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SHORT COMMUNICATION

Notes on giant armadillo *Priodontes maximus* (Cingulata: Chlamyphoridae) distribution and ecology in *Eucalyptus* plantation landscapes in eastern Mato Grosso do Sul State, Brazil

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Abstract Despite its wide distribution in South America, ranging from northern Venezuela and the Guianas south to Paraguay and northern Argentina, the vulnerable giant armadillo (*Priodontes maximus*) occurs at low densities and is little studied due to its elusive habits. In Brazil species' records have been collected from the Pantanal and central Cerrado but little information is known from the eastern border of Mato Grosso do Sul. Here we report 97 records of giant armadillo in this region from areas of private lands using camera-traps and signs of presence in Cerrado and Atlantic Forest biomes.

Keywords: Atlantic Forest, camera-trap, Cerrado, forestry plantation, private lands

Notas sobre a distribuição e a ecologia do tatu-canastra *Priodontes maximus* (Cingulata: Chlamyphoridae) em paisagens de plantação de eucaliptos no leste do estado de Mato Grosso do Sul, Brasil

Resumo Apesar de sua ampla distribuição na América do Sul, que vai do norte da Venezuela e das Guianas ao sul do Paraguai e ao norte da Argentina, o vulnerável tatu-canastra (*Priodontes maximus*) ocorre em baixas densidades e é pouco estudado devido aos seus hábitos crípticos. No Brasil, os registros da espécie têm sido coletados no Pantanal e Cerrado central, mas há pouca informação na fronteira leste do Mato Grosso do Sul. Neste estudo são relatados 97 registros de tatu-canastra nessa região, coletados por meio de armadilhas fotográficas e vestígios nos biomas Cerrado e Mata Atlântica.

Palavras-chave: armadilha fotográfica, Cerrado, Mata Atlântica, propriedades particulares, silvicultura

Easily recognized by its size, the giant armadillo *Priodontes maximus* (Kerr, 1792) is the largest among the 20 species of living armadillos (Abba & Superina, 2010; Gibb *et al.*, 2016), with adult weights averaging around 30 kg (Carter *et al.*, 2016). Despite its wide distribution in South America, the species tends to occur at low population densities (Aguiar & Fonseca, 2008) and it is classified as Vulnerable by the International Union for the Conservation of Nature (IUCN, 2017) and the Brazilian National List of Endangered Species (Brasil, 2014). Major threats to the species include poaching and habitat loss (Abba & Superina, 2010; Desbiez & Kluyber, 2013).

In Brazil, the giant armadillo is found in Cerrado, Pantanal, Amazon, and Atlantic Forest biomes (Chiarello *et al.*, 2015). It is considered extinct in the state of Paraná and restricted to a few localities in the southeastern part of the country (Chiarello *et al.*, 2008; Srbek-Araujo *et al.*, 2009).

The species feeds mainly on ants and termites, destroying anthills and termite mounds during foraging (Anacleto & Marinho-Filho, 2001; Chiarello

