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EFFECT OF HABITAT AND LANDSCAPE FRAGMENTATION ON THE MEDIUM AND LARGE MAMMALIAN COMMUNITIES IN THE SOUTHEASTEARN ATLANTIC FOREST IN MINAS GERAIS

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Tese apresentada à Universidade Federal de
Lavras, como parte das exigências do Programa de
Pós-Graduação em Ecologia Aplicada, área de
concentração Ecologia e Conservação de Recursos
em Paisagens Fragmentadas e Agrossistemas, para
a obtenção do título de Doutora.

Prof. Dr(ª). Marcelo Passamani
Orientador

Prof. Dr(ª). Salvador Mandujano
Coorientador

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IRMA ALEJANDRA SOTO WERSCHITZ

EFEITO DA FRAGMENTAÇÃO DE HABITAT E PAISAGEM SOBRE AS COMUNIDADES DE MAMÍFEROS DE MÉDIO E GRANDE PORTE DA MATA ATLÂNTICA SUDESTE DE MINAS GERAIS:

EFFECT OF HABITAT AND LANDSCAPE FRAGMENTATION ON THE MEDIUM AND LARGE MAMMALIAN COMMUNITIES IN THE SOUTHEASTEARN ATLANTIC FOREST IN MINAS GERAIS:

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2023

*Ao Paolo e Heliangelus por estarem ao meu lado todos os dias, nos momentos de indiferença
e nos mais criativos.*

*Às minhas testemunhas silenciosas, das quais só pude me despedir à distância, minha mãe
(Irma Werschitz) e meu pai (Jaime Soto).*

*À Iván, Laritza, César e Jaime, por estarem ao meu lado incondicionalmente. Muito obrigada
meus irmãos. Vocês estão sempre em meu coração.*

À bola peluda, meu suposto apoio emocional durante a pandemia da covid.

DEDICO

To all the beautiful people I met in Brazil and who accompanied me at different times, all of them special.

To my brothers for always helping me, and for making it easier for me to visit them in Mexico. Specially to my two loves, Heliangelus and Paolo. Thank you for always being there for me, and for being witnesses of the whole path lived in Brazil.

I love you family!

RESUMO

A quantidade de habitat e a fragmentação das paisagens na Mata Atlântica brasileira contribuem para o declínio da população e extinção de espécies, especialmente de especialistas florestais. Descrevemos a composição da comunidade de mamíferos de médio e alto porte no sudeste da Mata Atlântica de Minas Gerais e analisamos como as assembleias de mamíferos respondem à diferentes variáveis da paisagem. Especificamente: (1) descrever a diversidade, abundância e ocupação naïve da comunidade de mamíferos, (2) comparar a diversidade alfa, abundância relativa e ocupação naïve das assembleias de mamíferos entre floresta sazonal e floresta ombrófila, (3) determinar como a quantidade de habitat, área núcleo, tamanho do fragmento, área do fragmento focal, e conectividade estrutural e funcional, influenciam a riqueza das comunidades de mamíferos nativos, especialistas, generalistas e exóticos e (4) conhecer a beta-diversidade entre todos os fragmentos e entre a floresta estacional e ombrófila. Adicionalmente, (5) apresentamos uma breve comunicação com o primeiro registro de cachorro-vinagre (*Speothos venaticus*) na Mata Atlântica de Minas Gerais, e (6) produzimos o vídeo "Selfies na Mata Atlântica" para divulgar os resultados obtidos nesta tese. Realizamos esta pesquisa entre janeiro de 2019 a março de 2020 em 28 fragmentos da Mata Atlântica, em 15 municípios de Minas Gerais e um do Rio de Janeiro. Identificamos uma diversidade gama de 33 espécies, principalmente das ordens Carnivora e Artiodactyla. Os perfis de diversidade alfa e equidade não diferiram entre as florestas, e a abundância relativa diferiu apenas para *Leopardus wiedii*. A ocupação naïve não atingiu a completude (naïve≠1), variando entre 5% – 68%, sendo que as espécies *Eira barbara* e *Didelphis aurita* apresentaram os maiores valores. As diferenças entre os dois tipos de vegetação foram dadas pela β-diversidade, que corresponde praticamente à rotatividade de espécies entre as florestas. Portanto, devemos conservar os remanescentes florestais nativos, sazonais e ombrófilas, para garantir a persistência dos mamíferos nativos, principalmente as espécies mais ameaçadas. A inferência multimodelo confirmou a hipótese espécie-área apenas para espécies especialistas, cuja riqueza respondeu positivamente na escala de 3000 m. As espécies exóticas responderam negativamente na escala 1000 m, e as espécies generalistas e nativas não responderam significativamente à percentagem da quantidade de habitat. No entanto, ao comparar o efeito da quantidade de habitat com as outras métricas da paisagem, descobrimos que a conectividade funcional é o modelo mais parcimonioso, para espécies nativas e especialistas. Além disso, encontramos uma alta diversidade beta e substituição de espécies entre os locais (90% e 85%, respectivamente) e uma baixa nidificação de espécies (4%). Em conclusão, cada grupo de mamíferos responde de maneira diferente às métricas da paisagem em uma grande escala espacial, portanto, para detectar o efeito das métricas da paisagem, é necessário considerar grupos de espécies, nativas, especialistas, generalistas e exóticas. Esses resultados destacam a importância de promover a conectividade funcional entre os fragmentos florestais e aumentar os -stepping stones- a fim de favorecer a conservação de um maior número de espécies e reduzir a extinção das espécies especialistas na Mata Atlântica brasileira de Minas Gerais.

