Desbiez, 2017), and protects 8,032 hectares of native Cerrado. Before its implementation, the park was a cattle ranch and is considered in regeneration rather than pristine Cerrado. The records presented in this study were made through the use of camera traps (HC–500, HC–550, HC–600, and PC–850; Reconyx, Holmen, USA) placed strategically to monitor the giant armadillo population at the PNMP. Between April 2022 and March 2023, we established a camera trap array (n = 70 camera sites) throughout the PMNP. To build the trap array, first, we defined camera locations using ArcGIS, predefining their locations throughout the area, and applying a 1km spacing among them. Then, we applied a 250 m buffer around the pre-defined point locations to actively search for evidence of *P. maximus* to optimize the final placement of the camera traps. In this way, the whole park was covered. All cameras were set to "no delay" rapid fire mode, recording a burst of three photos every time it was triggered (one frame per second) and without any intervals between triggers (0 seconds). This allowed cameras to record animal behavior continuously while the animal remained in the camera's range, i.e., in the burrow's vicinity. All camera records were accompanied by information on the date, time, and temperature of the sighting, as recorded by the camera trap device. We used the photo's time stamps to calculate the time elapsed in each continuous photo sequence of a certain individual behavior to characterize the duration of the

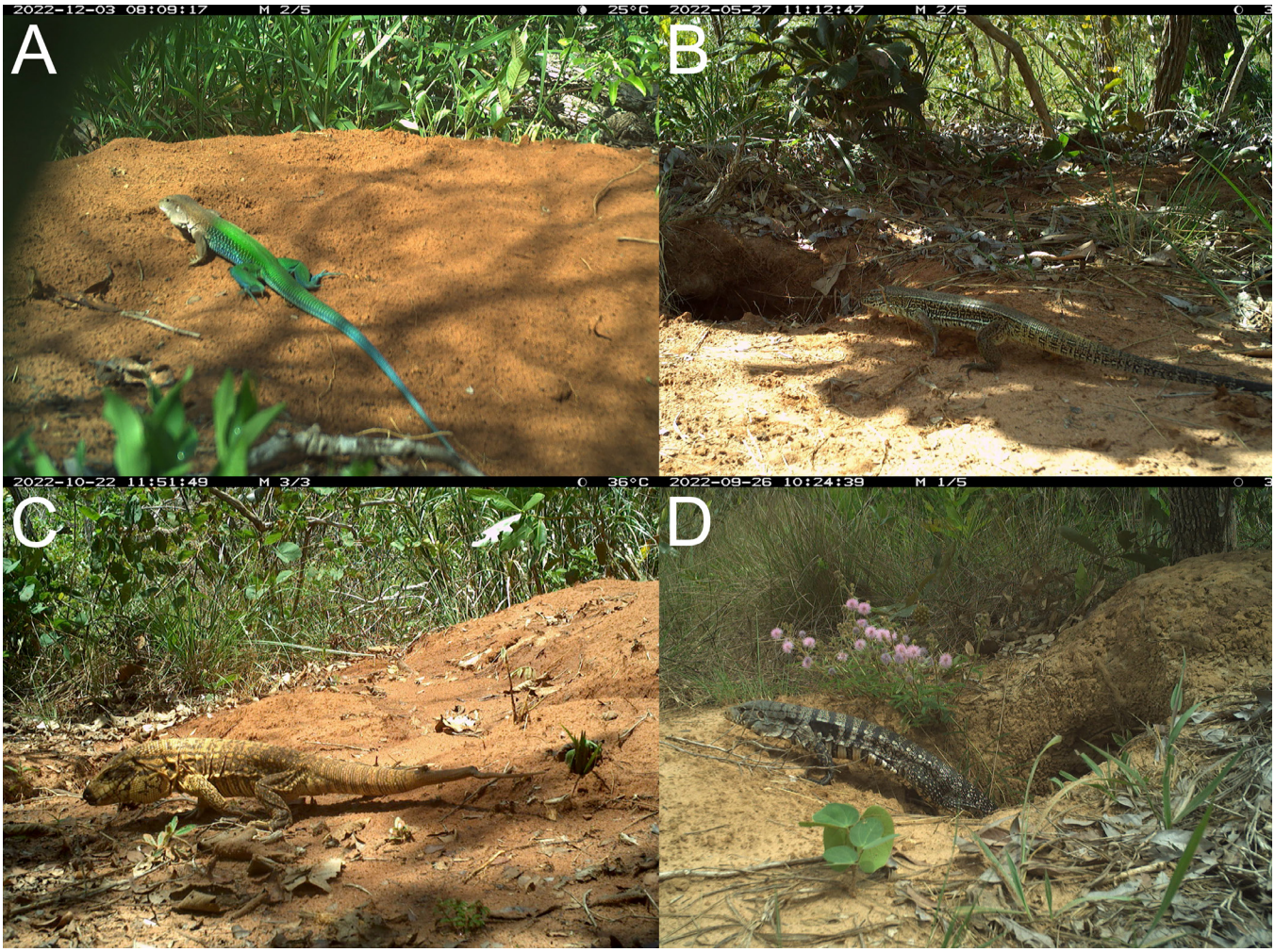

Figura 1. Registros de teídeos usando as tocas de tatu-canastra no Pombo Natural Municipal do Pombo, município de Três Lagoas, estado de Mato Grosso do Sul, Brasil. Indivíduos adultos de (A) *Ameiva ameiva*, (B) *Tupinambis quadrilienatus*, (C) *Salvator duseni* e (D) *Salvator merianae*.

Figure 1. Teiids recorded in front of giant armadillo (***Priodontes maximus***) burrows in Parque Natural Municipal do Pombo, Três Lagoas Municipality, Mato Grosso do Sul state, Brazil. Adult individuals of (A) *Ameiva ameiva*, (B) *Tupinambis quadrilienatus*, (C) *Salvator duseni*, and (D) *Salvator merianae*.

