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ARTICLE

Mammal prevalence after the fire catastrophe in northeastern Pantanal, Brazil

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Abstract. Fire might occur under natural conditions in the Pantanal of Brazil; however, with climate change, severe periods of drought potentiated the devasting fires in 2020, resulting in substantial wildlife loss. Considering that mammal communities are strongly affected by fire and habitat alterations, the aim of this study was to evaluate possible differences in mammal diversity and the number of records before and one year after the fire in one region of the Pantanal of Mato Grosso, Brazil (Parque SESC Baía das Pedras – PSBP). The data collection was performed using camera trapping between 2015 and 2017 and 2021, together with visual field observations in PSBP. We observed that the mammal assemblage composition was similar before and one year after the fire. Four species were more or less frequent in burned areas than in unburned ones. Since the fire was controlled in this area, avoiding its total destruction, and the species that fled from the surrounding areas, which were completely burnt, might be using PSBP as a refuge while the vegetation recovers elsewhere. Therefore, the PSBP might have contributed to protecting mammal species after the fire and maintaining and conserving biodiversity on a regional scale in the Pantanal of Mato Grosso, Brazil.

Keywords. Adaptation; Camera traps; Mammal community; Pantanal; Wildfire.

INTRODUCTION

The Pantanal of Brazil is a seasonal wet-dry ecosystem (Aragão *et al.,* 2018) and represents the largest wetland in the world. The region contributes to global biodiversity and climate stability (Girard, 2012) and plays a major role in the worldwide discussion about sustainable management and protection of wetlands (Junk & Nunes da Cunha, 2012). The devastating fires in 2020 put the Pantanal in the global media spotlight, stressing the threats to the conservation of this unique ecosystem. During this historically unprecedented wildfire event, approximately 39,030 km^2 of the Pantanal was burned, representing a 376% increase compared to the annual average of the area burned each year and reaching areas that were not previously affected by fires in recent decades (Garcia *et al.,* 2021; Libonati *et al.,* 2021). The combination of atypical dry weather conditions, human activities, and lack of adequate environmental policies and surveillance are seen as the major causes of the 2020 fire events in the Pantanal (Pivello *et al.,* 2021; Barbosa *et al.,* 2022).

After a severe drought in 2019, the 2020 drought was considered the most extreme and widespread drought in the Pantanal in over 70 years, which affected the hydroclimatological function of the region and increased the risk of uncontrolled fires (Garcia *et al.,* 2021; Marengo *et al.,* 2021; Pivello *et al.,* 2021; Libonati *et al.,* 2022). For decades, the Pantanal has experienced

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an annual decrease in water surface area (Barbosa *et al.,* 2022); however, the structure and function of the floodplain ecosystem depend on the annual hydrological cycle of floods and droughts (Junk *et al.,* 1989; Calheiros *et al.,* 2012). The Pantanal serves as a large water reservoir, storing water during the rainy period and delivering it gradually to the lower sections of the Paraguay River (Marengo *et al.,* 2015, 2016). Due to climate change, severe drought periods are expected to become more frequent in the Pantanal, affecting flooding dynamics and ecosystem functioning (Thielen *et al.,* 2020) and potentially amplifying the risk of fire events.

Fire is not new to the region, and natural fires have occurred long before human settlement (Power *et al.,* 2016). The Pantanal is considered a fire-dependent biome where fire is essential to maintain ecological processes (Hardesty *et al.,* 2005) that under natural conditions might occur every 3-6 years (Pivello *et al.,* 2021). As long as the natural patterns and periodicities of flooding and wildfires are maintained, the wetland system is considered stable and resilient (Oliveira *et al.,* 2014). However, changes in land use and climate have modified the natural fire regime (Pivello, 2011; Pivello *et al.,* 2021). The frequency, intensity, and duration of fire events determine the severity of effects on the floral and faunal composition of biomes (Miller & Thode, 2007; Cochrane & Barber, 2009; van Wagtendonk *et al.,* 2012; Gill *et al.,* 2013; Roberts *et al.,* 2015; Armenteras *et al.,* 2021).