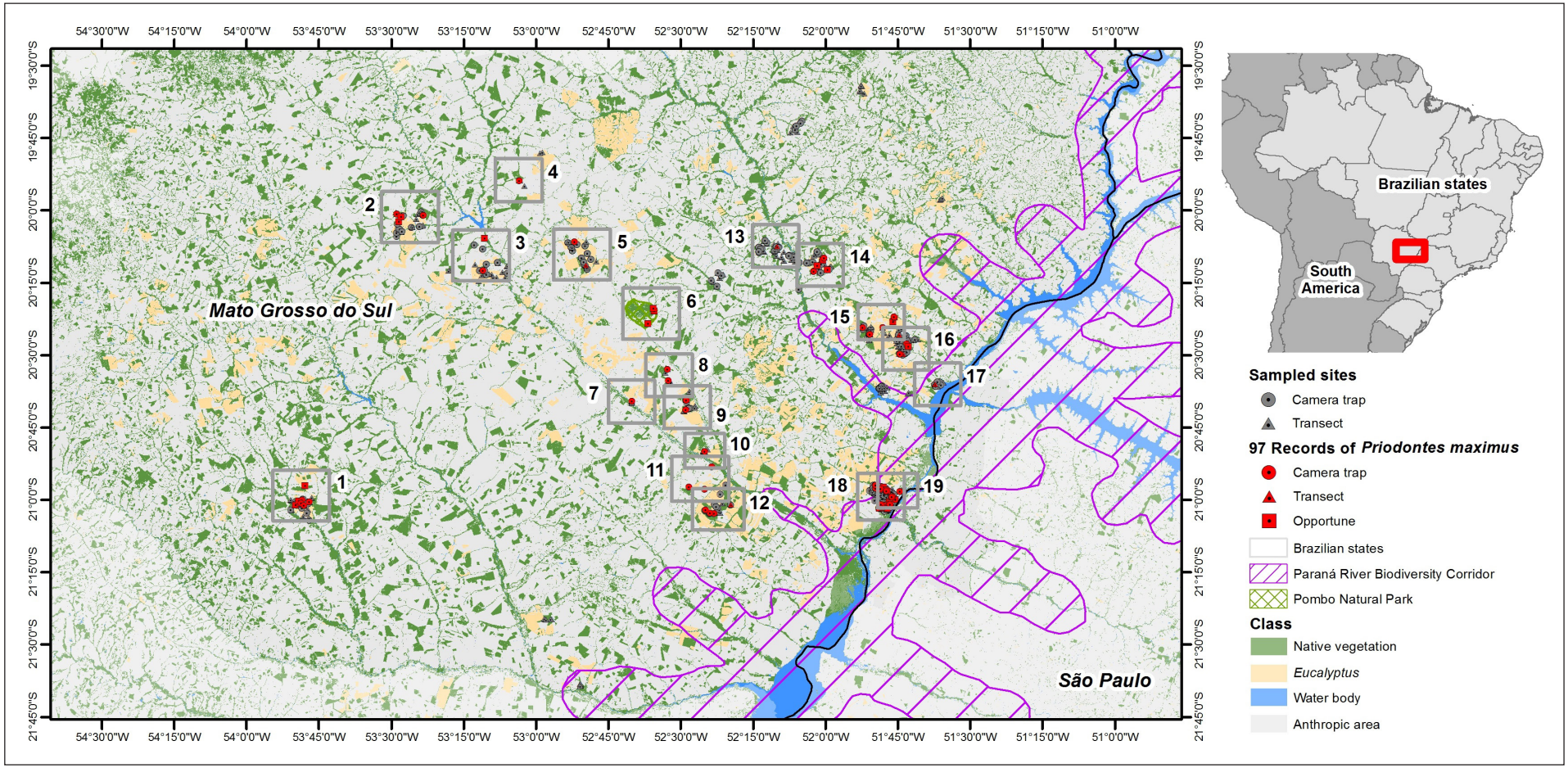

FIGURE 1. Location of the study areas, which comprised 29 private farms of *Eucalyptus* plantation and one protected area in eastern Mato Grosso do Sul, Brazil. The numbered panels show the 18 farms and the protected area with *Priodontes maximus* records. The basis for this map was made available by the Brazilian Foundation for Sustainable Development (FBDS) using Rapid Eye images (5 meters of spatial resolution), base year 2013. A supervised classification and vectorization of four classes of interest with subsequent evaluation of the quality of the mapping was performed. Verification was done in a 1: 10,000 scale using checkpoints randomly distributed in the scenes of Rapid Eye images (100 points per scene) and the result reached the minimum percentage of 95% hits in all scenes.

et al., 2008). While foraging, the giant armadillo uses its powerful front claws, long vermiform tongue, large salivary glands, and small teeth to capture and consume prey (Redford, 1985). *Priodontes maximus* can also eat other invertebrates such as spiders, worms, small snakes, and even carrion (Carter *et al.*, 2016). Recently, the giant armadillo was recognized as an ecosystem engineer because its excavations for burrows can create new habitat for other species (Leite-Pitman *et al.*, 2004; Desbiez & Kluyber, 2013; Aya-Cuero *et al.*, 2017; Massocato & Desbiez, 2017).

Due to its fossorial and nocturnal habits, as well as the fact that individuals can remain inside the burrow for several days and are rarely seen (Eisenberg & Redford, 1999; Noss *et al.*, 2004), few studies have been conducted in nature and little information about the ecology and behavior of the giant armadillo is known. What data are available mostly have been obtained by indirect signs, occasional visual contacts or dead specimens (Silveira *et al.*, 2009). However, the increasing use of camera-trapping in recent years has broadened knowledge of the giant armadillo, including in the Cerrado of central Brazil (Anacleto & Marinho-Filho, 2001; Santos-Filho & Silva, 2002; Silveira *et al.*, 2009; Zimbres *et al.*, 2013), Atlantic Forest (Srbek-Araujo *et al.*, 2009), and Pantanal (Trolle, 2003; Trolle & Kéry, 2005; Porfirio *et al.*, 2012).