interaction with the burrow in each record. Finally, we followed the methods proposed by Desbiez & Kluyber (2013) to classify the records into four categories: (1) animal passing by in front of the burrow, (2) animal interacting with burrow or sand mound for less than 5 sec, (3) interaction with burrow or sand mound for more than 5 sec, and (4) animal enters the burrow.

Camera traps placed in front of giant armadillo burrows recorded teiid lizards (*A. ameiva*, *S. merianae*, *S. duseni*, and *T. quadrilineatus*; Table 1) on 17 occasions. Average air temperature of records was 35.47 °C (range: 17–50 °C). According to our findings, *A. ameiva* (Figure 1A) was the teiid with the highest number of records in burrows of giant armadillos, with a total of 12 observations throughout the year (see Table 1 for details on period of the year, time of the day and temperature). *Ameiva ameiva* was recorded interacting with the burrows between the months of September and December. Most of the records were obtained from the same burrow, during late morning and early afternoon when air temperature was recorded to be above 31°C. For this species, we recorded all four categories of interaction with the burrow. Nevertheless, there were three records of this species interacting with the burrows earlier in the morning while air temperature was lower, between 17 and 25 °C (Table 1).

Individuals of *T. quadrilineatus* (Figure 1B) were identified based on the species' distinct external morphology, which was

Tabela 1. Dados sobre as quatro espécies de teídeos registradas no Parque Natural Municipal do Pombo, município de Três Lagoas, estado de Mato Grosso do Sul, Brasil, de maio a dezembro de 2022. O tempo de interação significa o tempo que os indivíduos passaram dentro das tocas do tatu-canastra e/ou no monte de areia das tocas. NA: registro com apenas uma fotografia.

Table 1. Data on Teiid species recorded at Parque Natural Municipal do Pombo, Três Lagoas municipality, Mato Grosso do Sul state, central Brazil from May to December 2022. The interaction time means the time spent by the individuals inside the giant armadillo burrows and/or in the sand mound of burrows. NA: record with only one photograph.