While many animals, especially those with limited mobility, might be killed directly by fire, animal communities are strongly affected by the resulting habitat alteration (Smith, 2000; Frizzo *et al.,* 2011). How well a species copes with the consequences of fire is influenced by many factors, including body size, feeding habits, foraging behavior, predation vulnerability, population size, and reproduction rate (Silveira *et al.,* 1999; Pires *et al.,* 2005; Frizzo *et al.,* 2011; Nieman *et al.,* 2021; Culhane *et al.,* 2022).

Research on the direct impact of fire on mammals in Brazil is scarce, particularly in the Pantanal biome (Frizzo *et al.,* 2011; Berlinck *et al.,* 2021). The majority of existing studies focus on small mammal communities in other biomes (*e.g.,* Henriques *et al.,* 2000; Briani *et al.,* 2004; Pedó *et al.,* 2010; Mendes-Oliveira *et al.,* 2012; Vieira & Briani, 2013; Durigan *et al.,* 2020; González *et al.,* 2021), and only a few address the impact on medium- and large-sized mammals, particularly Giant Anteaters (*Myrmecophaga tridactyla*), Giant Armadillos (*Priodontes maximus*), and Yellow Armadillos (*Euphractus sexcinctus*) (Silveira *et al.,* 1999; Prada & Marinho-Filho, 2004). Therefore, the effects of recent fire events on the wildlife of the Pantanal have yet to be evaluated. Current estimates assume that approximately 17 million vertebrates were directly killed by fires (Tomas *et al.,* 2021), and large predators, such as Jaguars (*Panthera onca*), might be among the species most affected (de Barros *et al.,* 2022).

Therefore, the aim of this study was to evaluate potential differences in mammal species diversity and the number of records before and one year after the fires of 2020 in the Pantanal of Mato Grosso, Brazil.

MATERIAL AND METHODS

Study area

This study was carried out in the northeastern Pantanal in the Park of Serviço Social do Comércio (SESC) Baía das Pedras (PSBP), a privately protected unit of the SESC Pantanal nature reserve, Mato Grosso, Brazil (16°39′S, 56°47′W) (Fig. 1). The area covers approximately 4,200 ha and is located on the floodplain of the Cuiabá River, one of the major tributaries of the Paraguay River within the Pantanal.

The regional climate is tropical humid with marked seasonality between the winter and summer periods. The precipitation varies between 1,000 and 1,500 mm and decreases in winter, resulting in a very dry period (Junk *et al.,* 2014). The annual hydrological cycles may be divided into four periods: dry, characterizing the terrestrial phase caused by a strong hydric deficit from July to September; rising water, when the rain starts, from October to December; wet, with the highest levels of inundation from January to March; and the receding water period, when the level of the water starts to decline from April to June (Heckman, 1998).

The area evaluated is situated in the extreme southeastern region of the PSBP, which corresponds to the area affected by the fire. Only 3% of its area was completely burnt; however, the fire consumed 93% of the SESC Private Natural Heritage Reserve (RPPN), the largest private reserve in the country, which is situated beside the Parque SESC Baía das Pedras (Fig. 2). According to the SESC's workers and firemen, the fire burned from the ground to the dossel of forests and savanna patches. Considering this, the habitat structure and resource availability for animals were possibly strongly affected, which might have affected the mammal diversity in this area.