Palavras-chave: Comunidade de mamíferos. Diversidade. Fragmentação. Perda de habitat. Inferência multi-modelo. *Speothos venaticus*.
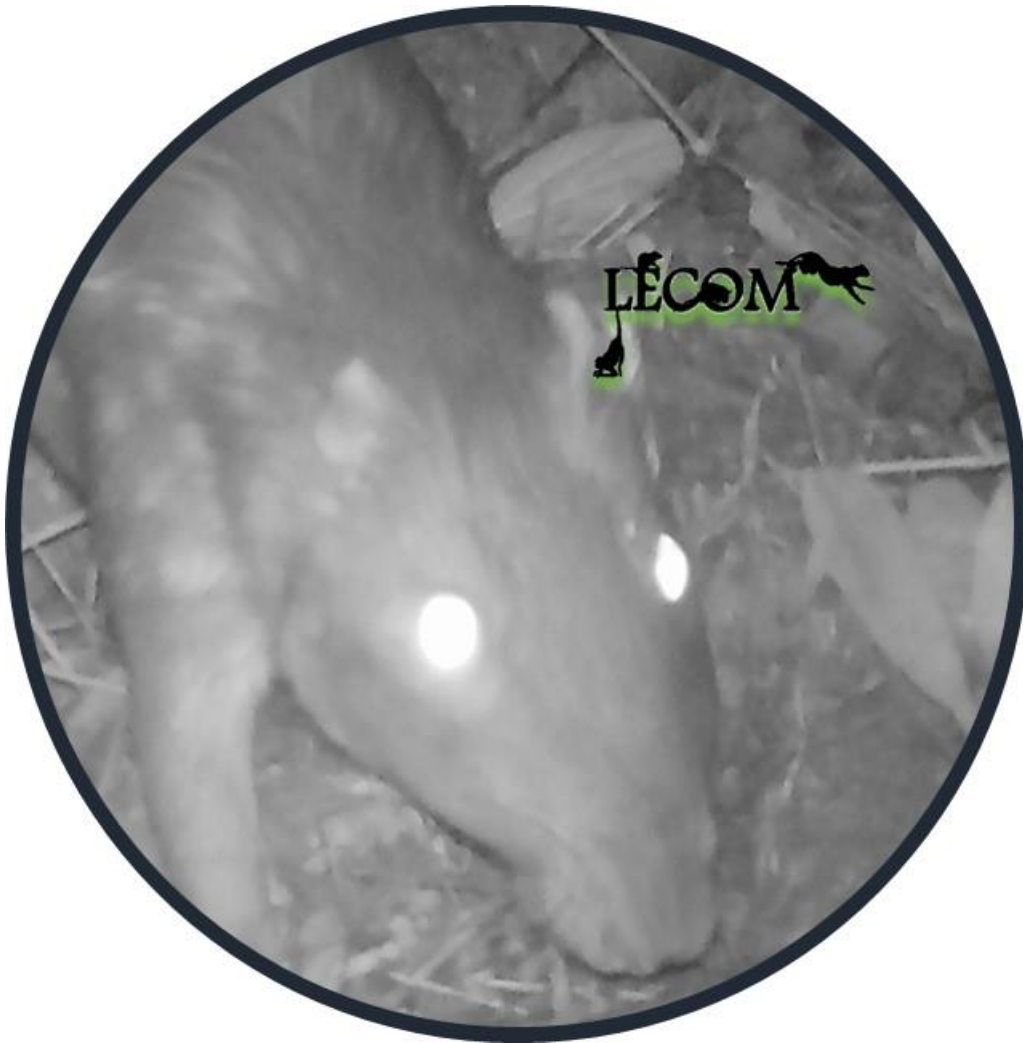
ABSTRACT

The habitat amount and fragmentation of landscapes in the Brazilian Atlantic Forest contribute to population size declines and species extinction, especially for forest specialists. We describe the composition of medium and high mammals' community in the southeastern Atlantic Forest of Minas Gerais and analyzing how mammal assemblages respond to landscape and different landscape variables. Specifically: (1) describe the diversity, abundance, and naïve occupancy of the mammal community, (2) compared the α, relative abundance and naïve occupancy of the mammal assemblages between seasonal and ombrophilous forest, (3) determine how the habitat amount, core area, patch size, area of the focal fragment, structural and functional connectivity, influences the richness of native, specialist, generalist, and exotic mammalian communities, and (4) know the beta-diversity across the all fragments and seasonal and ombrophilous forests. Additionally, (5) we present a short communication with the first record of bush dog (*Speothos venaticus*) in the Minas Gerais Atlantic Forest, and (6) we produce the video "Selfies in the Atlantic Forest" to disseminate the results obtained in this thesis. We conducted this research between January 2019 to March 2020 in 22 fragments in the southeastern Brazilian Atlantic Forest, in 15 municipalities of Minas Gerais and one of Rio de Janeiro. We identified a gamma diversity of 33 species, principally of the orders Carnivora and Artiodactyla. Alpha diversity and evenness profiles were not different between seasonal and ombrophilous forests, and the relative abundance only differed for *Leopardus wiedii*. The naïve occupancy did not reach completeness (naïve≠1), ranging between 5% – 68%, and the species *Eira barbara* and *Didelphis aurita* had the highest values. The differences between the two types of vegetation were given by the β-diversity, corresponds practically to the species turnover between forests. Therefore, we must conserve native forest remnants, seasonal and ombrophilous, to ensure the persistence of native mammals, mainly the most threatened species. The inference multi-model confirms the species-area hypothesis only to specialist species, their richness responds positively at the scale of 3000 m. The exotic species responds negatively at the scale 1000 m, and the generalist and native species did not respond significantly to percentage the habitat amount. However, when contrasting the effect of habitat amount with the other metrics of landscape, we found the functional connectivity is the most parsimonious model, for native and specialist species, indicating a possible threshold to ensure their occurrence. Additionally, we found a high beta diversity and species substitution between sites (90% and 85% respectively), and low species nesting (4%). In conclusion, we found that each group of mammals responds differently to the landscape metrics at a large spatial scale, therefore, to detect the effect of landscape metrics requires considering species groups, like native, specialist, generalist, and exotic species. These results highlight the importance of promoting functional connectivity between forest fragments and increasing the -stepping stones- to favor the conservation of a greater number of species and reduce the extinction of specialist species in the Brazilian Atlantic Forest of Minas Gerais.

Keywords: Diversity, fragmentation, habitat loss, mammal community, multi-model inference, *Speothos venaticus*.

SUMÁRIO

FIRST PART

1 GENERAL INTRODUCTION

The Atlantic Forest of South America is one of the most endangered major ecoregions worldwide, with only 11.7% of its original vegetation cover remaining, most of which consisting of highly disturbed forest remnants now smaller than 50 ha (Bogoni *et al*. 2018). Therefore, the Brazilian Atlantic Forest is an ideal study system to understand the impacts of habitat loss and fragmentation in natural areas (Ribeiro et al. 2009), like medium-sized mammal species. The remnants of the Atlantic Forest are mostly isolated, influencing the number of species that can survive within the fragments (Beca *et al*. 2017). The effects of these multiple factors result in high levels of defaunation throughout the Atlantic Forest, especially the loss of large vertebrates, which could influence the forest composition and ecological cascades (Galetti *et al*. 2017).

Community structure and diversity arise from intricate and ever-changing phenomena, influenced by multiple spatial and temporal processes. Understanding the distribution patterns of species across various scales and identifying the underlying factors have been fundamental objectives in ecological research (Santos *et al*., 2021). However, even that habitat loss is an important driver of extinction, the relevance of habitat fragmentation remains under debate (Semper-Pascual et al. 2021), standardized and large-scale analysis is still lacking (Püttker et al. 2020), metrics such as edge effect and connectivity have received comparatively little attention (Teixido et al. 2020), and the effect of high environmental impacts correlated with changes in composition across space (Beta diversity) remains poorly understood (Palmerin et al. 2018), but influence species richness (Norris et al. 2010; Maseko et al. 2020). Therefore, through the analysis of alpha, beta, and gamma diversity, we can measure the diversity changes at different spatial scales (Socolar et al. 2015), promoting studies multiscale, necessary to understand the dynamics of communities in time and space (Presley et al. 2019), species change, the degree of homogenization among mammal communities (Palmerin et al. 2018) and understand the effects of anthropogenic impacts on landscapes, increasing concerns about the threats to the Atlantic Forest (Magioli et al. 2015).

