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ECOSYSTEMS

Human presence as a determinant of the occurrence of mammals in a high diversity protected area of Cerrado-Caatinga ecotone in Brazil

ADRIELE A. PEREIRA, CLARISSA ROSA, LUCAS D.B. FARIA, LUCAS G. DA SILVA & MARCELO PASSAMANI

Abstract: The Cerrado domain and its biodiversity has suffered several anthropogenic influences. Our objective was to evaluate the influence of biotic and anthropic variables on the mammal community in a protected area in the Cerrado-Caatinga ecotone. For this we sampled the mammals using camera traps (4,072 days/trap) for 16 months. We used generalized mixed linear models (GLMM) with model selection via Akaike's Information Criteria corrected for small sample size (AICc) to assess the influence of variables on richness, abundance and functional groups of mammals. We made a total of 663 photographic records of 16 species of medium and large mammals. The richness and number of mammals was negatively influenced by the distance to human settlements while carnivores were not affected by any of the variables evaluated, herbivores and generalists were more common in areas closer from human habitation. Despite the presence of large areas of native vegetation, our results show that there is a dominance of common and generalist species. The protected area is vulnerable to different sources of human pressure and the design and implementation of a management plan can be a key tool for protecting biodiversity and regulating the use of natural resources by local communities.

Key words: Brazilian semi-arid, functional groups, savanna, neotropics.

INTRODUCTION

The Neotropical region is one of the most biodiverse complexes of ecosystems in the world (Myers et al. 2000). Brazil is considered the country with the greatest diversity of mammals in the world, with 775 species in its national territory (Abreu et al. 2022). In this context, because of the large number of mammal's species, ecotone areas connecting distinct domains in the neotropics are key regions for biodiversity monitoring and conservation (Pimm et al. 2018).

One of the most important mammal biodiversity ecotones in Brazil is the transition zone between the two major dominated semi-arid domains: Cerrado and Caatinga. The Cerrado domain covers 20% of the Brazilian territory and is composed of many distinct physiognomic open landscapes and is listed as a biodiversity hotspot (Myers et al. 2000). This characteristic allied to its geographic position allow contact zones with three other domains (Atlantic Forest, Amazon and Caatinga), contributing to high biodiversity levels recorded in this domain (Rocha et al. 2011). The domain has 251 mammal species described, of which 12.75% (n=32) are endemic (Paglia et al. 2012). Additionally, the Caatinga domain is considered

as the only domain exclusive from Brazil, covering approximately 11% of the national territory occupied by semi-arid environments (Leal et al. 2005, Albuquerque et al. 2012). There are 153 mammal species of with occurrence in the Caatinga, which 15% (n=21) are endemic (Paglia et al. 2012).

Mammals play important roles in forest regeneration through seeds dispersion, regulation of prey populations, maintenance of fauna assembly with important ecological functions, and ecosystem dynamics in the long term (Quintela et al. 2020, Terborgh et al. 2008). Mammal diet is classified into 15 distinct trophic categories (Paglia et al. 2012) and more complex habitats were proven to support more guilds (Dotta & Verdade 2007). However, this group is strongly affected by habitat degradation and fragmentation from human activities (Munguía et al. 2016, Rija et al. 2020). Distinct species of mammals can respond in different ways to habitat fragmentation: some of them can decline to dramatic levels or disappear in some cases, whereas some species are favored (Munguía et al. 2016).

The creation and maintenance of protected areas are important strategies to safeguard biodiversity, and can avoid the loss of species that suffer with anthropogenic pressures (Porras et al. 2016). In the ecotone between Cerrado and Caatinga domains, northern Minas Gerais State, there is a mosaic of protected areas called Sertão-Veredas-Peruaçu. Into this mosaic, the most representative area and the largest sustainable use protected area in the Minas Gerais State is the 'Area de Preservação Ambiental do Rio Pandeiros' (APA Pandeiros), being classified as "highest priority" for biodiversity conservation in Minas Gerais (Nunes et al. 2009).

The APA Pandeiros region has a rich biodiversity and endemic species (Fonseca et al. 2008) including mammals (Pereira et al. 2020, Nascimento-Costa et al. 2016, Ferreira et al. 2020). However, it has been suffering several impacts such as habitat fragmentation, introduced species, livestock, agriculture, reduction of vegetation cover and siltation (Fonseca et al. 2008, Dias et al. 2017, Dos Santos et al. 2020). In this context, our study aimed to evaluate the influence of biotic and anthropogenic variables on the medium and large mammals' community and its functional response into this ecotone protected area.