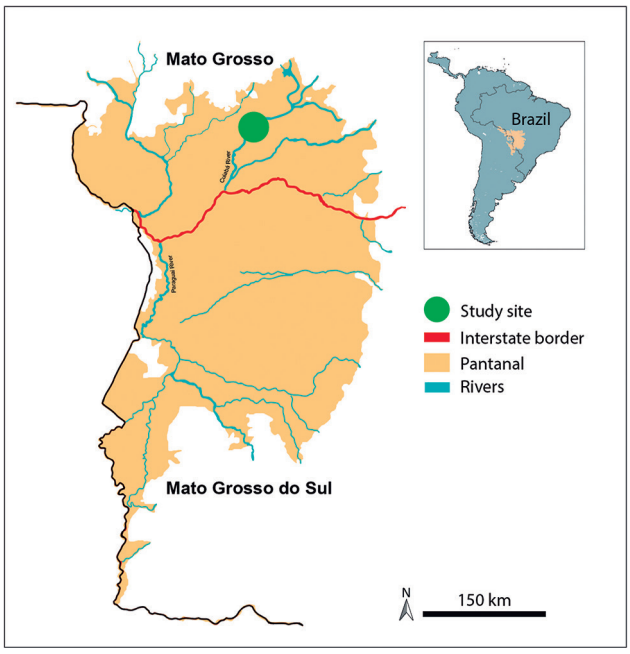

Figure 1. Map of the Pantanal biome in Brazil, showing the study site in Poconé (green), Mato Grosso state.

