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Underground jaguars: first record of a jaguar (*Panthera onca*) using a giant armadillo (*Priodontes maximus*) burrow

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ABSTRACT
There are several behavioral adaptations used by mammals to reduce the metabolic costs of preventing homeostasis disruption caused by excessive heat such as seek shaded places. Burrows are great thermal refuges that provide buffered cooler microclimates. Here we report the first record of a jaguar *Panthera onca* using a giant armadillo *Priodontes maximus* burrow, potentially as a thermal refuge. This behavior was recorded in the Grande Sertão Veredas National Park, Cerrado biome, Central Brazil. As future global scenarios expect higher temperatures, giant armadillo burrows may become progressively more important during daily and seasonal periods of extreme heat.

Keywords: behavior, Cerrado, *Panthera onca*, *Priodontes maximus*, threatened species

RESUMO - Onças subterrâneas: primeiro registro de uma onça-pintada (*Panthera onca*) usando uma toca de tatu-canastra (*Priodontes maximus*)
Existem várias adaptações comportamentais utilizadas pelos mamíferos para reduzir os custos metabólicos da prevenção da perturbação da homeostase causada pelo calor excessivo, como buscar locais sombreados. Tocas são ótimos refúgios térmicos, pois fornecem microclimas mais frescos e protegidos. Aqui relatamos o primeiro registro de uma onça-pintada *Panthera onca* utilizando toca de tatu-canastra *Priodontes maximus* potencialmente como refúgio térmico. Esse comportamento foi registrado no Parque Nacional Grande Sertão Veredas, bioma Cerrado, Brasil Central. Como os cenários futuros globais preveem temperaturas mais elevadas, as tocas de tatu-canastra podem se tornar progressivamente mais importantes durante os períodos diários e sazonais de calor extremo.

Palavras-chave: Cerrado, comportamento, espécies ameaçadas, *Panthera onca*, *Priodontes maximus*

Extreme temperatures are one of the climatic parameters that shape animal behavior (Angilletta et al. 2010). There are several behavioral adaptations that can be used by mammals to reduce the metabolic costs of preventing homeostasis disruption and its deleterious effects on metabolism caused by excessive heat such as retreat in shaded cooler places (Smith & Kok 2006; Terrien et al. 2011; Giroux et

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al. 2021). This strategy is less costly than evaporative cooling (Fuller et al. 2021) and may drive animal decision-making and movement patterns (Angilletta et al. 2010; Terrien et al. 2011; Giroux et al. 2021). In this scenario, burrows stand out as great thermal refuges by providing buffered cooler microclimates (Desbiez & Kluyber 2013; Fuller et al. 2016).

Burrowing species, such as the aardvark *Orycteropus afer* (Pallas, 1766) and the giant armadillo *Priodontes maximus* (Kerr, 1792) are considered ecosystem engineers by altering their physical surroundings and promoting new habitats and environmental heterogeneity that influence resources for different species (Eldridge & Whitford 2009; Whittington-Jones et al. 2011; Desbiez & Kluyber 2013). The giant armadillo is the largest of living armadillo measuring up to 1.50 m and weighing up to 60 kg (Silveira et al. 2009; Carter et al. 2016; Desbiez et al. 2019). Although regionally widespread, the species always occurs at low population densities and are locally rare (Desbiez et al. 2020). The species is distributed throughout South America and globally classified as Vulnerable (Anacleto et al. 2014). Giant armadillos dig large characteristic excavations for shelter and feeding. Burrows are the deepest excavations, where the animal usually spends the day sleeping, and are typically 40 cm wide and can be 5 m deep, depending on habitat type (Desbiez & Kluyber 2013; Carter et al. 2016). In the Pantanal, it was observed that giant armadillos, on average, dig a new burrow every two to three days. Therefore, there are many giant armadillo burrows in an individual's home range. These burrows create new habitats and influence resource availabilities for hundreds of vertebrate species throughout their distribution (Aya-Cuero et al. 2017; Desbiez & Kluyber 2013; Di Blanco et al. 2020; Fontes et al. 2020; Massocato & Desbiez 2017). These giant armadillo burrows are often used as a refuge against extreme temperatures as deep in the burrow the temperature is constant between 25 ˚C and 26 ˚C (Desbiez & Kluyber 2013). Some species such as the scansorial southern tamandua *Tamandua tetradactyla* (Linnaeus, 1758), or other species of armadillos spent long periods of time in the burrow especially during cold spells or extreme heat (Desbiez & Kluyber 2013) Some carnivore species such as the Pampas fox *Lycalopex gymnocercus* (Fischer, 1814), the taira *Eira barbara* (Linnaeus, 1758), the Geoffroy's cat *Leopardus geoffroyi* (d'Orbigny & Gervais, 1844), the ocelot *Leopardus pardalis* (Linnaeus, 1758) and the puma *Puma concolor* (Linnaeus, 1771) were predominantly recorded investigating the burrows entrances, probably searching for hunting opportunities, but were also observed resting in burrows for prolonged periods (Desbiez & Kluyber 2013; Di Blanco et al. 2020). Up to date, there has not been no record of jaguars *Panthera onca* (Linnaeus, 1758) interacting with a giant armadillo burrow.