MATERIALS AND METHODS

Study area

Our study was carried out in the APA Pandeiros (Figure 1), located in Minas Gerais State, southeastern Brazil, a transition region between the Caatinga and Cerrado. This protected area is designed for sustainable use that allows low impact activities of local communities inside its territory, has an area of 393,060 ha with the aim of protecting the Pandeiros river and all its flooded plain drainage (Nunes et al. 2009).

According to the Köppen classification, the climate is defined as tropical savanna (Aw) with well separated dry and rainy seasons. The average annual temperature varies between 21 °C to 24 °C and the average annual precipitation varies between 900 to 1,200 mm. With a well-marked dry (May-October) and wet (November-April) seasonality (INMET 2020), the region is flat, with an altitude ranging between 460 and 490 m. Due to the study area being located between the Cerrado and Caatinga domains, phytophysiognomies exhibits high diversity, with very particular adaptations, presenting a mixture of riparian forest, dry forest, grasslands, savannas and flooded areas (Fonseca et al. 2008).

In 1958, a hydroelectric power dam was installed on the Pandeiros river banks, which

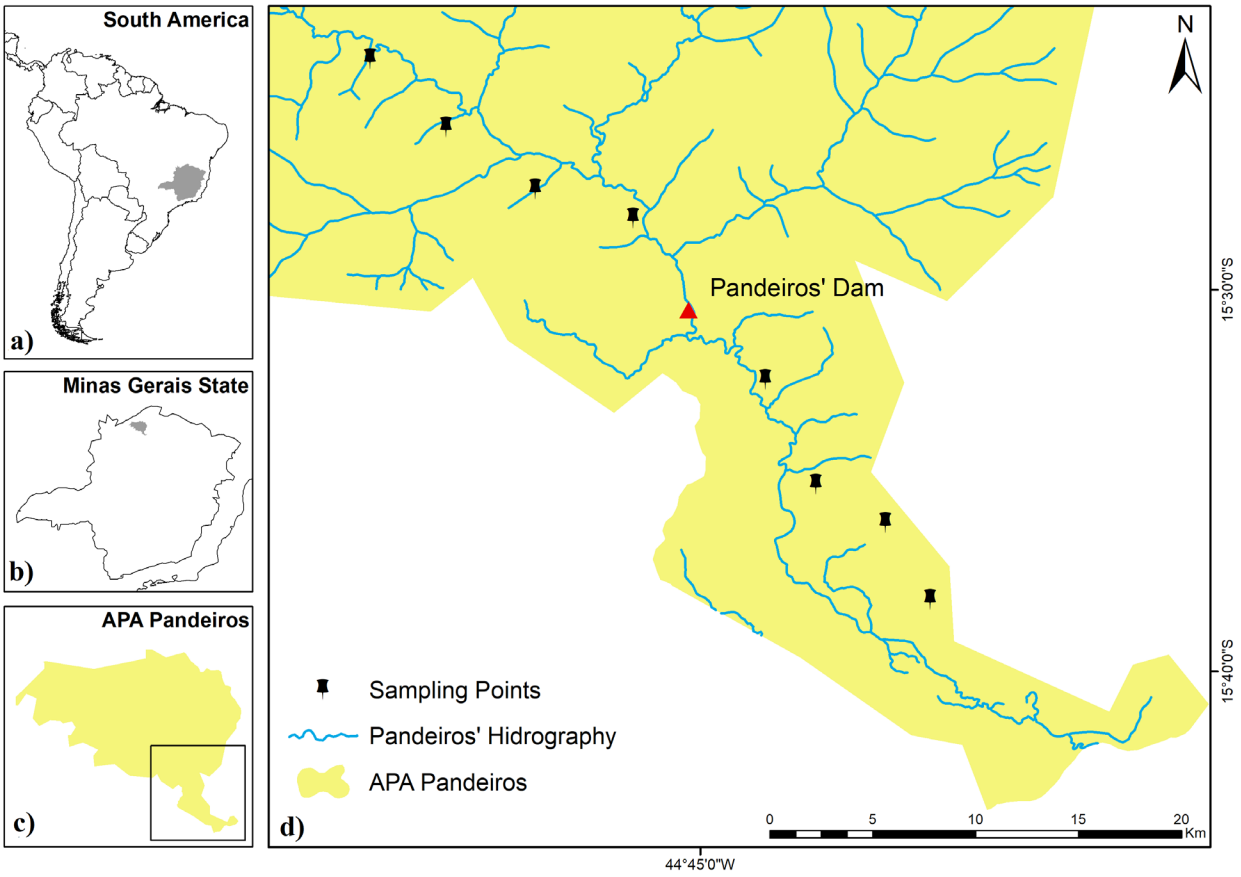

Figure 1. a) Study area showing South Americas, b) Minas Gerais state, c) Pandeiros municipality and d) sampling points within the limits of Área de Proteção Ambiental Pandeiros.

is currently deactivated since an environmental disaster occurred in 2007 (Fonseca et al. 2008, Nunes et al. 2009). In addition, although there is a great diversity of native vegetation, APA Pandeiros has suffered intense pressure as results of human activities, such as deforestation, poaching, fire, subsistence agriculture and livestock production (Dias et al. 2017, Nascimento-Costa et al. 2016, Nunes et al. 2009). The APA Pandeiros as a high diversity of fauna and flora, that is under severe threats, and can be considered of extreme biological importance and a priority for biodiversity conservation and scientific research (Nunes et al. 2009).

Data collection

For the medium and large mammals sampling we selected eight camera trap stations placed 5 km apart, four upstream and four downstream from the dam. Baits or other attractives were not used, as they can make sampling selective due to the increased degree of detection for some species (Cutler & Swann 1999, Srbek-Araujo & Chiarello 2007). At each sampling station, we installed a Bushnell® HD camera trap approximately 50 cm from the ground. We maintain the stations in continuous operation for a period of 17 months (from July 2015 to November 2016). We set the camera traps at a minimum interval of 10 seconds between photos and kept it in operation 24 hours/day. We review the traps every two months for data collection (image