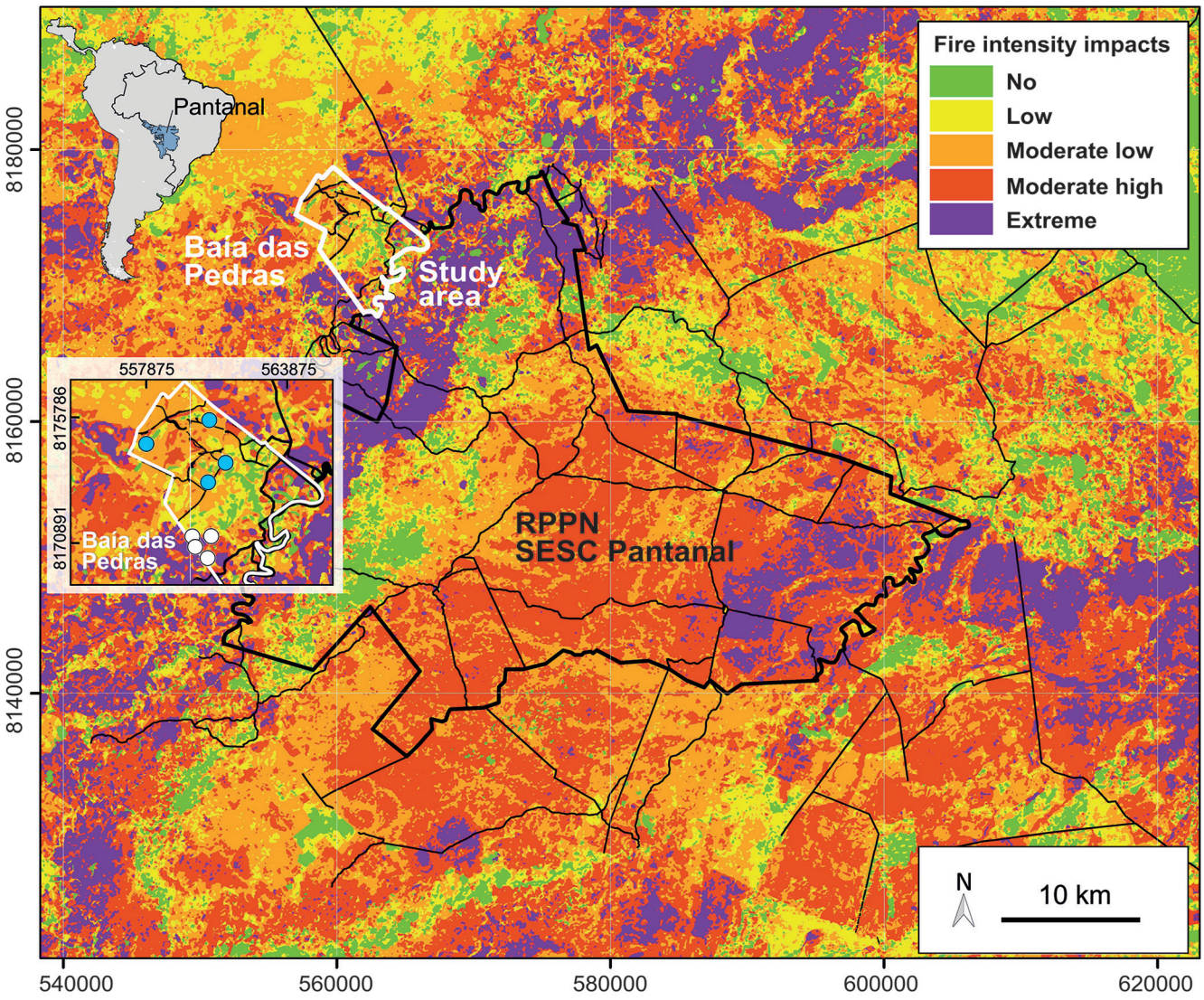

Figure 2. Map of our study area Parque SESC Baía das Pedras (PSBP) and surroundings, showing the fire intensity (low to extreme) in the region of Poconé, Mato Grosso, Brazil. White line: border of the study area, thin black lines: roads and dirt roads, thick black line: border of RPPN SESC Pantanal (SESC Private Natural Heritage Reserve). Smaller panel: camera trap stations established in our study area before (cyan) and after (white) the fire. Source: SESC Pantanal.

Data collection

Data were collected one year after the fire event using camera traps and opportunistic field observations over eight field days in areas affected by the fire. A total of four camera trap stations were established: two in savanna (steppic and shrubby savanna) and two in forest habitats (monodominant forest and semideciduous forest). At each station, a single camera trap was repeatedly installed during four field surveys covering three different seasonal periods (receding 2021 and 2022, dry 2021, and rising 2021). For one station in the steppic savanna, data collection was only possible during receding 2022. During each field survey, camera traps were active for 14 consecutive days and nights resulting in a total sampling effort of 210 trap-days.

Camera trap data collected after the fire event were compared with camera trap data obtained in the study area between 2015 and 2017 when there was no fire. The pre-fire data are part of a long-term, grid-based camera trap project (see Burs *et al.,* 2023 and Senič *et al.,* 2023 for details), from which we chose four camera trap stations. The area most impacted by the fire was not covered during this previous study; however, we selected four stations placed in areas with the same phytophysiognomy observed after the fire. We considered 14 consecutive trap days from two receding periods, one dry period, and one rising period. For one station in the monodominant forest only data from the receding period 2017 were available, resulting in a total effort of 210 trap days before the fire.

Camera traps were installed approximately 60 cm above the ground on tree trunks. We used three different camera trap models (Reconyx PC800, Bushnell Trophy Cam Aggressor, Uway VH400). All camera traps operated using a passive infrared-triggered system (trigger time < 1 s) and were active 24 h per day. Camera traps were set to shoot photos (up to 10 photos per trigger) or videos (10 s per trigger) with no delay (max 1 s) between record sequences. No baits were used. Distances between camera trap stations ranged between approximately 300 and 6,800 m (Ø 3,800 m).

Data analysis

To assess mammal species frequency before and after the fire, only independent camera trap records of a particular species were considered. Following O'Brien *et al.* (2003), an independent record was defined as (1) consecutive records of different individuals of the same or different species; (2) consecutive records of individuals of the same species taken more than 30 minutes apart; and (3) non-consecutive records of individuals of the same species.

As our method was not suitable for small mammal species (Rowcliffe *et al.,* 2008; Tobler *et al.,* 2008; Glen *et al.,* 2013), we excluded all records showing species with a head-body length smaller than 25 cm. Additionally, as direct field observations of mammals during camera trap deployment were only available after the fire, these records were considered additional information about a species' presence and were not included in the analysis. Species nomenclature followed the International Union for Conservation of Nature (IUCN) red list of threatened species (IUCN, 2022). The conservation status definition followed Portaria MMA Nº 148 (BRASIL, 2022).