Brazil has strong environmental laws concerning conservation of natural ecosystems, including the Forest Code (Federal Law No. 12.651/2012), which requires rural landowners to maintain at least 20% of their properties as native vegetation and to restore the area along streams and rivers. Nearly 85% of Cerrado and Atlantic Forest remnants are located on private properties (Oliveira *et al.*, 2010; Sparovek *et al.*, 2011), which thus assume an important role in the conservation of biodiversity. Although some sectors of Brazilian agriculture do not fulfill their legal obligations, the forestry sector, due to certification requirements, has a satisfactory record regarding restoration of degraded areas and habitat conservation (Silva *et al.*, 2007; Egeskog *et al.*, 2016).

In Brazil and many other countries, plantation forests are the focus of controversial opinions, with arguments that afforestation with commercial monocultures may or may not be suitable as habitat for certain species (Brockerhoff *et al.*, 2008). This debate can involve costs and benefits at different scales, for example, global environmental benefits are obtained at the expense of local impacts or, conversely, the benefits of local economic development collide with global needs for nature protection (Buongiorno & Zhu, 2014; Hemström *et al.*, 2014; Andersson *et al.*, 2016).

With the growth of the forest-based industry in Mato Grosso do Sul, mainly in the eastern region of the state (IBA, 2016), the substitution of livestock pastures by forestry plantations has been increasing over the years (Kudlavicz, 2011). This modification of the regional landscape has profound consequences for biodiversity conservation because the conversion of pastures to forestry can reduce the edge effects of forest fragments (Antongiovanni & Metzger, 2005) and be suitable for forest dwelling species. On the other hand, the replacement of natural grassland (a common and endangered habitat in the Cerrado; Klink & Machado, 2005) with

FIGURE 2. Direct and indirect signs of presence of *Priodontes maximus*: **A.** photo from a camera-trap; **B.** burrow; **C.** track.

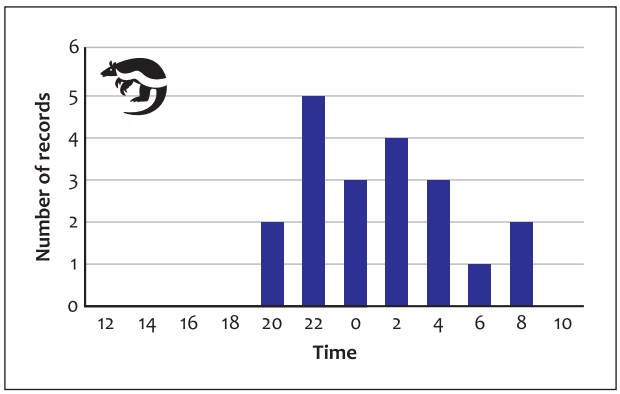

FIGURE 3. Activity pattern of the giant armadillo based on camera-trap and visual records.

commercial tree plantations may be detrimental to wildlife that inhabit open areas. Protecting the diverse suite of open and forested habitats of the Brazilian Cerrado is crucial, although the current Brazilian Forest Code fails to take into account this habitat variety, only mentioning "forests and other forms of native vegetation" throughout its entire text.

Given this scenario, this study aimed to fill information gaps about the occurrence of the giant armadillo with data collected in eastern Mato Grosso do Sul state, in landscapes with a predominance of forestry and *cerradão* phytophysiognomies—the latter a native forest of the Cerrado biome. We report the first records of the giant armadillo on private lands of this region (in Cerrado and Atlantic Forest Biomes) using camera-trapping and signs of presence data.

The study area comprised 29 private farms of *Eucalyptus* commercial plantation (properties of Fibria-MS Celulose Sul Mato Grossense Ltd., Eldorado Brasil Celulose S/A, Niobe Florestal S/A, and Frigg Florestal S/A) and one protected area, Parque Natural Municipal do Pombo (**FIG. 1**). As part of a mammal species monitoring program on *Eucalyptus* farms, transects and camera trapping surveys were carried out from August 2007 until September 2017 in areas of native vegetation and commercial forestry. A total of 173 camera traps were installed at fixed stations along dirt roads or in the forests and programmed to operate continuously (24 h/day) taking pictures (see **FIG. 2A**) or shooting video (minimum interval of 30 s). Recorded observations were considered independent for photos and videos obtained at each camera trap station every 24 h (1 day).