The jaguar is the American apex predator (Hunter 2019) globally classified as Near Threatened by the IUCN Red List (Quigley et al. 2017), with severe population declines throughout its distribution (de la Torre et al. 2017). Mean body weight varies enormously across its range, but adult males can weigh from 102 to 140 kg in the Pantanal (Fragoso et al. 2023a). Jaguars are primarily terrestrial but are known to climb trees (Fragoso et al. 2023a); in fact, in the Amazon some populations can spend months adopting an arboreal lifestyle (Ramalho et al. 2021). However, to our knowledge there are no reports of jaguars going underground. Here, we report the

first record of this big felid using a giant armadillo burrow potentially as a thermal refuge.

This report is part of an ongoing project started in 2018 and expanded in 2022 on the ecology and conservation of jaguars and pumas on a 2,500 km^2 area in the Cerrado, Central Brazil, which encompasses the Grande Sertão Veredas National Park and a private property called Fazenda Trijunção (Fig. S1), in the borders of the States of Bahia, Goiás, and Minas Gerais. The landscape is characterized by savannas with different levels of arboreal cover and palm swamps (veredas) with altitudes ranging from 600 m to 850 m (Recoder & Nogueira 2007; Carvalho & Batista 2013). The climate is classified as tropical savanna (Aw) (Köppen 1936) with local annual average temperatures of 25.33°C (range = 11.5 °C - 38.9 °C), rainfall (1,400 mm) concentrated in summer and a dry season of three to five months in winter (Radam 1982; Recoder & Nogueira 2007).

Surveys were carried out with the use of camera traps, radio telemetry, satellite monitoring, active searches for jaguars and pumas, and checking clusters from the GPS collars data (under license numbers: 83480-2 / 87047-1). Since the beginning of the project, we have recorded 25 individual jaguars in the study area. In 2023 we captured and placed GPS transmitters (TGW-4577-4, Telonics Inc., Mesa, Arizona, USA) programmed to collect one location per hour (24 locations/day) on two male jaguars (M02 and M13). On June 27, 2023, during fieldwork to check a cluster formed by M02 a day earlier from 11:00 to 18:00, we found a giant armadillo burrow in a slope with difficult access surrounded by tall grass (latitude -14.933292; longitude -45.747847; Fig. 1). There were no trees in the area. On June 29 we installed a motion triggered camera (Trophy Cam HD 119717CW, Bushnell, Overland Park, Kansas, USA) set to record 20" videos with 1" between recordings in front of the entrance of the giant armadillo burrow. On July 13, 27 videos grouped into six sequences were filmed (Table 1) of the same male entering and exiting the burrow between 08:30 and 18:11 (Table S2; Fig. 2). Analyzing the videos, M02 spent 419 minutes inside and 161 minutes outside but in the proximity of the burrow (Table 1). A local weather station that collects rain gauge, temperature, humidity, wind speed, dew point, and solar radiation data show that the maximum temperatures during the days in which M02 was inside the giant armadillo burrow were 28.3 °C and 33 °C, respectively. Although they are not the hottest temperatures recorded in the study area (they can reach up to 38. 9°C), M02 was probably looking for shade from the heat, cooler microclimate, and a safe place to rest, as landscape is dominated by open grasslands and the shade is a scarce resource, with the nearest well shadiest areas (veredas) closest to 4.7 and 7.3 km away from the burrow site. Astete et al. (2017) suggested that the jaguars and pumas in the neighboring biome, Caatinga, seek regions of higher altitudes with cliffs, canyons and caves to protect themselves from local high temperatures. Another big cat, the leopard *Panthera pardus* (Linnaeus, 1758), also uses caves to retreat during the hottest hours of the day in Africa (Bothma 1998).

M02 was monitored from June 2023 to January 2024, when he was found dead of natural causes. At the time of capture, his age was estimated to be at least 13 years old due to his body and teeth condition. Pantanal jaguars live up to 15-16 years in the wild (Fragoso et al. 2023b), but there is no reliable estimate for the Cerrado ones.

M02 also was a relatively small jaguar (69.7 kg) which may facilitate the use of giant armadillo burrows. Further investigations may reveal if this behavior is an intrinsic characteristic of this particular individual or if it is a common behavior in this jaguar population.

Despite the intensive monitoring in the region from January 2022 to February 2024 with 17,889 camera trap nights (range = 28-51 simultaneous sampling stations) and a total of 150,668 videos, giant armadillo seems to be a naturally rare species with only 11 independent records (60 minutes of interval between records to avoid autocorrelation; Foster et al. 2013). However, even in areas where giant armadillos are almost extinct, their burrows persist and they continue to play an important role in terms of ecological 'footprint' (Fontes et al. 2020) by providing buffered cooler microclimates for a wide array of species (Di Blanco et al. 2020). As global future scenarios expect higher temperatures (Pike & Mitchell 2013), giant armadillo burrows may become even more important during daily and seasonal periods of extreme heat as temperature buffers, humidity reservoirs and potential shelters to extreme climate conditions (Di Blanco et al. 2020).