To evaluate differences in the number of records before and after the fire the exact binomial goodness-of-fit test was used. Only species with $n \geq 10$ were considered for this analysis. To evaluate differences in the species diversity between different habitats (savanna and forest) and periods (receding, dry, and rising) before and after the fire, we employed a PERMANOVA using presence/absence data of the mammal species. PERMANOVA is a non-parametric multivariate analysis that we used with 9,999 permutations with the Bray-Curtis dissimilarity measure to calculate F and indicate the differences within the treatments (Anderson & Walsh, 2013). To assess whether closer camera trap stations had a more similar species composition we performed a Mantel test prior to the PERMANOVA. Level of significance was set at $p < 0.05$.

RESULTS

In total, 23 medium to large mammal species were detected by camera traps and visual observations, comprising nine orders and 15 families (Table 1). Considering only camera trap data, four species, *Hydrochoerus hydrochaeris, Tayassu pecari, Dasypus novemcinctus,* and *Myrmecophaga tridactyla,* were detected only before the fire, and two species, *Sapajus libidinosus* and *Priodontes maximus,* were detected only after the fire. *Tayassu pecari, M. tridactyla,* and *H. hydrochaeris* were directly sighted after fire, and three species were only visually detected after fire: *Speothos venaticus, Cerdocyon thous,* and *Lontra longicaudis* (Table 1, Fig. 3).

Seven species had sufficient sample size to compare the number of records before and after the fire. *Pecari tajacu* was significantly more frequent before the fire ($\chi^2 = 6.368$, df = 1, $p = 0.019$), *Sylvilagus brasiliensis* ($\chi^2 = 68.582$, df = 1, $p < 0.001$), *Tapirus terrestris* ($\chi^2 = 6.095$, df = 1, $p = 0.020$), and *Dasyprocta azarae* ($\chi^2 = 4.667$, df = 1, $p = 0.044$) were more frequent after the fire. *Leopardus pardalis* ($\chi^2 = 4.482$, df = 1, $p = 0.052$) showed a strong tendency to be more recorded after the fire. *Mazama* sp. ($\chi^2 = 1.222$, df = 1, $p = 0.315$) and *Procyon cancrivorus* ($\chi^2 = 0.310$, df = 1, $p = 0.711$) were similarly recorded before and after the fire (Fig. 4).

Table 1. Mammal species detected by camera traps and visual observations in periods before (2015-2017) and after fire (2021-2022) in the Pantanal of SESC Parque Baía das Pedras, Poconé, Mato Grosso, Brazil. Threat category definition according to Portaria MMA Nº 148, 7 June 2022: VU = vulnerable. X = Species detected visually only. Species nomenclature followed the International Union for Conservation of Nature (IUCN) red list of threatened species (IUCN, 2022).

Taxon	Before	After	Threat category
Cetartiodactyla			
Cervidae			
Blastocerus dichotomus	2	1	VU
Mazama sp.	44	55	
Tayassuidae			
Pecari tajacu	15	4	
Tayassu pecari	3	X	VU
Carnivora			
Canidae			
Cerdocyon thous	—	X	
Speothos venaticus	—	X	VU
Felidae			
Leopardus pardalis	8	19	
Herpailurus yagouaroundi	1	1	VU
Puma concolor	1	4	
Mustelidae			
Eira barbara	2	4	
Lontra longicaudis	—	X	
Procyonidae			
Nasua nasua	6	2	
Procyon cancrivorus	13	16	
Cingulata			
Dasypodidae			
Dasypus novemcinctus	1	—	
Chlamyphoridae			
Priodontes maximus	—	1	VU
Didelphimorphia			
Didelphidae			
Didelphis sp.	3	1	
Lagomorpha			
Leporidae			
Sylvilagus brasiliensis	6	85	
Perissodactyla			
Tapiriidae			
Tapirus terrestris	13	29	VU
Pilosa			
Myrmecophagidae			
Myrmecophaga tridactyla	2	X	VU
Tamandua tetradactyla	5	1	
Primates			
Cebidae			
Sapajus libidinosus	—	4	
Rodentia			
Caviidae			
Hydrochoerus hydrochaeris	7	X	
Dasyproctidae			
Dasyprocta azarae	14	28	