In addition to camera traps, 187 transects of different lengths (ranging from 500 m to 2 km) were sampled along dirt roads in order to identify traces of presence, such as scats, tracks, and burrows (**FIG. 2**). On average, 32 transects per year were carried out. Some trails were sampled only once

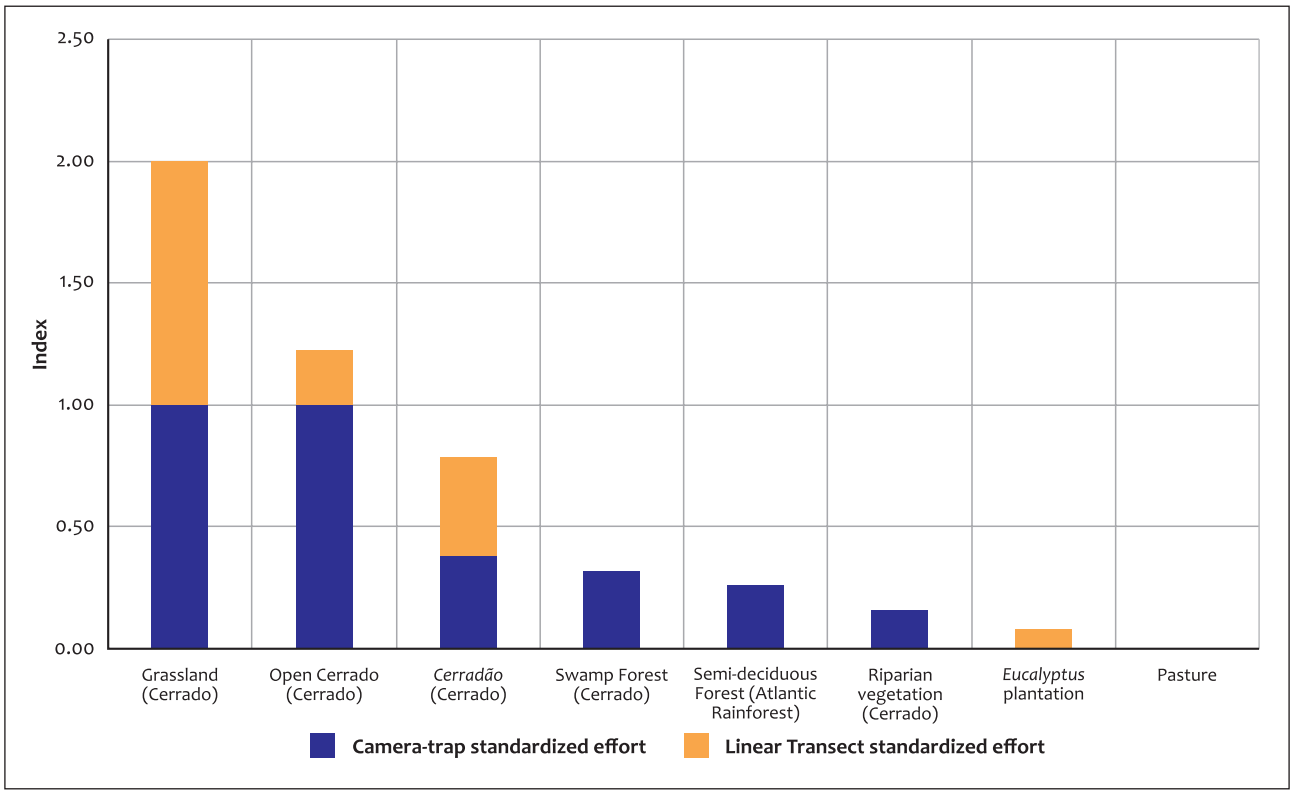

FIGURE 4. Habitat use index based on standardized sampling effort and records of giant armadillo in eastern Mato Grosso do Sul, Brazil.

TABLE 1. Description of records, sampling effort, and habitat use index for giant armadillo in eastern Mato Grosso do Sul, Brazil.