For most mammal species threatened with extinction included in the Brazilian Red List in Minas Gerais, there is not yet sufficient data on their size populations, records, and distributions, which makes it difficult to understand their conservation status (Corrêa *et al*. 2021). There are gaps in the occurrence of many species, especially in the interior of forests, which reinforces the importance of increasing sampling efforts in the Atlantic Forest (Figuereido *et al*. 2021) to develop guidelines for identifying priority areas for species conservation (Corrêa *et al*. 2021). The level of threat and the mammals ecological importance highlight the need to estimate new information at large spatial scales, about the mammals

richness (Barros *et al*. 2021), diversity, habitat use, and species distribution (Vilas *et al*. 2022), the organization of assemblages (Barros *et al*. 2021), the species occurrence (Barros *et al*. 2021; Regolin *et al*. 2020; Vilas *et al*. 2022), and beta diversity (Beselga *et al*. 2010).

In the chapter 1 of this research, "Influence of forest type on the diversity, abundance, and naïve occupancy of the mammal assemblage in the southeastern Brazilian Atlantic Forest" our goal was using the species richness, abundance, and distribution of medium and large-sized terrestrial mammal recorder in the southeastern of Minas Gerais, to investigate the influence of seasonal and ombrophilous forests on the gamma, alpha, and beta diversity in the Brazilian Atlantic Forest. In the chapter 2, "Effect of habitat loss and landscape fragmentation on the native, specialist, generalist, and exotic mammals communities in the southeastern Atlantic Forest of Minas Gerais" our main goal was to examine spatial patterns in the mammalian richness, particularly (a) evaluate through a multiscale analysis the effect of the habitat amount and core areas in the mammalian richness in native, specialists, generalists and exotic species; (b) determine how the habitat amounts, core areas, patch size, area of the focal fragment, structural connectivity, and functional area, determine the richness of native, specialists, generalists and exotic species; and (c) know what is the turnover and homogenization of mammal species between sites, establishing the Beta-diversity of mammals. In the chapter 3, we include a short communication, "First record of Bush Dog (*Speothos venaticus*) in the Atlantic Forest of Minas Gerais, Brazil". Finally, in the chapter 4, we presented one video about this thesis.

REFERENCES

DE BARROS, R. A. et al. **The value of a small urban green area to the medium and large-sized mammals conservation**. Research, Society and Development, v. 10, n. 8, p. 1–16, 2021.

BECA, G. et al. **High mammal species turnover in forest patches immersed in biofuel plantations**. Biological Conservation, v. 210, p. 352–359, 2017.

BASELGA, Andrés. **Partitioning the turnover and nestedness components of beta diversity**. Global ecology and biogeography, v. 19, n. 1, p. 134-143, 2010.

BOGONI, J. A. et al. **Wish you were here: How defaunated is the Atlantic Forest biome of its medium to large-bodied mammal fauna?** PLOS ONE, v. 13, n. 9, p. e0204515.13:e0204515, 2018.

CORRÊA, T. C. V.; MENDES, L. M.; DE MELO BARBOSA, K. J. V. ; DE MELO, F. R. **Medium and large-sized mammals in Private Natural Heritage Reserves in the Quadrilátero Ferrífero of Minas Gerais, Brazil**. Neotropical Biology and Conservation, v. 16, n. 2, p. 383-396, 2021.

FIGUEIREDO, M. D. S. L. et al. **Tetrapod Diversity in the Atlantic Forest: Maps and Gaps**. The Atlantic Forest: History, Biodiversity, Threats and Opportunities of the Mega-diverse Forest, Springer International Publishing, Cham, p. 185–204. 2021.

GALLETI, M. et al. **Ecological and evolutionary legacy of megafauna extinctions**. Biological Reviews, v. 93, n. 2, p. 845-862, 2018.

MAGIOLI, M.; RIBEIRO, M. C.; FERRAZ K. M. P. M. B.; RODRIGUES, M. G. **Thresholds between functional diversity and patch size**. Animal Conservation, v. 18, n. 6, p. 499-511, 2015.

MASEKO, M. S. et al. **Effects of habitat-patch size and patch isolation on the diversity of forest birds in the urban-forest mosaic of Durban, South Africa**. Urban Ecosystems, v. 23, p. 533-542, 2020.

NORRIS, D. F.; MICHALSKI, F.; PÉRES, C. A. **Habitat patch size modulates terrestrial mammal activity patterns in Amazonian Forest fragments**. Journal of Mammalogy, v. 91, n. 3, p. 551–560, 2010.

PALMEIRIM, A. F.; BENCHIMOL, M.; MORANTE-FILHO, J. C.; VIEIRA, M. V.; PERES, C. A. **Ecological correlates of mammal β-diversity in Amazonian land-bridge islands: from small-to large-bodied species.** Diversity and Distributions, V. 24, P.1109–1120, 2018.

PRESLEY, S. J.; CISNEROS, L. M.; KLINGBEIL T. B.; WILLIG, M. R. **Landscape ecology of mammals**. Journal of Mammalogy, v. 100, n. 3, p. 1044–1068, 2019.

PÜTTKER, T. et al. **Indirect effects of habitat loss via habitat fragmentation: A cross-taxa analysis of forest-dependent species**. Biological Conservation, v. 241, p. 108368, 2020.

REGOLIN A. L. et al. **Spatial heterogeneity and habitat configuration overcome habitat composition influences on alpha and beta mammal diversity**. Biotrópica, v. 52, n. 2, p. 970–982, 2020.

RIBEIRO, M.C. et al. **The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation**. Biological Conservation v. 142, p. 1141–1153, 2019.

SANTOS, F. et al. **Site and species contribution to β-diversity in terrestrial mammal communities: Evidence from multiple Neotropical forest sites.** Science of The Total Environment, v. 789, 2021.

SEMPER-PASCUAL A. et al. **How do habitat amount and habitat fragmentation drive time-delayed responses of biodiversity to land-use change?** Proceedings of the Royal Society B, v. 288, p. 20202466, 2021.

SOCOLAR, J. B.; GILROY, J. J.; KUNIN, W. E.; EDWARDS, D. P. **How should beta-diversity inform biodiversity conservation?** Trends in Ecology and Evolution, v. 31, p. 67–80, 2015.

TEIXIDO A. et al. **Major biases and knowledge gaps on fragmentation research in Brazil: Implications for conservation**. Biological Conservation, v. 251, p. 108749, 2020.

VILAS BOAS, A. H., et al. **Survey of medium-and large-sized mammals in Atlantic Forest remnants of Conceição dos Ouros, Minas Gerais, Brazil**. Biodiversity Data Journal, v. 10, p. e82139, 2022.