Figure 3. Mammal species detected by camera traps and visual observations in periods before (2015-2017) and after fire (2021-2022) in the Pantanal of SESC Parque Baía das Pedras, Poconé, Mato Grosso, Brazil. (A) *Blastocerus dichotomus;* (B) *Mazama* sp.; (C) *Pecari tajacu;* (D) *Tayassu pecari;* (E) *Cerdocyon thous;* (F) *Speothos venaticus;* (G) *Leopardus pardalis;* (H) *Herpailurus yagouaroundi;* (I) *Puma concolor;* (J) *Eira barbara;* (K) *Lontra longicaudis;* (L) *Nasua nasua;* (M) *Procyon cancrivorus;* (N) *Dasypus noventicus;* (O) *Priodontes maximus;* (P) *Didelphis* sp.; (Q) *Sylvilagus brasiliensis;* (R) *Tapirus terrestris;* (S) *Myrmecophaga tridactyla;* (T) *Tamandua tetradactyla;* (U) *Sabajus libidinosus;* (V) *Hydrochoerus hydrochaeris;* (W) *Dasyprocta azarae.* Species nomenclature followed the International Union for Conservation of Nature (IUCN) red list of threatened species (IUCN, 2022).

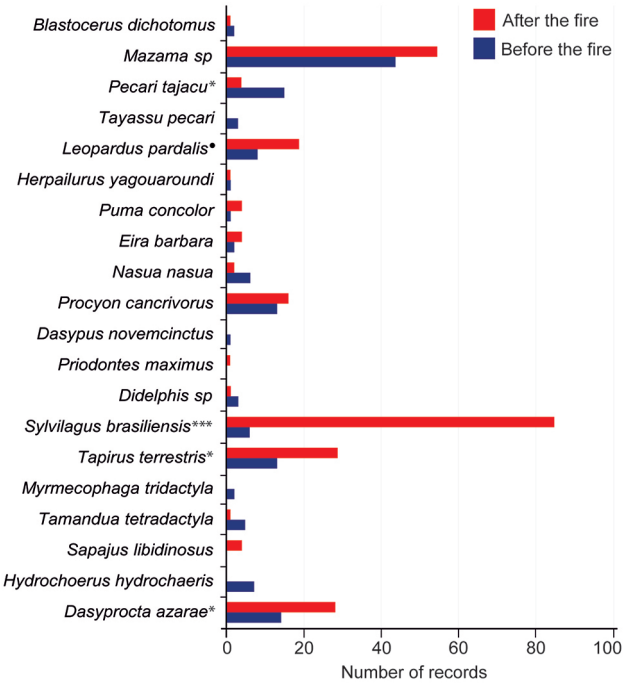

Figure 4. Number of records of mammals obtained by camera traps before (blue) and after fire (red) in the Pantanal of SESC Parque Baía das Pedras, Poconé, Mato Grosso, Brazil. Level of significance: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; black dot: marginal significance level.

The PERMANOVA suggested no significant differences in mammal species diversity between habitats ($F = 1.040$, $p = 0.472$) or periods before and after the fire ($F = 0.476$, $p = 0.921$). The result of the Mantel test showed no significant correlation, indicating that there is no distance decay of similarity ($r = 0.068$, $p = 0.355$). Seven species classified as vulnerable to extinction (BRASIL, 2022) were detected in the area, five of them observed before and after the fire (*Blastocerus dichotomus, T. pecari, H. yagouaroundi, T. terrestris,* and *M. tridactyla*), and two only after fire (*S. venaticus* and *P. maximus*) (Table 1).