CTO: Camera-trap occurrences

LTO: Linear transect occurrences

OO: Opportune occurrences

TO: Total occurrences = CTO + LTO + OO

CTE: Camera-trap effort

LTE: Linear transect effort

CTOR: Camera-trap occurrences ratio = (CTO/CTE) × 100

LTOR: Linear transect occurrences ratio = LTO/LTE

SCTO: Standardized camera-trap occurrences $SCTO_i = \frac{CTOR_{MAX} - CTOR_i}{CTOR_{MAX} - CTOR_{MIN}}$, where i = habitat type, $CTOR_{MAX}$: Maximum CTOR value among habitat types, and $CTOR_{MIN}$: Minimum CTOR value among habitat types

SLTO: Standardized linear transect occurrences $SLTO_i = \frac{LTOR_{MAX} - LTOR_i}{LTOR_{MAX} - LTOR_{MIN}}$, where i = habitat type, $LTOR_{MAX}$: Maximum LTOR value among habitat types, and $LTOR_{MIN}$: Minimum LTOR value among habitat types

THUI: Total habitat use index = SCTO + SLTO

Species	CTO	LTO	OO	TO	CTE (days)	LTE (km)	CTOR	LTOR	SCTO	SLTO	THUI
Grassland (Cerrado)	1	2	1	4	59	6.5	1.70	30.77	0.99	1.00	1.99
Open Cerrado (Cerrado)	2	1	2	5	117	14.5	1.71	6.90	1.00	0.22	1.22
Cerradão (Cerrado)	9	42	18	69	1390	336.7	0.65	12.47	0.38	0.41	0.78
Swamp Forest (Cerrado)	3	1	0	4	555	0	0.54	0.00	0.32	0.00	0.32
Semi-deciduous Forest (Atlantic Rainforest)	1	0	1	2	224	0	0.45	0.00	0.26	0.00	0.26
Riparian vegetation (Cerrado)	1	0	1	2	367	3.5	0.27	0.00	0.16	0.00	0.16
Eucalyptus plantation	0	7	4	11	245	290	0.00	2.41	0.00	0.08	0.08
Pasture	0	0	0	0	73	28	0.00	0.00	0.00	0.00	0.00
Total	17	53	27	97	3029	679	0.56	7.80			

(eucalypt farms with rapid fauna inventory) and others up to 20 times (eucalypt farms with long-term monitoring, usually conducted seasonally). Opportune detections (outside of the survey period) of species traces during monitoring campaigns were also considered. The location of cameras and signs of presence were georeferenced with a GPS navigator and then exported to ArcGis 10 software (Environmental Systems Research Institute, Redlands, CA, USA).

A total of 70 point localities of the giant armadillo were obtained on 18 private farms from transects (7.8 records/100 km) and camera traps (0.56 pictures/100 camera-trap days), totaling an effort of 679.2 km and 3,029 trap-days. Opportune detections such as tracks, burrows, and sightings accounted for an additional 27 records, thus generating 97 total records for the species.

Camera-trap and visual records combined (n=20) indicated that giant armadillos were nocturnally active (*i.e.*, outside their burrows), specifically between 20:13 hr and 08:41 hr, and more active from 22:00 hr to 04:00 hr (**FIG. 3**). Despite the low number of records, this corresponds quite well with the pattern obtained by Noss *et al.* (2004), Silveira *et al.* (2009), and Aya-Cuero *et al.* (2017).

For landscape description of the giant armadillo's occurrence, we used a land cover map to determine the percentage of various habitat types within a 1.8 km radius of each animal's point location (**APPENDIX 1**). The mapping was done manually through the ArcMap extension of ArcGis, based on images available in Google Earth®. The 1.8 km radius was chosen to represent the approximate home range of the giant armadillo, based on Silveira *et al.* (2009).

Collectively, the location points encompassed, on average, 43% of *Eucalyptus* plantations, 35% of native vegetation and 15% of pasture (**APPENDIX 2**). Considering the surroundings of just the occurrence points on 18 private farms, there was substantial variation in how much commercial forest (eucalypts) was encompassed, from 2% to 89%, and also of native vegetation, from 5% to 85%.