transfer), maintenance (changing batteries, if necessary) and cleaning the traps. In this study, each photograph taken by the camera traps was considered an independent record. However, when more than one photograph of the same species was obtained at the same point within a period of 1 hour, only one was considered as independent observation (Srbek-Araujo & Chiarello 2013). To assess the effects of the environment on the mammals that inhabit the Brazilian semi-arid region, we locally sampled six environmental variables: (1) proportion of natural area, (2) plant biomass, (3) tree density, (4) occurrence of domestic animals, (5) distance from camera traps to the nearest house or building, and (6) abundance of potential preys (i.e. small mammals).

To measure the proportion of native vegetation, we defined a 1 km radius buffer at each sampling point, where we collected data on the percentage of natural area using RapidEye satellite image with a spatial resolution of five meters in the E-Cognition software (Baatz et al. 2004). For plant biomass, we carried out at each sampling point, three transects separated 300 m from each other, where we selected in each transect, three plots of size 10m x 10m spaced 10 meters apart, totaling nine plots at each sampling point. Then we measure circumference at ground height (CGH) using tape measure and total height (HT) by visual estimate for all trees individuals with CGH ≥ 10 cm. From the CGH, we calculated the diameter at ground height (DGH) using the DGH = CGH/π ratio. Based on the data collected, we determine green biomass for each point using the equation described by Rezende et al. (2006). Through these plots, we also calculate the density of trees at each point (DT = N/ha) as the ratio between the number of individuals (N) over the sampled area.

To quantify the number of domestics animals, such as cows (*Bos* sp.), donkeys (*Equus africanus asinus*), horses (*Equus caballus*), domestic dogs (*Canis familiaris*) and cats (*Felis catus*), we use the records from our camera trap stations (records with one-hour apart). To measure the distance in a straight line from the human settlement closest to the camera at each point, we used the free software Google Earth Pro. The abundance of potential prey (small mammals) in each area was obtained by extracting data from the study by Carvalho (2016) that sampled small mammals at the same sampling points in the same period.

Data analysis

We used five response variables: species richness of native species, total abundance of mammal records and total abundance for three functional groups, the latter grouped into carnivores, generalists and herbivores, according to Srbek-Araujo & Kierulff (2016). Functional group 1, defined as 'Carnivores', includes strict invertebrate or vertebrate predators. Functional group 2 defined as 'Generalists' that covers species with the most varied diet, being represented by the subgroups Insectivore/Omnivore and Frugivore/Omnivore. Finally, the functional group 3 called 'Herbivores' is composed of the subgroups Frugivore/Herbivore and Herbivore (herder). Prior to models' evaluation we performed the Pearson correlation test between each pair of fixed factors, excluding those with a correlation greater than or equal to 0.6 from the analysis, which results in the removal of both biomass and density of trees that were correlated with percentage of natural area.