DISCUSSION

The mammal species diversity observed in our study area one year after the fire did not show significant differences compared with the period before the fire; however, our results suggest that some species were more or less recorded after than before the fire.

Similar results to ours were observed in the Cerrado biome. Durigan *et al.* (2020) found that fires had little effect on species composition and did not reduce the richness of several vertebrates, including small mammals, birds, lizards, frogs, and plant species. The results by De Pinho *et al.* (2017) further indicate that medium and large mammal richness is not substantially affected by fire frequency in the Cerrado.

On a global scale, fire has even been shown to positively affect the diversity of mammals (Moritz *et al.,* 2023), but the first estimations from the Pantanal suggest that the direct impact of the severe fire event was immense. Small rodents, armadillos, ungulates, primates, large rodents, and anteaters were among the mammals found dead after the fire (Tomas *et al.,* 2021). However, given their higher mobility, medium and larger mammals are more likely able to escape to less impacted areas (Frizzo *et al.,* 2011). As the fire was most extreme in the surroundings of the PSBP area, mammals from adjacent areas may have found shelter and food at our study area. According to the results, burned areas appear to have recovered sufficiently one year after the fire in order to maintain species diversity at a similar level as before the fires.

When considering the direct observations, *D. novemcinctus* was the only species not detected after the fire. Species such as *D. novemcinctus* are probably able to avoid the immediate danger from fire by retreating to their burrows (McDonough & Loughry, 2005); however, it is also possible that the recent fire incident was too severe for armadillos, and other species that depend on burrows, to survive in response to high temperatures and underground fire. Nonetheless, the absence of this species should be interpreted with caution, given the small number of camera trap stations and limited period of sampling of this study. Previous studies suggest that the dense undergrowth in recovering areas can favor the species (Peres *et al.,* 2003; Michalski & Peres, 2007); thus, further sampling might reveal the species' presence as well.

Although not recorded by camera traps in burned areas, *M. tridactyla, T. pecari,* and *H. hydrochaeris* were directly sighted. Myrmecophagous species such as *M. tridactyla,* but also *P. maximus,* have been shown to use burned and unburned areas similarly and appear to not experience food resource limitation after the fire (Prada & Marinho-Filho, 2004). However, *M. tridactyla* is suspected to be more vulnerable to fire due to its slow movement and inflammable fur (Silveira *et al.,* 1999); thus, the species might appear in lower densities after the fire in the area.

In contrast, highly water-associated species such as *H. hydrochaeris* (Mamede & Alho, 2008) could be expected to be less subject to fire incidents. Given the species' habitat preference, however, it is possible that the chosen camera trap locations in burned areas were not adequate to record the species.

Previous studies on *T. pecari* found that it can be entirely missing in burnt forests (Peres *et al.,* 2003), but there is also evidence that the species benefits from more severe, recurrent fires and is more abundant in impacted sites (Michalski & Peres, 2007). Given the lack of camera trap records, the species did not use burned areas intensively one year after the fire.

The presence of certain species exclusively after the fire should also be interpreted with caution, as based on our previous long-term study (author's unpublished data), all 23 recorded mammal species were present in the PSBP before the fire.

The results of our capture success comparison before and after the fire suggest that the smallest investigated mammal, *S. brasiliensis,* thrived after the fire, and *D. azarae* and *T. terrestris* were also more frequently

found after the incident. In addition to the potential increase in the number of records possibly caused by individuals coming from adjacent, more heavily impacted areas, highlights the species' ability to rapidly cope with environmental changes. *Tapirus terrestris* is known to prefer forested habitats (Burs *et al.,* 2023) but has also been shown to be highly tolerant toward disturbed areas (Medici *et al.,* 2022) and reportedly colonizes areas with pioneer vegetation that replaces the mature forest after large fires (Flesher & Medici, 2022). The regrowth of nutritious vegetation in burned areas has been shown to attract large herbivorous species, but small species can also benefit from the increased food availability (Sensenig *et al.,* 2010; Eby *et al.,* 2014; Green *et al.,* 2015; Nieman *et al.,* 2021). The high number of records of *S. brasiliensis* and *D. azarae* might thus be a response to the high food availability. Previous studies on small mammals impacted by fire also suggest that species strongly associated with closed canopies are more negatively impacted than species associated to open habitats, with fire favoring generalist species (Camargo *et al.,* 2018; González *et al.,* 2021). Both species show a rather flexible habitat use (Reis *et al.,* 2010; Mamede & Alho, 2008) and might thus adapt more rapidly to the structural changes caused by fire than other species.