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Figure 1. *Priodontes maximus* burrow surrounded by tall grass (A) and the entrance in detail (B).

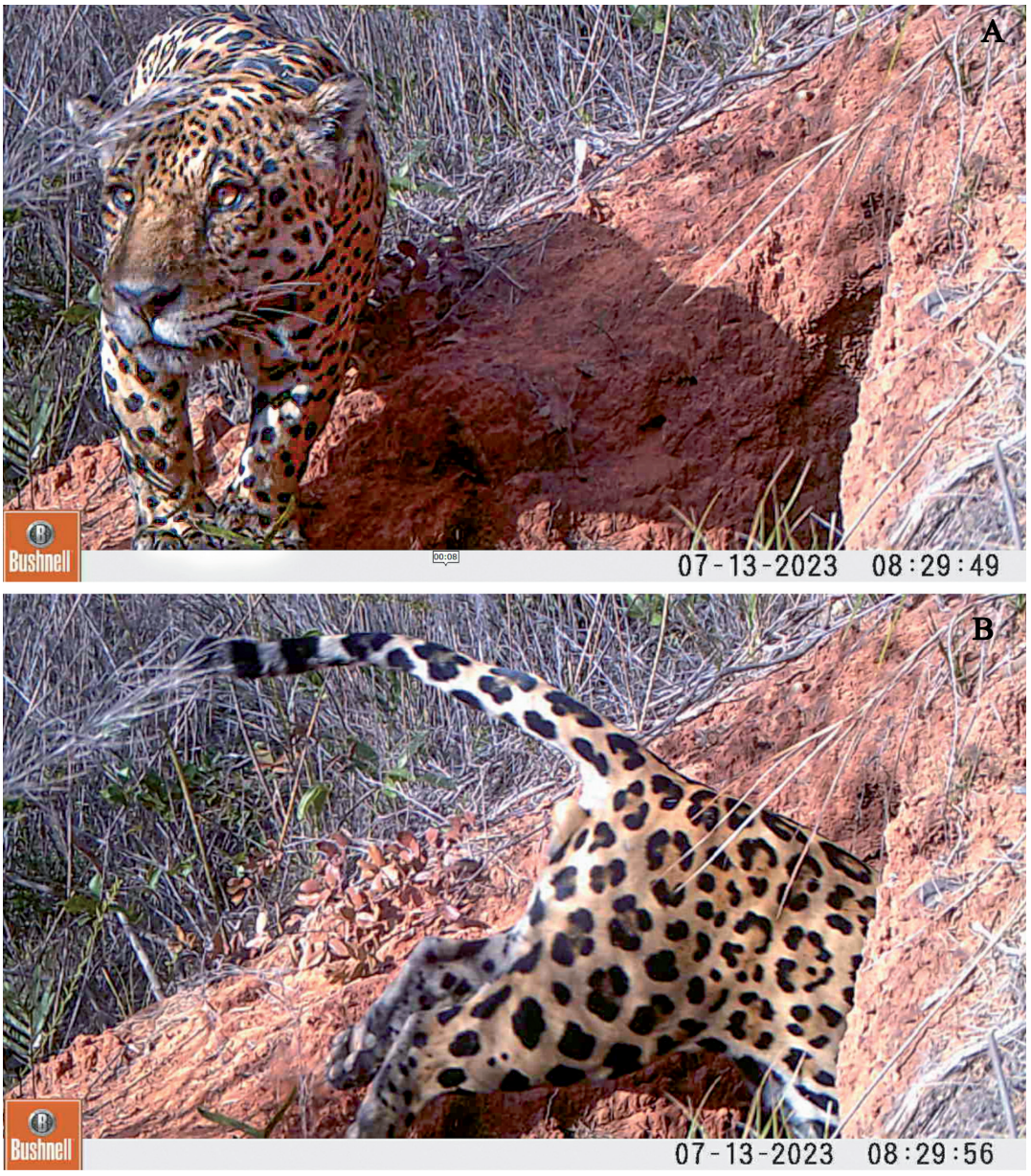

Figure 2. M02 (*Panthera onca*) arriving (A) and entering the *Priodontes maximus* burrow (2).

Table 1. Time spent by M02 (*Panthera onca*) inside and outside the *Priodontes maximus* burrow on 13 July 2023.

Initial time	Final time	Duration	Status
08:30:00	10:50:30	02:20:30	inside
10:50:52	11:24:00	00:33:08	outside
11:24:20	13:33:42	02:09:22	inside
13:33:58	15:22:34	01:48:36	outside
15:22:42	17:52:28	02:29:46	inside
17:52:28	18:11:50	00:19:22	outside

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ONLINE SUPPLEMENTARY MATERIAL

Figure S1. Location of the study area in the borders of the States of Bahia, Goiás, and Minas Gerais, Brazil

Table S2. Behavioral assessment of the M02 (*Panthera onca*) in a *Priodontes maximus* burrow