To evaluate how mammal's respond to environmental variables we used generalized linear mixed models (GLMM – *lme4* package, Bates et al. 2015) and weighted the models using the Akaike Information Criterion corrected for small samples (AICc, Burnham et al. 2011). We pooled the response variables per season

and sampling point, leading to eight sampling points in dry season and eight sampling points in the wet season. We built the models using the Poisson distribution (Zuur et al. 2009) and proportion of native vegetation, plant biomass, tree density, occurrence of domestic animals, distance from camera traps to the nearest human settlement, and abundance of potential preys (i.e. small mammals) as fixed factors. We used both seasonality (dry and wet season) and river location of sampling point (upstream or downstream from hydropower dam) as random factors in space and time respectively (Millar & Anderson 2004). We selected these random factors due to the unknown historically impacts of the dam on mammals and because seasonality is a factor that may influence the distribution of mammals in Cerrado and Caatinga (Mendes Pontes 2004, Haugaasen & Peres 2005). We performed multimodel inference (Burnham & Anderson 2002) by automating model selection with a *dredge* function (*MuMIn* package—Barton 2016) using as criteria a non-overlap of ΔAICc < 2, in order to find the model that best described their influence on the response variables (Burnham et al. 2011, Burnham & Anderson 2002). All analyses were conducted using the software *R* (R Development Core Team 2022).

RESULTS

Our study totalized a sampling effort of 4,072 days/trap. During this sampling period, we obtained 237 independent records of 16 species of medium and large size mammals native from APA Pandeiros region (Table I). The two main species in number of records were the *Mazama gouazoubira* (N = 107) and the *Cerdocyon thous* (N = 63), together representing 71% of the records.

The functional group 1 Carnivores is composed of the species *Leopardus pardalis, Leopardus tigrinus, Leopardus braccatus, Herpailurus yagouaroundi, Puma concolor* and *Galictis cuja*. The functional group 2 Generalists represents the most diverse group, represented by the species *Didelphis albiventris, Cerdocyon thous, Lycalopex vetulus, Euphractus sexcinctus, Cabassous unicinctus, Conepatus amazonicus* and *Procyon cancrivorus*. Finally, the functional group 3 Herbivores were represented by the species *Mazama gouazoubira*, *Pecari tajacu* and *Sylvilagus brasiliensis* (Srbek-Araujo & Kierulff 2016).

The group Herbivores comprised three species and the largest number of records (N = 112, 47%), followed by generalists (N = 97, 41%) and carnivores (N = 33, 11%). Domestic animals were recorded in 426 independent records, which 86% (N = 365) were cows and 11% (N = 45) were domestic dogs. The medium number of domestics mammals was 53 records (max = 7/min = 116), while humans was eight in each sampled station (max = 1 / min = 51). The proportion of native vegetation varied between 73 to 100%, while the tree density varied from 2.7 to 5.5 individuals per hectare. The distance from sampling stations to human settlements varied from 220 to 3310 meters. Mean abundance of small size mammals was 11 records (min = 2, max = 26) in each sampling station.

Species richness of native species was negatively related to distance from the human settlement (Figure 2a), and generalists abundance was negatively affected by distance from the human settlement (Figure 2b), domestic animals (Figure 2c), and small mammals (Figure 2d). In other hand, carnivores abundance did not depict a relationship with any of the variables (Table III). The total abundance of mammal records and herbivores abundance (Table IV) also were mainly affected by distance from the human settlement. Also, herbivores were affected by the proportion of native area (Figure 3a, b).

Table I. Species and number of records of mammals identified by camera traps in the "Área de Preservação Ambiental do Rio Pandeiros", Cerrado-Caatinga Ecotone in Minas Gerais, Brazil.