Rather than looking at the larger scale habitat associations with each occurrence point, we next examined the specific type of habitat in which each point was obtained. Our records of the giant armadillo were collected in different Cerrado and Atlantic Forest physiognomies, including areas of swamp forests, natural grassland, semi-deciduous rainforest, open Cerrado (woodland), *cerradão* (tall woodland), riparian vegetation, and also in sites of *Eucalyptus* plantation. Most of the occurrence points were in native vegetation (89%), followed by 11% in *Eucalyptus* plantation and no records in pasture. **FIGURE 4** shows the standardized effort (camera-trap and linear transect) related to the occurrence of *P. maximus* in each habitat type sampled. Standardization was performed using the range

method, in which data range from 0 to 1 (**Table 1**). First, a ratio of the number of occurrences and sampling effort was calculated for each habitat type and each sampling method (occurrences/camera-trap day and occurrences/km, respectively). Then, the ratio obtained between the different habitats was standardized, where the maximum value for each method represents "1" and the minimum "0". In this case, "0" represents the places where the species was not registered. Finally, the habitat use index was calculated by adding the standardized occurrences for each type of method (index ranges from 0 to 2), with the highest values representing preferred habitats.

Although the reported habitat preference of *P. maximus* is for open areas (Santos-Filho & Silva, 2002; Silveira *et al.*, 2009; Abba & Superina, 2010), some authors registered the species in more closed physiognomies, such as *cerradão* (Anacleto, 1997; Anacleto & Diniz-Filho, 2008; Aya-Cuero *et al.*, 2017). The *Eucalyptus* farms surveyed in our study were predominantly surrounded by closed habitats, and we recorded the species in more forested areas (79% of records). Even so, comparing the sampling effort spent on grassland and *cerradão*, for example, the habitat use by the species shows some tendency for open areas when it is available (**Fig. 4**). The lack of conserved open habitat types on private lands may be one of the reasons why many giant armadillo occurrences are in closed Cerrado outside the limits of protected areas (Silveira *et al.*, 2009). Clearly, additional studies are needed in order to better understand the natural history, habitat preferences, and basic ecology of giant armadillos (Meritt Jr., 2006; Carter *et al.*, 2016).

Also of importance is that 38% of the giant armadillo occurrences were located in the Parana River Biodiversity Corridor (also known as the Trinational Biodiversity Corridor; ICMBio, 2008; MMA, 2016; see **Fig. 1**). Together with the data of Massocato & Desbiez (2017), our results confirm the presence of the giant armadillo in the Brazilian territory of this corridor.

The evidence of some individuals using forestry landscapes (10 tracks and 1 burrow) suggests that giant armadillos may use dirt roads within eucalypt stands as a connection between remnants of native vegetation, for food resources, or both. Despite their nomadic foraging behavior, the species is sensitive to environmental disturbance and does not tolerate intense human presence (Quiroga *et al.*, 2017). Thus, its occurrence could be considered an indicator of environmental quality (Anacleto & Diniz-Filho, 2008; Silveira *et al.*, 2009). One potential threat that *Eucalyptus* plantations may cause to giant armadillos and other species that feed mainly on ants and termites is the use of pesticides and chemicals with long residual periods. These insects are one of the main causes of economic losses for forestry plantations (Wilcken *et al.*, 2002), and the effects on wildlife of control methods need to be better assessed.

Although the Parque Natural Municipal do Pombo is included in the category of Full Protection by Federal Law No. 9.985/2000 (permission only for indirect use of its natural resources), the eastern region of Mato Grosso do Sul state lacks more protected areas. The results presented in this investigation reveal the importance that protected native vegetation areas on private lands, such as Legal Reserves and Areas of Permanent Protection (ensured by Federal legislation), may have for the conservation of giant armadillos in Cerrado and Atlantic Forest biomes. However, we believe a joint effort in the creation and maintenance of governmental and private protected areas, as well as ecological corridors capable of maintaining connectivity between them, will ultimately be vital for the conservation of the species in the region.

In regions with highly fragmented landscapes, plantation forests may be effective for the conservation of species, especially the most sensitive ones, if the understory of tree stands is retained and is connected to adjacent areas of natural habitats (Brockerhoff *et al.*, 2013; Begotti *et al.*, 2018). Although forest certification (*e.g.*, Forest Stewardship Council International – FSC) can provide the means by which producers meet rigorous sustainable forestry standards, there is no definition of priority areas needed for maintenance of the functional connectivity between plantations (Hardt *et al.*, 2015). Connectivity is important, especially in patchy landscapes permeated by an agricultural matrix, because it enables the flow of individuals from isolated populations (Uezu *et al.*, 2005).

In summary, our results provide relevant information to guide decision-making, whether for the conservation of the species, subsidizing the future National Action Plan for the conservation of the giant armadillo, to fill information gaps for improvement in conservation strategies, to determine how lands are used and occupied, or to support the creation of protected areas in the region.