SECOND PART – ARTICLES

ARTICLE 1

Influence of forest type on the diversity, abundance, and naïve occupancy of the mammal assemblage in the southeastern Brazilian Atlantic Forest

Influencia del tipo de bosque en la diversidad, abundancia, y ocupación "naïve" del ensamble de mamíferos en el sureste de la Mata Atlántica brasileña

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Abstract

The Brazilian Atlantic Forest has the highest rate of native vegetation destruction, one of the principal drivers of mammal extinctions. It is a priority to reduce information gaps in terms of the α, β, and γ diversity patterns, abundance, occupation records, and habitat use, as well as understand how native vegetation helps mammal species to persist in fragmented landscapes. Our objective was establishing the γ diversity, and to assess the extent to which the α, and β diversity, the relative abundance, and naïve occupation of medium and large-sized mammal communities contrast between seasonal and ombrophilous forests. We conducted this research between January 2019 to March 2020 in 22 fragments in the southeastern Brazilian Atlantic Forest, in 15 municipalities of Minas Gerais and one of Rio de Janeiro. We calculate Hill's numbers with iNEXT.4steps package, β-diversity with the Betapart package, the relative abundance index (RAI), and naïve occupancy (PAO). To compare the RAIs between species and the type of vegetation were used the Kruskal-Wallis and Mann-Whitney statistical tests. Finally, we calculated the correlation between the RAIs and the PAOs. We identified 81% native and 19% non-native mammals and a gamma diversity of 32 species, principally of the orders Carnivora and Artiodactyla. Our results showed that alpha diversity and evenness profiles were not different between forests (seasonal q0=0.91, q1=0.99, q2=1, J=0.83; ombrophilous q0=0.96, q1=0.99, q2=1, J=0.85). However, in terms of beta diversity, we found a low value of overall beta diversity (βJAC=0.37) that corresponds practically to the turnover (βJTU=0.34), while the nestedness is almost non-existent (βJNE=0.02). The relative abundance was different for the species of the all-mammal assemblage (H=115.24, P=0.000), with the highest values for *Didelphis aurita* (*RAI*=4.55±7.66) and *Cuniculus paca* (*RAI*=2.35±3.73) and the minor values for *Speothos venaticus* (*RAI*=0.04±0.24) and *Galictis cuja* (*RAI*=0.06 ±1.19). The relative abundance of species did not differ between the two vegetation sites (U=453.5; Z=0.37; P=0.70), and only *Leopardus wiedii* showed significant differences between forests (U=84.5; P=0.01). The naïve occupancy did not reach completeness for any species (naïve≠1), ranging between 5% to 68%. The highest values were for the species *Eira barbara* (68%) and *Didelphis aurita* (55%), and the lowest values (5%) for *Tayassu pecari*, *Tamandua tetradactyla*, and *Speothos venaticus*, while the exotic species had less than 40%. In the seasonal forest, the naïve occupancy was between 7% to 57%, and in the ombrophilous forest, between 12% to 88%. *Eira barbara* and *Didelphis aurita* had the highest occupation in both forests. The γ diversity was representative and consistent with the species found in the Atlantic Forest, and the relative abundance and naive occupancy reflected the rarity of most species in the area and their vulnerability to local extinction. Additionally, the only difference between the two forests corresponds to species turnover. Therefore, we must conserve native remnants of both forests to ensure the existence of native mammals, mainly the most threatened species, to prevent more dramatic scenarios of local extinction in the Atlantic Forest.

Keywords

Resumen

La Mata Atlántica brasileña presenta la mayor tasa de destrucción de la vegetación nativa, causa principal de la extinción de mamíferos. Es prioritario reducir las lagunas de conocimiento en cuanto a los patrones de diversidad α, β, y γ, abundancia, ocupación y uso del hábitat, así como entender cómo la vegetación nativa favorece la persistencia de mamíferos en paisajes fragmentados. Nuestro objetivo fue establecer la diversidad γ, y evaluar en qué medida la diversidad α y β, la abundancia relativa y la ocupación naïve de las comunidades de mamíferos medianos y grandes, contrastan entre bosques estacionales y ombrófilos. Realizamos esta investigación de enero de 2019 a marzo de 2020, en 22 paisajes del sudeste de la Mata Atlántica. Calculamos los números de Hill con el paquete iNEXT.4steps, la abundancia relativa, ocupación naïve, y la β-diversidad, utilizando el paquete Betapart. Obtuvimos los índices de abundancia relativa (RAI) y la ocupación relativa o naïve (PAO). Para comparar los RAI entre especies y el tipo de vegetación utilizamos las pruebas estadísticas de Kruskal-Wallis y Mann-Whitney. Finalmente, calculamos la correlación entre los RAI y los PAO. Identificamos 81% de especies de mamíferos nativos, 19% de especies no nativas y una diversidad gamma de 32 especies, principalmente de los órdenes Carnivora y Artiodactyla. La diversidad alfa y los perfiles de uniformidad fueron iguales entre los bosques (estacional $q0=0.91$, $q1=0,99$, $q2=1$, $J=0,83$; ombrófilo $q0=0,96$, $q1=0,99$, $q2=1$, $J=0,85$). Sin embargo, encontramos un valor bajo de diversidad beta total ($\beta JAC=0,37$) que corresponde al recambio de especies ($\beta JTU=0,34$), mientras que la anidación fue casi inexistente ($\beta JNE=0,02$). La abundancia relativa difirió para el ensamblaje de mamíferos ($H=115,24$, $P=0,000$), correspondiendo los valores más altos a las especies *Didelphis aurita* ($RAI=4,55\pm7,66$) y *Cuniculus paca* ($RAI=2,35\pm3,73$) y los menores a *Speothos venaticus* ($RAI=0,04 \pm 0,24$) y *Galictis cuja* ($RAI=0,06\pm1,19$). La abundancia no difirió entre los dos sitios de vegetación ($U=453,5$; $Z=0,37$; $P=0,70$), y sólo *Leopardus wiedii* mostró diferencias significativas entre bosques ($U=84,5$; $P=0,01$). La ocupación naïve no alcanzó la completitud (naïve$\neq1$) y osciló entre el 5% al 68%. Los valores más altos fueron para las especies *Eira barbara* (68%) y *Didelphis aurita* (55%), los más bajos (5%) para las especies *Tayassu pecari*, *Tamandua tetradactyla*, y *Speothos venaticus*, mientras las especies exóticas presentaron valores menores al 40%. En el bosque estacional, la ocupación naïve fue de entre el 7% al 57%, y en el bosque ombrófilo, entre el 12% al 88%. *Eira barbara* y *Didelphis aurita* presentaron la mayor ocupación en ambos bosques. La diversidad γ fue representativa y consistente con las especies encontradas en el Bosque Atlántico, la abundancia relativa y la ocupación naïve reflejaron la rareza de la mayoría de las especies en el área y su vulnerabilidad a la extinción local. Adicionalmente, la única diferencia entre los dos bosques corresponde al recambio de especies. Por lo tanto, debemos conservar los remanentes nativos de ambos bosques para asegurar la existencia de los mamíferos nativos, principalmente las especies más amenazadas, para evitar escenarios más dramáticos de extinción local en el Bosque Atlántico.