Taxon	Common name	Number of records
ORDER ARTIODACTYLA		
Family Cervidae		
Mazama gouazoubina (G. Fischer, 1814)	Gray Brocket	108
Family Tayassuidae		
Pecari tajacu (Linnaeus, 1758)	Collared Peccary	1
ORDER CARNIVORA		
Family Canidae		
Cerdocyon thous (Linnaeus, 1766)	Crab-eating Fox	63
Lycalopex vetulus (Lund, 1842)	Hoary Fox	9
Family Felidae		
Leopardus pardalis (Linnaeus, 1758)	Ocelot	5
Leopardus tigrinus (Schreber, 1775)	Northern Tiger Cat	12
Leopardus braccatus (Molina, 1782)	Pampas Cat	1
Herpailurus yagouaroundi (É. Geoffroy Saint-Hilaire, 1803)	Jaguarundi	6
Puma concolor (Linnaeus,1771)	Puma	2
Family Mephitidae		
Conepatus amazonicus (Lichtenstein, 1838)	Striped Hog-nosed Skunk	1
Family Procyonidae		
Procyon cancrivorus (G. Cuvier, 1798)	Crab-eating Raccoon	2
Family Mustelidae		
Galictis cuja (Molina, 1782)	Lesser Grison	1
ORDER CINGULATA		
Family Dasypodidae		
Cabassous unicinctus (Linnaeus, 1758)	Southern Naked-Tailed Armadillo	1
Euphractus sexcinctus (Linnaeus, 1758)	Yellow Armadillo	6
ORDER DIDELPHIMORPHIA		
Family Didelphidae		
Didelphis albiventris (Lund, 1840)	White-eared Opossum	16
ORDER LAGOMORPHA		
Family Leporidae		
Sylvilagus brasiliensis (Linnaeus, 1758)	Tapeti	3

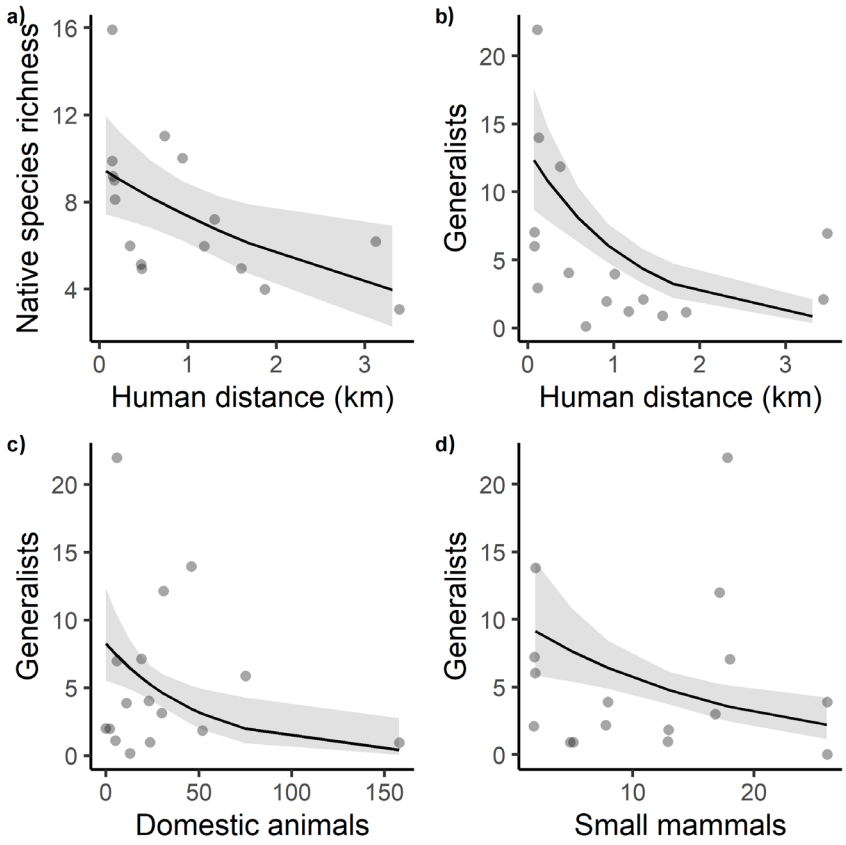

Figure 2. General linear mixed model (GLMM) depicting the relationship of richness **(a)** and generalists abundance **(b-d): a)** negative relationship between human distance from settlement and native species richness; **b)** negative relationship between generalists abundance and human distance from settlement, **c)** domestic animals and **d)** small mammals. Solid dots represent observed data; Light gray areas represent confidence intervals based on standard error (± 1.96*SE).