Species	Burrow ID	Latitude	Longitude	Date	Hour	Temperature (°C)	In sand mound	In burrow	Interaction time
Ameiva ameiva	C04	-20,33386	-52,66084	2022-09-12	10:17	42		X	9 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-10-03	11:59	41		X	6 min 18 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-10-04	12:48	47		X	3 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-10-15	12:52	43		X	2 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-10-24	10:21	31	X	X	1 min 27 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-10-26	12:54	49		X	5 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-10-28	15:00	50		X	2 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-11-03	07:56	17	X		NA
Ameiva ameiva	E01	-20,35540	-52,68236	2022-11-29	09:39	31	X		NA
Ameiva ameiva	E01	-20,35540	-52,68236	2022-11-30	09:32	29		X	6 min 30 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-12-03	08:09	25	X		44 sec
Ameiva ameiva	E01	-20,35540	-52,68236	2022-12-11	08:28	24	X		3 sec
Salvator duseni	D02	-20,35056	-52,67920	2022-10-22	11:52	35		X	14 min 34 sec
Salvator merianae	K02	-20,39830	-52,61656	2022-09-26	10:24	31		X	15 sec
Tupinambis quadrilineatus	J02	-20,39191	-52,63033	2022-05-27	11:12	36	X		3 sec
Tupinambis quadrilineatus	J02	-20,39191	-52,63033	2022-07-20	10:14	35	X		11 sec
Tupinambis quadrilineatus	E01	-20,35540	-52,68236	2022-11-30	12:19	37	X		1 sec