Palabras clave

Biodiversidad, Brasil, conservación, índice de abundancia relativa, mamíferos, uso del hábitat

Introduction

The Atlantic Forest is a biodiversity hotspot (Myers *et al*. 2000), but also one of the most defaunated subregions of the planet mainly because of anthropogenic drivers (Bogoni *et al*. 2020; Galetti *et al*. 2021). Contains one of the most downsized mammal faunas, with an average historical loss of 62 % (Bogoni et al. 2020), among other factors, due to habitat loss, fragmentation of the landscape (Bogoni et al. 2018; Haddad et al. 2015; Püttker et al. 2020; Ribeiro et al. 2009), expansion of crops and livestock, wildlife trafficking, urbanization, industrial development (Campanili and Schäffer 2010), land protection status, habitat type, and landscape-scale habitat area (Bogoni et al. 2020).

Of the 770 mammal species occurring in Brazil (Abreu *et al*. 2021), the Atlantic Forest has 384 species, 262 are terrestrial, and 109 endemics (Figueiredo *et al*. 2021). Minas Gerais state includes approximately 70 % of the mammal species found in the entire Brazilian Atlantic Forest, with almost 60 endemics species (Campanili and Schäfer 2010). Unfortunately, Minas Gerais has 45 species threatened with extinction (Lista das Espécies da Fauna Ameaçadas de Extinção no Estado de Minas Gerais Copam 2010). This vulnerability has caused the local species extinction (Bogoni *et al*. 2020) and the alteration of ecological processes (Oliveira *et al*. 2020) and ecosystem services (Bogoni *et al*. 2020a). The degree of threat is a consequence of the high sensitivity of mammals to changes in landscape structure (Regolin *et al*. 2020), floristic composition (Galetti *et al*. 2009), modification of the abundance of species (Fahrig *et al*. 2019), the communities composition (Beca *et al*. 2017), and size of assemblages (Bogoni *et al*. 2020a).

For most mammal species threatened with extinction included in the Brazilian Red List in Minas Gerais, there is not yet sufficient data on their size populations, records, and distributions, which makes it difficult to understand their conservation status (Corrêa *et al*. 2021). There are gaps in the occurrence of many species, especially rare species, principally in the interior of forests, which reinforces the importance of increasing sampling efforts in the Atlantic Forest (Figuereido *et al*. 2021) to develop guidelines for identifying priority areas for species conservation (Corrêa *et al*. 2021). Methods such as camera trapping can yield satisfactory results in monitoring medium to large mammals of neotropical forests (Srbek-Araujo and Chiarello 2005) because it is highly effective compared to other methods (Rovero and Spitale 2016) that allows for highly standardized data collection at regional or global scales (Wearn *et al*. 2019). Especially useful to get information about uncommon, rare, or cryptic mammals to make decisions for the conservation of biodiversity hotspots (Trolliet *et al*. 2014).

Species richness, abundance, and distribution patterns are defined by environmental and landscape conditions and vary according to spatial scale (Bogoni *et al*. 2017). At small scales, species respond to forest type, while at larger scales, their response remains poorly understood (Bogoni *et al*. 2016). Consequently, we need to obtain more information (Barros *et al*. 2021) on species abundance (Galetti *et al*. 2009; Bogoni *et al*. 2020), diversity, habitat use, species occurrence (Beselga *et al*. 2010; Vilas *et al*. 2022) and assemblage organization to understand the ecological needs of mammals in different habitat types (Barros *et al*. 2021; Regolin *et al*. 2020; Vilas *et al*. 2022).

Therefore, is a priority to understand how native vegetation helps many species to persist in fragmented agricultural landscapes (Ikin *et al*. 2014), and stablish the α, and β-diversity components, to understand the processes that cause differences in species assemblages (Regolin *et al*. 2020). This knowledge could be used as a baseline to make comparisons between current, past, and future species richness, comparisons between locations, and inferences about species distributions (Cooke *et al*. 2019; Steinbeiser *et al*. 2019), the management of natural areas (Corrêa *et al*. 2021) and land-use decisions (Wearn *et al*. 2017), to expand and strengthen public policies and good agricultural practices, and support the Vegetation Protection Law of Brazil to recover the native vegetation in the Atlantic Forest (Brancalion *et al*. 2016).

Our objective was establishing the γ diversity, and to assess the extent to which the α, and β diversity, the relative abundance, and naïve occupation of medium and large-sized mammal communities contrast between seasonal and ombrophilous forests. Our specific objectives were: (a) analyze variation in gamma diversity, abundance, and naïve occupation among forest fragments; (b) compare alpha diversity, abundance, and naïve occupation, between seasonal and ombrophilous forests; and (c) assess beta-diversity between forests and components, turnover, and nesting. We expected that forest type affects mammalian assemblies showing significant differences between α diversity, abundance, and occupancy. Additionally, we expected a high beta diversity ($> 70\%$) due the high nestedness species between forests.

<div align="center">Materials and Methods</div>

Mammal sampling

This study was carried out at 22 fragments located in the southeastern Brazilian Atlantic Forest, in 15 municipalities of Minas Gerais and one of Rio de Janeiro (46°0'W 43°0'W; 23°0'S 21°0'S) (Figure 1; Supplementary material 1) covering an area of 22 049 km^2 approximately.

The selection of fragments was based on satellite images provided by Google Earth Pro software and on updated maps of remnant forest fragments made available by the SOS Mata Atlântica Institute (2013/2014), having as selection criteria, a priori, the presence of seasonal and ombrophilous forest. The distance between fragments was greater than 2.85 km.

We surveyed medium- and large-sized mammals (≥1 kg) using a single sampling station in each fragment with one camera trap at each sampling point (Bushnell® HD Bushnell Outdoor Products, California, USA). At various times between January 2019 to March 2020, the camera trap stations in each fragment operated continuously 24 hours per day for an average of 130 days in each station. To avoid pseudo-replication, we used an interval of 24 h between pictures of the same species to guarantee independence between them (Porfirio *et al.*2014).

The survey area was a highly fragmented landscape surrounded by agricultural matrices or villages. The regional relief is rugged and occurs at elevations ranging from 887 m to 2,087 m a.s.l. The lower elevations are predominantly humid temperate sites with dry winters and hot summers (Cwa type), while the mountainous areas have dry winters and rainy and moderately hot summers (Cwb type) (Instituto Brasileiro de Geografia e Estatística IBGE 2012).

We organize the data using the Wild.ID Program 0.9.31 (Conservation International 2018). We identified the species at the lowest taxonomic level possible, grouping the records of *Mazama americana* and *Mazama gouazoubira*, as *Mazama* sp., due to the difficulty of differentiating between these two species.

Gamma, alpha, and beta diversity

We obtained the gamma diversity (Whitaker 1972) in the southeastern Brazilian Atlantic Forest using the TEAM library program 1.7.R for Windows (Rovero and Spitale 2016). In order to evaluate the effectiveness of the sampling and compare it with the richness of native species in other studies of the Atlantic Forest, we excluded the domestic species from this analysis. Accumulation curves were generated with the Vegan package (Oksanen et al., 2013) and the non-parametric estimator Jackknife 1 with the Biodiversity R package (Kindt and Coe 2005). The first order Jackknife estimator is one of the most precise techniques to reduce the bias of the estimated values (Burnham and Overton 1979).