Table II. Ranking of the best generalized linear mixed models for predicting variables affecting mammals at Pandeiros Environmental Protection Area, semi-arid Brazil. Model selection by the Akaike Information Criterion for all five response variables: species richness of native species, total abundance of mammal records and total abundance for three functional groups (carnivores, generalists and herbivores). df: degree of freedom. Dist: Distance of human settlement. *Represents models selected by AICc < 2.

Best Models (and qualitative effects)	df	AICc	△AICc	Weight
*Richness ~ Dist (-)	4	85.5	0.0	0.55
Richness ~ +1	3	88.8	3.32	0.11
*Register ~ Dist (-)	4	113.5	0.0	0.48
*Register ~ Dist (-) + Small Mammals (-)	5	114.1	0.63	0.35
Register ~ Dist (-) + Domestic Animals (+)	5	114.5	3.99	0.1
*Hebivores ~ Natural Area (-) + Dist (-)	5	86.6	0.0	0.25
*Hebivores ~ Dist (-) + Domestic Animals (+)	5	87.7	1.1	0.15
*Hebivores ~ Dist (-)	4	87.9	1.3	0.14
*Hebivores ~ Natural Area (-) + Dist (-) +... Domestic Animals (+)	6	88.2	1.6	0.12
Hebivores ~ Natural Area (-)	4	88.8	2.22	0.09
*Generalist ~ Dist (-) + Domestic Animals (-), Small Mammals (-)	6	122.8	0.0	0.52
Generalist ~ Dist (-)	4	125.1	2.33	0.15

Table III. Generalized linear mixed models performed on species richness of native species, and abundance of generalist and carnivores. For abundance of carnivores the null model was selected. SE: Standard errors; Dist: Distance of human settlement.

Model	Parameters	Estimate	SE	Z-value	P-value
Species Richness	Intercept	2.261	0.1264	17.885	< 0.001
	Dist				
Generalists	Intercept	3.593	0.4916	7.309	< 0.001
	Dist	-0.823	0.1794	-4.592	< 0.001
	Domestic animals	-0.019	0.0071	-2.651	< 0.01
	Small mammals	-0.059	0.0207	-2.849	< 0.01
Carnivores	Intercept	0.4055	0.2041	1.986	< 0.05

Table IV. Model average and importance for models evaluating the effects on total abundance of mammal records and abundance of herbivores. SE: standard errors; CI_i: coefficient interval; Imp: Importance of parameters for the models. Dist: Distance from the human settlement.

Model	Parameters	Estimates	SE	$CI_{2.5\%}$	$CI_{97.5\%}$	Imp	P-value
Total	Intercept	2.989	0.1728	2.630	3.349	-	< 0.001
abundance	Dist	-0.353	0.0888	-0.546	-0.160	1	< 0.001
	Small mammals	-0.017	0.0089	-0.037	0.002	0.42	= 0.08
Herbivores	Intercept	3.642	1.6968	0.202	7.082		< 0.05
	Dist	-0.321	0.1357	-0.618	-0.025	1	< 0.05
	Natural area	-0.034	0.0135	-0.064	-0.005	0.57	< 0.05
	Domestic animals	0.005	0.0024	-0.0001	0.011	0.4	= 0.06

DISCUSSION

The distance to human settlement is the variable that best explains the changes in small and large mammal community into APA Pandeiros, revealing the pattern of direct relationship between low distances from human settlements and high richness and abundance of native mammals. Distinct species can respond in different ways about human interferences (Laurance 2008, Munguía et al. 2016) and there are some cases where human activities causing low impact can result in favorable habitats to generalist species (Olifiers et al. 2005, Devictor et al. 2008, Bocchiglieri et al. 2010, Duarte & Reis 2012, Lessa et al. 2012, Ahmadi et al. 2014). Our results depicted in the Table II and Figure 2 corroborate this scenario inside the APA Pandeiros, which present low human densities, and can favor some generalist species who can survive in long term into areas with some anthropogenic influence and low impact (Zanzini et al. 2018), such as *Mazama gouazoubira*,