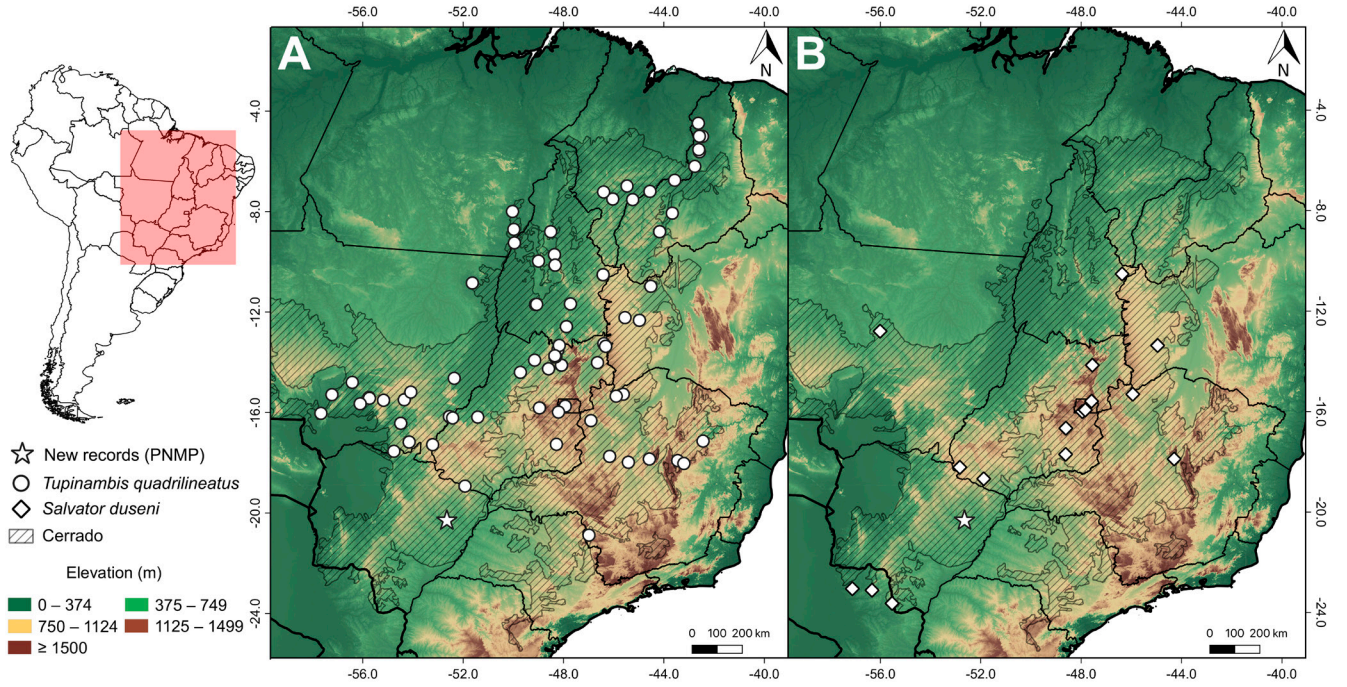

Figura 2. Mapa de distribuição de (A) *Tupinambis quadrilineatus* e *Salvator duseni* (B) no Cerrado, mostrando as localidades de ocorrência baseadas na literatura (Drummond et al., 2014; Oliveira & Costa, 2022) e os novos registros (estrela) no Pombo Natural Municipal do Pombo, município de Três Lagoas, estado de Mato Grosso do Sul, Brasil.

Figure 2. Distribution map of (A) *Tupinambis quadrilineatus* and (B) *Salvator duseni* along the Cerrado showing known localities based on the literature (Drummond et al., 2014; Oliveira & Costa, 2022) and the new records (star) in Parque Natural Municipal do Pombo (PNMP), Três Lagoas municipality, Mato Grosso do Sul state, Brazil.

later confirmed using specific literature that considered the overall external morphology and coloration patterns (Colli et al., 1998; Manzani & Abe, 1997) and expert consultation. Individuals of this species were recorded approaching and exiting the same armadillo burrow on two separate occasions during the dry season, in the months of May and July (Table 1). On the first occasion, the individual briefly inspects the entrance to the armadillo burrow for three seconds, while on the second occasion, the lizard appears already leaving the burrow (the camera trap sensor wasn't activated when the animal entered the burrow) and inspects the sand mound for 11 seconds. The third photographic record of this species was obtained at the beginning of the rainy season (in late November), coming out of another armadillo hole (Table 1). All records of the species were obtained during late morning, and early afternoon (11:12 a.m., 10:14 a.m., and 12:12 p.m.), at high temperatures (35–37 °C; Table 1).

Salvator duseni (Figure 1C) was recorded interacting with the giant armadillo burrow once in rainy season in October (Table 1). An individual entered a burrow late in the morning (11:52 a.m.; air temperature = 35 °C) and stayed inside for 14 minutes and 34 seconds. Two records of *S. duseni* were also made in giant armadillo feeding holes, which are much shallower structures than armadillo burrows (Desbiez & Kluyber, 2013). We also recorded another teiid from the same genus, *S. merianae* (Figure 1D), interacting with the armadillo burrows. An individual was recorded staying for 15 seconds inside a burrow in late September, around 10:24 a.m. (air temperature = 31° C; Table 1).

This is the first record of *T. quadrilineatus* in the Mato Grosso do Sul state and one of the southernmost distribution records for this species (Figure 2A). Recently, Oliveira and Costa (2022) revised and extended the species' distribution based on new records in the Minas Gerais state. According to their updated distribution map, the present record extends the species distribution approximately 170 kilometers south in a straight line from the closest known record, which is in the municipality of Aporé, in the Goiás state. Additionally, it is approximately 468 kilometers away from the type locality of the species in Fazenda Bandeirantes, Municipality of Baliza, Goiás, Brazil (Oliveira & Costa, 2022). The records of *S. duseni* also expand the distribution of this species within the Cerrado. The present record in PNMP

helps to fill a gap in the species distribution (Figure 2B). It also expands the range of the species approximately 195 kilometers to the south from the closest known record, which is at the Espora hydroelectric power plant in Aporé, Goiás, Brazil. Furthermore, it extends the species' distribution approximately 485 kilometers to the north from its southernmost known record, which is in Laguna Siete, Departamento de Concepción, Paraguay (Drummond et al., 2014).