To calculate the differences in the alpha diversity between seasonal and ombrophilous forests, the R package iNEXT.4steps online was used for rarefaction and extrapolation of species diversity with Hill numbers based on abundance data (Chao *et al* 2020). We used fifty bootstraps and a 95% confidence interval. Hill numbers included the species richness ($q = 0$),

Shannon diversity ($q = 1$), and Simpson diversity ($q = 2$) (Chao *et al*. 2014; Hsieh *et al*. 2016). We applied a four-step procedure to assess each forest (a) the sample completeness profile, (b) size-based rarefaction/extrapolation, (c) asymptotic and empirical diversity profiles, (d) non-asymptotic coverage-based rarefaction and extrapolation analysis, and (e) evenness profile among species abundances (Pielou J) derived from the slopes of the diversity profile (Chao *et al*. 2020).

To compare the species composition between seasonal and ombrophilous forests we used the Partitioning Beta Diversity into Turnover and Nestedness Components package (beta part-package) (Baselga and Orme 2012; Baselga *et al.* 2021) in R v4.1.0 (R Core Team, 2021). We computed using a resampling procedure, taking 100 random samples. Obtain the beta.JTU value of the turnover, measured as the turnover fraction of Simpson's dissimilarity, the beta.JNE of the nesting component, measured as the resulting fraction of Simpson's dissimilarity nesting and the beta.JAC value of the overall beta diversity. We did this analysis a) grouping the native and non-native species and b) only considering native species.

Species abundance

We calculated the relative abundance index (RAI) for each species as follows: RAI ij = Nj/days j * 100 nights traps, where "Nj" is the number of independent records of the species, "i" is each species, and "j" is each landscape (Mandujano and Pérez 2019), throughout the study area and at each forest. We performed all analyses with the RAI.1 (Mandujano and Pérez 2019) packages. Finally, we used the Kruskal-Wallis and Mann-Whitney statistical tests to compare the RAIs between species and vegetation type. In all the comparative analyzes carried out in this study, we used a value of significance of $p<0.05$. To know the magnitude of the differences obtained with the Kruskal Wallis test, we computed the epsilon-squared (Tomczak and Tomczak 2014).

Species distribution in the study area

We calculated the naïve occupancy also called Percent of Area Occupied PAO (MacKenzie and Kendall 2002; sensu Kéry & Royle 2015), throughout the study area and at each type of forest. It was calculated as the number of camera trap sites occupied by each species divided by the total number of sites surveyed. Maximum values with an occupancy of 1.0 correspond to 100% occupancy. Subsequently, to know how the spatial distribution influences the abundance of each species, we calculated the correlation between the RAIs and the PAO (Mandujano and Pérez 2019). We performed all analyses using the R program 4.2.1 (R Core Team 2021).

Results

Gamma, alpha and beta diversity

Based on 2 856 camera traps/day, we recorded 589 independent camera trap events of mammalian species for the entire region. The mammal richness in the study area was 32 species (Figures 2-3), distributed among 26 genera, nine orders, and 17 families (Table 1). Regarding the species richness of native mammals, there were 26 species distributed among 22 genera, 8 orders, and 15 families (Table 1). The accumulation curve almost reached the asymptote, and according to the expected richness (Jackknife 1 = 29 ± 2 species) of mammalian species, the sampling effort was sufficient. Therefore, we obtained a representative percentage (90%) of the species in the area.

The orders Carnivora and Artiodactyla were the most represented, with five and four families, respectively. The order Rodentia was represented by two families, while Cingulata, Didelphimorphia, Lagomorpha, Perissodactyla, Pilosa, and Primates were represented by only one family each. Most of the registered species were native to the Atlantic Forest (81 %), domestic (16 %), and exotic (3 %) (Table 1). Additionally, we obtained one new record for southeastern Minas Gerais, the bush dog *Speothos venaticus* (Soto-Werschitz *et al*. 2023 in press).

There are some differences in the categorization of threatened species at the global (International Union for the Conservation of Nature IUCN 2021), national (Instituto Chico Mendes de Conservação da Biodiversidade ICMBio 2018), and state levels (Copam 2010). Among the species recorded on the List of Endangered Species of Fauna in Minas Gerais state, the species *Leopardus pardalis, L. guttulus, Pecari tajacu, Puma concolor*, and *Tamandua tetradactyla* are classified as vulnerable; *L. wiedii* is classified as threatened and *Sapajus nigritus, Speothos venaticus*, and *Tayassu pecari* as critically endangered (Copam 2010) (Table 1). The other species recorded in the study area, are listed as Least Concern (IUCN 2021; ICMBio 2018) or are not included in the state list (Copam 2010).

We obtained the sample completeness profile with a representative number of species in both assemblages (seasonal $q0=0.91$, $q1=0.99$, $q2=1$; ombrophilous forest $q0=0.96$, $q1=0.99$, $q2=1$) with 24 and 25 mammal species, respectively (Figures 4-a, 4-b, 4-c; Supplementary material 2). The size-based rarefaction and extrapolation analysis and the asymptotic empirical diversity profiles indicate that our asymptotic diversity estimates for these forests are satisfactory to infer true diversities ($q=1$ and $q=2$) (Figures 4-b, 4-c; Supplementary material 2). The diversity and evenness measures were calculated up to a

standardized coverage value of $Cmax$ = 99.8 %. Finally, the alpha diversity, q=0, q=1, q=2, and evenness profile among species abundances, were not different among forests (Figures 4-a, 4-b, 4-c, 4-d, and 4-e; Supplementary material 2). We observed that the profile curve descends abruptly in both vegetations, and the values of Pielou J' index, showed an equal evenness among species abundances in each forest, seasonal (J = 0.83) and ombrophilous (J = 0.85) (Figure 4-e; Supplementary material 2).

Considering the 31 species present in the assemblage, the overall beta diversity between sites was βJAC = 0.37, the turnover was βJTU = 0.34, and species nestedness was βJNE = 0.02 (Figure 5-a). Included only the native species, the total beta diversity between sites was βJAC = 0.28, the turnover was βJTU = 0.25, and species nestedness was βJNE = 0.03 (Figure 5-b). Therefore, we found a low value of overall beta diversity, presenting a low number of exclusive species in each forest. Six species were unique to the seasonal forest (*Dasypus septemcinctus*, *Didelphis albiventris*, *Speothos venaticus*, *Tamandua tetradactyla*, *Equus ferus*, and *Felis silvestris*), and seven species were unique to the ombrophilous forest (*Euphractus sexcinctus*, *Galictis cuja*, *Herpailurus yagouaroundi*, *Leopardus wiedii*, *Tayassu pecari*, *Bos taurus*, and *Equus africanus*). Nevertheless, considering all species in the assemblage and only the native species, the overall beta diversity corresponds practically to the turnover, while the nestedness is almost non-existent.