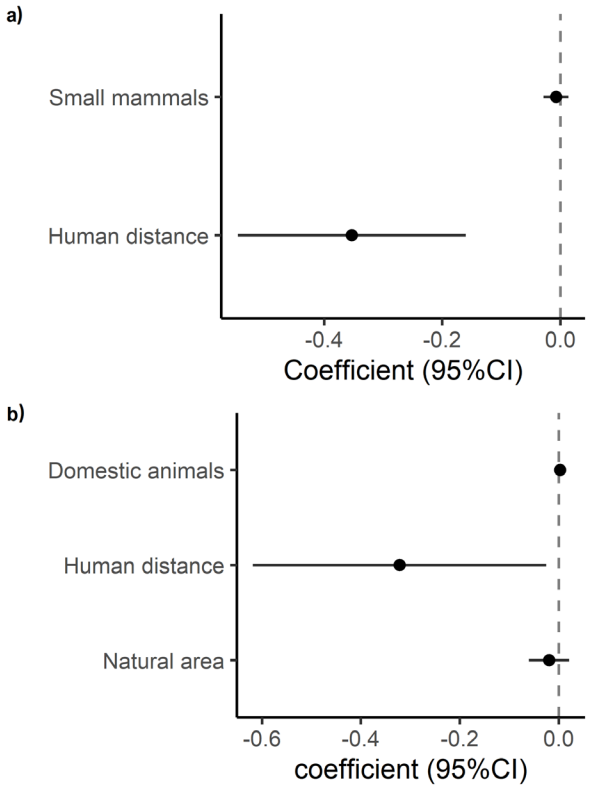

Figure 3. Multimodel inference assuming general linear mixed model (GLMM). a) total abundance of mammal records affected negatively by small mammals and human distance from settlement. b) abundance of herbivores affected negatively by the proportion of native area, human distance from settlement and Domestic animals. Solid dots represent the average of parameters values selected from the models; Confidence intervals crossing zero (vertical dashed gray line) represent non-significance.

Cerdocyon thous and *Didelphis albiventris*, with highest number of records. A recent study by Ferreira et al. (2020) about strict Protected Areas and Environmental Protection Areas (including APA Pandeiros evaluated herein) verified that top predators, large insectivores and large herbivores/frugivores are extremely rare in the Environmental Protection Areas. These results corroborate our data, with low number of records of large mammals such as *Puma concolor* and *Pecari tajacu* and total absence of *Tapirus terrestris, Myrmecophaga tetradactyla* and *Chrysocyon brachyurus*. In this context, the rarity or absence of many large mammals can bring benefits for other species of small body, especially close from human settlements, and explaining the positive correlation between the presence of native mammals and its proximity to human settlements, with *M. gouazoubira* being the species with the largest number of independent records.

Regarding functional groups, herbivores and generalists were the most important in response to human settlements proximity. In this study, herbivores were represented by *Mazama gouazoubira, Pecari tajacu* and *Sylvilagus brasiliensis*. The high abundance of this species into APA Pandeiros can be explained by the absence or low abundance of potential top predators, such as the jaguar (*Panthera onca*) and the puma (*Puma concolor*) (Duarte & Reis 2012). We do not recorded jaguars in the area and obtained only two records of pumas. In fact, Ferreira et al. (2020) verified that in the APAs Cavernas Peruaçu complex (which APA Pandeiros is included), top predators, large insetivores and herbivores are extremely rare. Moreover, *M. gouazoubira* have a high ecological plasticity and generalist habits, occurring commonly in anthropized areas (Rodrigues et al. 2014), which can explain its presence in all sampling stations and the high abundance in sampling stations close to human settlements.

The small canid *Cerdocyon thous* and the marsupial *Didelphis albiventris* are two common species of mammals found in the study area with generalist diet and use of habitats (Rocha et al. 2008). They broadly occur in the entire Cerrado and Caatinga domains (Cáceres 2002) and prey small vertebrates and invertebrates (e.g. Bueno & Motta-Junior 2004, Jácomo et al. 2004). Both species are very tolerant to human presence and very well adapted to human activities (Almeida et al. 2008), which can explain and drive the strong correlation with the close to human

settlements found in our study. Additionally, we recorded 10 species of small mammals in low abundance (91 individuals), suggesting a non-efficient sampling effort focusing this group (see Pereira et al. 2020).

The explanatory variables "domestic animals" and "small mammals" presented negative correlation with generalists. Domestic animals were mostly composed by cattle (86%) and domestic dogs (11%). A previous study by Nascimento-Costa et al. (2016) in the same study area evidenced strong presence of free range cattle in native vegetation and exotic pasture. The cattle can promote negative impacts on the native species, changing habitats, competing by resources and influencing the native species behavior, which tends to avoid completely or in part these modified areas (Shepherd & Ditgen 2005, Chaikina & Ruckstuhl 2006, Eaton et al. 2016, Porras et al. 2016). These previous studies only evaluated the cattle impacts using photographic records, without the use of detailed methods to analyze the magnitude of these impacts. Therefore, our data is not enough to infer a direct patterns or interferences caused by cattle in our results.