These records of *T. quadrilineatus* and *S. duseni* in the Mato Grosso do Sul state confirm their endemic status in the Cerrado, an ecoregion that has suffered significant losses and threats throughout Brazil (Rodrigues et al., 2022). The region where we recorded the species has suffered from severe degradation and is predominantly covered by small remnant fragments of native Cerrado vegetation (Ferraz-Almeida & Mota, 2021; Reynolds et al., 2016). PNMP is currently one of the largest protected remnants of Cerrado habitat in the state and one of the few large remnants where giant armadillos can still be found (Ferraz et al., 2021). The importance of this native remnant can be further highlighted because the landscape surrounding the park is rapidly changing due to land use changes, with vast areas of cattle ranching grasslands being replaced by silvicultural activities, such as *Eucalyptus* plantations (Bispo et al., 2023; Rodrigues et al., 2022).

Armadillo burrows are valuable microhabitats for lizards and are commonly used as shelters by various species in different regions, particularly in open and arid environments (Desbiez & Kluyber, 2013; Huey & Pianka, 1977; Montaño et al., 2013). These burrows offer a diversity of microhabitats, allowing lizards to regulate their body temperature by moving between the cooler, deeper parts of the burrow and the warmer, shallow areas near the entrance (Di Blanco et al., 2020). For example, *S. rufescens* in Bolivian Chaco uses armadillo burrows built by the yellow armadillo (*Euphractus sexcinctus*) or the nine-banded armadillo (*Dasypus novemcinctus*) (Montaño et al., 2013). In the temperate Pine savannas of the United States, lizards, such as *Aspidoscelis sexlineata* and *Sceloporus undulatus*, use burrows built by the nine-banded armadillo (Howze & Smith, 2022). Other teiid lizards have been previously recorded interacting with giant armadillo burrows, such as *Tupinambis teguixin* (Linnaeus, 1758) in Pantanal wetlands (Desbiez & Kluyber, 2013). Here we record four teiid species interacting with burrows created by the giant armadillo, which indicates these structures could be providing shelter, resources, and thermoregulation opportunities for these species. This highlights the importance of acknowledging ecological interactions and interdependencies between different species in the management and conservation of ecosystems (Diamond, 1984), and emphasizes the crucial role of the giant armadillo as an ecosystem engineer (Fontes et al., 2020).

The availability of armadillo burrows may be crucial for the sheltering and survival of teiid species in the Cerrado savanna, a tropical environment that is suffering from continuous habitat degradation. The degradation of the Cerrado has a significant impact on the fauna associated with the savanna vegetation, including the recorded teiid species and the threatened giant armadillo (Reynolds et al., 2016). The lack of habitat and decreasing environmental quality and increasing isolation of individuals can lead to a reduction in population and eventually local extinction of the species, which would be an irreparable loss to the biodiversity of the region (Desbiez & Kluyber, 2013; Ferraz-Almeida & Mota, 2021; Fontes et al., 2020). Consequently, the loss of keystone species such as the giant armadillo would lead to losses of biotic interactions such as those enabled by the use of their burrows by multiple vertebrate and invertebrate species (Ferraz-Almeida & Mota 2021; Fontes et al., 2020).

The Cerrado of Mato Grosso do Sul suffers from high rates of deforestation and fragmentation, with only 16% of the state area still covered by native Cerrado. These fragments are small, averaging only 9 ha, and only 1.6% of the area of these remnants is inside strictly protected areas (Reynolds et al., 2016). Hence, PNMP is one of the largest strictly protected remnants of native Cerrado in Mato Grosso do Sul, covering 8,000 ha. The park is crucial for local biodiversity conservation, as shown by the relevant species records presented in this study. Further studies should focus on the park's contribution to metapopulations and landscape connectivity in this highly degraded Cerrado region, beyond just its biodiversity composition.

Overall, the use of camera traps provided a non-invasive and efficient way to document the presence of four teiid species (*A. ameiva*, *T. quadrilineatus*, *S. duseni*, and *S. merianae*) interacting with giant armadillo burrows in an understudied savanna location. The results of this study contribute to our understanding of these species' distribution and habitat requirements, highlighting the importance of preserving and protecting threatened species to maintain ecological interactions (Fontes et al., 2020). Results from this study further highlight the importance of the PMNP, in which almost no research has been conducted, but is an important refuge for fauna in a rapidly changing landscape.

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