Relative abundance

The RAIs were different for the mammal species (H = 115.24, *d.f.* = 30, P=0.000), but the difference between the species did not suggest a strong effect (Epsilon-squared ε^2 = 0.16). Four species had the highest abundance indices, *Didelphis aurita* (RAI = 4.55 ± 7.66), *Cuniculus paca* (RAI = 2.35 ± 3.73), *Pecari tajacu* (RAI = 1.65 ± 7.1), *Eira barbara* (RAI = 1.65 ± 6.03) (Figure 6-a; Supplementary material 3). In contrast, the species with the lowest indices of abundance were *Speothos venaticus* (RAI = 0.04 ± 0.24) and *Galictis cuja* (RAI = 0.06 ± 1.19) (Figure 6-a; Supplementary material 3). Among the non-native species, *Canis familiaris* (RAI = 1.08 ± 2.55) had the highest relative abundance, while the *Sus scrofa* (RAI = 0.15 ± 0.56), and *Equus ferus* (RAI = 0.04 ± 0.18), *Equus africanus* (RAI = 0.04 ± 0.62), and *Bos taurus* (RAI = 0.06 ± 0.27), the lowest values (Figure 6-a; Supplementary material 3).

The relative abundance of species did not differ between the two vegetation sites (U = 453.5; Z = 0.37; P = 0.70). Additionally, only the specie *Leopardus wiedii* showed significant differences between forests (U = 84.5; P = 0.01) (Figure 6 - b). In the seasonal forest, the species *Didelphis aurita* (RAI = 4.70 ± 8.28), *Puma concolor* (RAI = 2.40 ± 7.55), and *Sylvilagus*

brasiliensis (*RAI* = 2.38 ± 8.91) had the highest abundance indices. In contrast, the species with the lowest indices of abundance were *Speothos venaticus* (*RAI* = 0.08 ± 0.03) and *Sus scrofa* (*RAI* = 0.08 ± 0.22) (Figure 6-b; Supplementary material 3). In the ombrophilous forest, the species *Didelphis aurita* (RAI = 4.28 ± 6.97), *Cuniculus paca* (*RAI* = 3.26 ± 5.3), and *Leopardus guttulus* (*RAI* = 2.23 ± 2.16) had the highest abundance indices. The species *Cabassous unicinctus* (*RAI* = 0.08 ± 0.22) and *Sapajus nigritus* (*RAI* = 0.08 ± 0.22) had the lowest indices of abundance (Figure 6-b; Supplementary material 3).

Distribution of species

The *naïve* occupancy in the study area did not reach totality for any mammal species (naïve < 1; detection rate, min = 0, max = 0.88). Therefore, most of the mammalian species presented a restricted occupancy to a few localities, and values lower than 50 % (Supplementary Material 3). The highest values were for the species *Eira barbara* (68 %), *Didelphis aurita* (55 %), *Cuniculus paca* (45 %), *Pecari tajacu* and *Puma concolor* (41 %), *Leopardus guttulus* and *Leopardus pardalis* (36 %). The species *Tayassu pecari*, *Tamandua tetradactyla*, and *Speothos venaticus* presented the lowest values (5 %). Regarding the exotics species, *Canis lupus familiaris* presented the highest naïve occupancy values (32 %), while *Sus scrofa* (9 %), *Bos taurus*, *Equus ferus*, *Equus africanus*, and *Felis silvestris* had the lowest values (5 %) (Supplementary Material 3).

In the seasonal forest, the naïve occupancy of the 24 mammal species ranged from 7 % to 57 %. The species with the highest values of naïve occupancy were *Eira barbara* (57 %), *Didelphis aurita* (50%), *Puma concolor*, and *Cuniculus paca* (43%) (Supplementary Material 3). In the ombrophilous forest, the naïve occupancy of the 25 mammal species ranged from 12 % to 88 %. The highest values were for *Eira barbara* (88 %), *Didelphis aurita*, *Pecari tajacu*, and *Leopardus guttulus* (62 %) (Supplementary Material 3).

Finally, we found a correlation of 75 % between the average RAI and naïve occupancy (r^2 = 0.75). The species *Didelphis aurita*, *Cuniculus paca*, *Pecari tajacu* and *Eira barbara* showed the high occupancy and RAIs (Figure 7; Supplementary Material 3).

<div align="center">Discussion</div>

A total of 32 mammalian species were recorder at Minas Gerais state, of which 9 species (35%) are threatened. This gamma diversity represented approximately 12 % of the terrestrial species of nonflying mammals recorded in the Brazilian Atlantic Forest (Figueiredo *et al*. 2021) and was very similar with the richness found in different localities of the Atlantic Forest, which varies from 17 to 39 species (Bogoni et al. 2016, 2017, 2018; Rios et al. 2021; Souza et al.

2019). Therefore, our results indicate the study area safeguarded a represented fraction of the original average richness of medium to large-sized in the Atlantic Forest, and that camera traps were a suitable method to record rare, uncommon, and cryptic species (Figuereido et al. 2021; Trolliet et al. 2014; Wearn et al. 2019) such as *Speothos venaticus*.

Contrary to expectations, we found no evidence for differences in alpha diversity and evenness profiles between forests. However, the order Carnivora was the richest order in both forest, which coincides with the results found in other works in the Atlantic Forest (Bogoni *et al*. 2018; Santos *et al*. 2016; Souza *et al*. 2019). This order presented the higher proportion of threatened species in Minas Gerais State (ICMBio 2018), which probably explains why we only recorded one larger mammal, the *Puma concolor*, who presented restricted naïve occupancy and low abundance. That are consequences of the high vulnerability of carnivores to local extinction in fragmented landscapes (Bogoni *et al*. 2018; Galetti *et. al*. 2021). 71.9 % of all mammal species recorded at Atlantic Forest weighed less than 10 kg (Bogoni *et al*. 2018) and mammal species such as *Panthera onca* and *Puma concolor* are absent from most landscapes, resulting advantageous for the mesocarnivores in the Atlantic Forest (Regolin *et al*. 2017). Therefore, our results reflect that species diversity is dominated by mesocarnivores (87 %), probably in agreement with the mesopredator release hypotheses (Crooks and Soulé 1999) and the record of *Puma concolor* is relevant to the Atlantic Forest of Minas Gerais because this mammal is a key species (Botelho *et al*. 2018) in the area.

We found most species presented distributions restricted to few landscapes (naïve < 0.5), and the majority had low relative abundances (RAI < 1). Thirty-five percent of the species in the area are on the List of Endangered Species of Fauna in Minas Gerais, which explains the values obtained. Additionally, in agreement with the elevated levels of defaunation present in the Atlantic Forest, proposed by Bogoni *et al*. (2016, 2018) and Rios *et al*. (2021), which correspond to more than 46% defaunation in our study area, according to Galetti *et al*. (2021). The observed beta-diversity could be due not only to differences between vegetation types but likely to a mixture of factors. Other factors could be influencing the results, like body size (Bogoni *et al*. 2017), activity areas (Botelho *et al*. 2018), and habitat loss and fragmentation (Püttker *et al*. 2020).