Regarding the free ranging dogs in the study area, the number of records (n=45) do not provided a strong data analysis to infer a negative influence under generalists, and are a insufficient number of records compared with other studies in protected areas (Srbek-Araujo & Chiarello 2008, Soto & Palomares 2015, Paschoal et al. 2016). The small number of domestic dogs found into APA Pandeiros compared with other studies inside protected areas in Brazil can be explained to low human density and high distance from highways, which difficult access to illegal poaching (Torres & Prado 2010, De Matos Dias et al. 2020). Moreover, despite even our study evidenced that human settlements do not influence the mammal community in our study area, the total absence of synergic species such as large peccarys (*Tayassu pecari*), lowland paca (*Cuniculus paca*) e agouti cotia (*Dasyprocta azarae*), and only one record of small peccary (*Pecari tajacu*) reveals that may have happened a historic hunting pressure under these species, as reported by the rangers team of APA Pandeiros.

Into the APA Pandeiros area, there is a small hydropower dam deactivated at least 13 years ago (Nunes et al. 2009). There is no evidence of influence by this dam under the mammal community. Our study recorded some top predators and endemic species, some of them are included into the national red list of endangered species (Brasil 2022), likewise *Lycalopex vetulus, Puma concolor*, *Herpailurus yagouaroundi*, *Leopardus braccatus* and *Leopardus tigrinus*. Nonetheless, we cannot neglect the fact of impacts caused by dams on many mammal communities (Passamani & Cerboncini 2013).

In conclusion, this study showed a non direct or positive influence of anthropic variables under medium and large sized mammal community in the APA Pandeiros area. This can be closely related to the number of records being of common species that can be tolerant to human presence and perturbations. Moreover, can be directly affected by domestic species with sympatric occurrence in the same area. As the APA Pandeiros is considered a protected area, is extremely important influence of decision makers regarding species management and conservation issues. Additionally, a detailed management plan for APA Pandeiros and new studies about their biodiversity are crucial for species persistence in the long term. Is a protected area inserted into the Cerrado, a biodiversity hotspot domain that currently suffer with habitats reduction in large scale, highlighting the importance of

the APA Pandeiros into a broader scenario for mammals conservation in this biome.

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ADRIELE A. PEREIRA[1]
https://orcid.org/0000-0002-6883-7574

CLARISSA ROSA[2]
https://orcid.org/0000-0001-7462-1991

LUCAS D.B. FARIA[3]
https://orcid.org/0000-0002-7230-800X

LUCAS G. DA SILVA[4,5]
https://orcid.org/0000-0002-7993-9015

MARCELO PASSAMANI[1,3]
https://orcid.org/0000-0002-0940-4074

[1]Programa de Pós-Graduação em Ecologia Aplicada, Universidade Federal de Lavras, Campus Universitário, Trevo Rotatório Prof. Edmir Sá Santos, s/n, 37200-900 Lavras, MG, Brazil

[2]Instituto Nacional de Pesquisas da Amazônia, Coordenação de Biodiversidade, Av. André Araújo, 2936, 69011-970 Manaus, AM, Brazil

[3]Universidade Federal de Lavras, Departamento de Ecologia e Conservação, Trevo Rotatório Prof. Edmir Sá Santos, s/n, 37200-900 Lavras, MG, Brazil

[4]Universidade de Brasília, Centro de Desenvolvimento Sustentável, Campus Darcy Ribeiro, Asa Norte, s/n, 70910-900 Brasília, DF, Brazil

[5]Instituto Nacional da Mata Atlântica, Ministério de Ciência, Tecnologia e Inovação do Brasil, Av. José Ruschi, 4, 29650-000 Santa Teresa, ES, Brazil

Correspondence to: **Marcelo Passamani**
E-mail: mpassamani@ufla.br

Author contributions

Adriele A. Pereira and Marcelo Passamani conceived and designed the experiments and conducted the field work. Adriele A. Pereira, Marcelo Passamani, Clarissa Rosa, Lucas D.B. Faria and Lucas G. da Silva analyzed the data and wrote the manuscript.