Factors such as facilitated detection of predators in areas with reduced vegetation height could also have impacted the species' use of burned areas (Hopcraft *et al.,* 2005; Valeix *et al.,* 2009). However, the increased density of smaller mammals can also attract predators (Green *et al.,* 2015), and during our study, potential predators such as *L. pardalis* and *Puma concolor* slightly increased their number of records after the fire.

Our results further indicate that *P. tajacu* was less frequent after the fire. Previous studies suggest that the species can also benefit from fire disturbance and the associated shift to productivity to the understory (Peres *et al.,* 2003; Peres & Barlow, 2004; Michalski & Peres, 2007). There are, however, reports supporting that *P. tajacu* uses burned areas less, presumably because of the lack of thermal cover (Bock & Bock, 1979; O'Brien *et al.,* 2005). In the Pantanal, forested habitats are considered important key habitats for the species (Desbiez *et al.,* 2009); the structural changes in the vegetation after the fire might thus not necessarily meet the species' habitat requirements.

The mammal assemblage recorded in our study presents important ecological functions and participates in essential ecosystem services, being paramount to ensure the recovery of the Pantanal after the severe fire events. For example, *T. terrestris* has a key role as a seed disperser and predator and has been shown to interact with a specific subset of mainly larger seeds in the Pantanal, supporting plant species diversity in the region (Donatti *et al.,* 2011; O'Farrill *et al.,* 2013). Likewise, *T. pecari, P. tajacu,* and *P. maximus* are considered important ecosystem engineers, modifying environment and ultimately creating new habitats and influencing resources for other species (Desbiez & Kluyber, 2013; Mandujano & Reyna-Hurtado, 2019; Fontes *et al.,* 2020). As insectivores *P. maximus,* but also *D. novemcinctus* and *M. tridactyla,* directly influence the dynamics of vegetation by controlling herbivorous invertebrates, which can cause damage to the plant populations when occurring in high abundance (Chiarello *et al.,* 2015). Medium and large predators such as *P. concolor* or *L. pardalis* are generally important for prey population regulation reducing the pressure of herbivores on plants (Miller *et al.,* 2001) and can also affect the nutrient dynamics of an ecosystem (Schmitz *et al.,* 2010).

In our study, mammal diversity remained similar to that before the fire, and some species appeared to intensively use burned areas. Our results provide an insight into some of the consequences of recent fire events on mammal diversity. However, the recovery of vegetation and species diversity in our study area might be different compared to larger areas in the Pantanal that suffered much more from environmental destruction.

The unburned part of PSBP in our study area likely contributed to the protection of the mammal species after the fire and to the maintenance of their populations on a regional scale.

It is important to manage the Pantanal environment to avoid catastrophes such as those observed between 2019 and 2020. The species diversity in our study was maintained after the fire; however, the high proportion of wildlife lost in other parts of the Pantanal could have been avoided with adequate fire containment measures. Since March 2020, the Rapid Burned Area Assessment (ALARMES) systematically monitors the daily evolution of burned area in the Pantanal and supports the environmental authorities in firefighting operations; however to prevent fire catastrophes, not only the improvement of response to fire, but addressing the underlying issues of increasing anthropogenic burnings, land use intensification, and climate change, and a better understanding of the current hydrological processes in the region is essential (Marengo *et al.,* 2021; Pivello *et al.,* 2021; Barbosa *et al.,* 2022).

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