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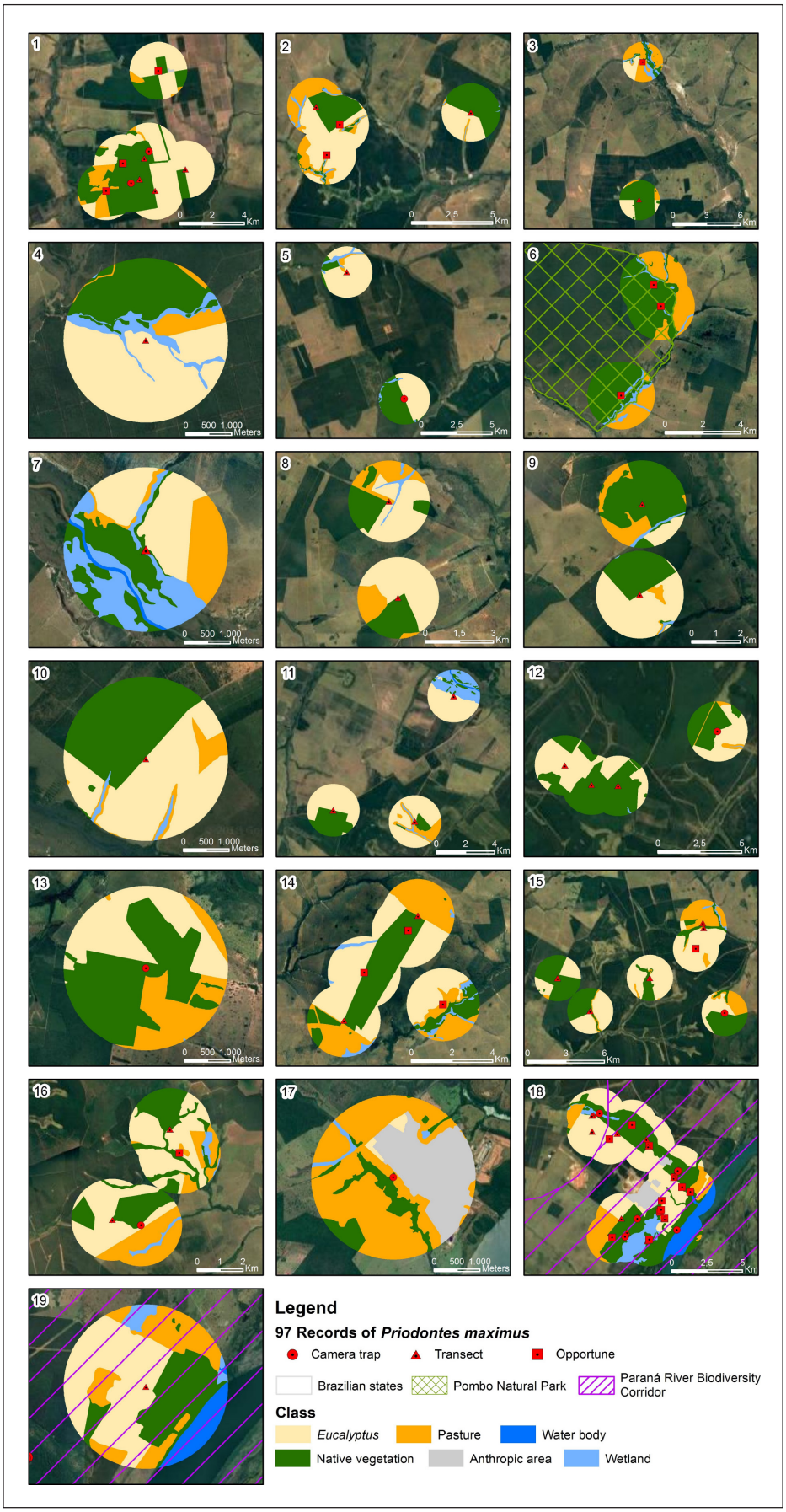
APPENDIX 1

Habitat type for each of the 97 location points of the giant armadillo on 18 private farms and Parque Natural Municipal do Pombo, eastern Mato Grosso do Sul, Brazil. Some location points overlap.



Appendix 2

Averaged percentage of land use types within a 1.8 km radius of each location point of the giant armadillo in eastern Mato Grosso do Sul, Brazil.