The most abundant species in the study area were *Didelphis aurita* and *Cuniculus paca*. However, our results differ from those of Souza *et al*. (2019), who finding the highest abundance for *Dasypus novemcinctus*, *Cerdocyon thous*, and *Procyon cancrivorous*. Therefore,

our results confirm that variation in species abundance and occupancy varied between landscapes, in agreement with Souza *et al*. (2019).

The only mammal species with the highest abundance indices and naïve occupancy in the seasonal and ombrophilous forest was *Didelphis aurita*. This didelphid presented strong plasticity in habitat, resource use, and higher matrix tolerance (Bogoni et *al.* 2016), which probably allows its presence in landscapes immersed in anthropized areas with agricultural matrices such as those in this study. Additionally, the images and characteristics of the animals did not allow us to identify them. We photographed the same individuals several times at some localities because the cameras were placed right in areas that covered their home range, consistent with the assertion that species with small ranges have a higher probability of detection (Santos *et al*. 2021). We did not observe differences in diversity, abundance, and evenness between forests, and the beta diversity is almost all turnover between forests. Therefore, must highlight the importance of conserving all native forest remnants, seasonal and ombrophilous, to ensure the persistence of specialist forest species (Ferreira *et al*. 2020), mainly of the rare and most threatened species, which are susceptible to local extinctions in the Atlantic Forest of Minas Gerais state.

Among the nonnative species, *Canis lupus familiaris* had mean abundance and restricted distribution (*RAI* = 1.8; 32 % naïve occupancy), and surprisingly, *Sus scrofa* had the lowest values (*RAI* = 0.15; 9 % naïve occupancy). This is one of the species with the greatest distribution in the Atlantic Forest. It continues to expand its distribution in the remnants of vegetation (Rosa *et al*. 2016, Galetti *et al*. 2021), and they continue to expand their range (Rosa *et al*. 2016, Galetti *et al*. 2021). Probably the wild boar does not yet extend its population to the areas we sampled, or we underestimated its abundance. They form large groups, so the probability of capturing all the individuals in a photograph is very low. Thus, we need planning management strategies to control their presence (De Assis Morais *et al*. 2020; Rosa *et al*. 2016) and not minimize their presence in the study area because this species increased disturbances to native fauna, predation, competition for resources, and transmission of diseases (Quintela *et al*. 2020). Thus, we need planning management strategies to control their presence (De Assis Morais *et al*. 2020; Rosa *et al*. 2016).

Our results reflect the rarity of most species in the Atlantic Forest and bring important information about medium and large-sized mammals' use of forests in the southeastern Atlantic Forest in Minas Gerais. In conclusion, it is necessary to know the alfa and beta diversity among the forest fragments in different landscapes, to design appropriate conservation

strategies for mammal species (Beselga 2010). Exists an urgent need for remaining large forest fragments and prioritizing restoration programs (de Matos et al. 2021; Ferreira et al. 2020; Rios et al. 2021) to conserve native forest remnants to ensure the persistence of forest species (Ferreira et al. 2020), improving the quality and complexity of the habitat of the native forest patches and the surrounding matrix (Regolin et al. 2020). Therefore, the conservation of both types of forests is essential to guarantee the presence of most mammal species in the area in the long term. We believe that prompt action may prevent more dramatic scenarios, as stated by Bogoni and collaborators (2016).

Acknowledgments

References

ABREU, E. F., *et al*. 2021-2. Lista de Mamíferos do Brasil. Dataset Open Access. Zenodo. Comitê de Taxonomia da Sociedade Brasileira de Mastozoologia (CT-BMz). https://doi.org/10.5281/zenodo.5802047.

DE ASSIS MORAIS, T., *et al*. 2020. The influence of population-control methods and seasonality on the activity pattern of wild boars (Sus scrofa) in high-altitude forests. Mammalian Biology 100:101–106.

DE BARROS, R. A., *et al*. 2021. The value of a small urban green area to the medium and large-sized mammals conservation. Research, Society and Development 10:e11710817043.

BECA, G, *et al*. 2017. High mammal species turnover in forest patches immersed in biofuel plantations. Biological Conservation 210:352–359.

BASELGA, A., 2010. Partitioning the turnover and nestedness components of beta diversity. Global Ecology and Biogeography 19:134-143.

BOGONI, J. A., *et al*. 2016. Landscape features lead to shifts in communities of medium- to large-bodied mammals in subtropical Atlantic Forest. Journal of Mammalogy 97:713–725.

BOGONI, J. A., *et al*. 2017. What would be the diversity patterns of medium- to large-bodied mammals if the fragmented Atlantic Forest was a large metacommunity? Biological Conservation 211: 85–94.

BOGONI, J. A., *et al*. 2018. Wish you were here: How defaunated is the Atlantic Forest biome of its medium- to large-bodied mammal fauna? PLOS ONE 13:e0204515.

BOGONI, J. A., C. A. PERES, AND K. M. FERRAZ. 2020. Extent, intensity and drivers of mammal defaunation: a continental-scale analysis across the Neotropics. Scientific Reports 10: 14750.

BOGONI, J. A., C. A. PERES, AND K. M. FERRAZ. 2020a. Effects of mammal defaunation on natural ecosystem services and human well being throughout the entire Neotropical realm. Ecosystem Services 45:101173.

BOTELHO, A. L. M., L. H. M. BORGES, AND B. MCFARLAND. 2018. Abundance and composition of the medium to large-sized mammals in a private area of a REDD+ project in Acre, Brazil. Biota Neotropica 18:e20170487.

BRANCALION, P. H., *et al*. 2016. A critical analysis of the Native Vegetation Protection Law of Brazil (2012): updates and ongoing initiatives. Natureza & Conservação 14:1-15.

BURNHAM, K. P., AND W. S. OVERTON. 1979. Robust estimation of population size when capture probabilities vary among animals. Ecology 60:927-936.

CAMPANILI, M., AND W. B. SCHÄFFER (eds.). 2010. Mata Atlântica: patrimônio nacional dos brasileiros. Ministério do Meio Ambiente. Secretaria de Biodiversidade e Florestas. Núcleo Mata Atlântica e Pampa. Brasília, D. F.

CHAO, A., C. H. CHIU, AND L. JOST. 2014. Unifying species diversity, phylogenetic diversity, functional diversity, and related similarity and differentiation measures through Hill Numbers. Annual Review of Ecology, Evolution, and Systematics 45:297–324.

CHAO, A., *et al*. 2020. Quantifying sample completeness and comparing diversities among assemblages. Ecological Research 35:292-314.

CONSERVATION INTERNATIONAL. 2018. Wild.ID 0.9.31. San Diego Supercomputer Center. U.S.A. TEAM - www.wildlifeinsights.org/team-network.

COOKE, R. S. C., F. EIGENBROD, AND A. E. BATES. 2019. Projected losses of global mammal and bird ecological strategies. Nature Communications 10:1-8.

CORRÊA, T. C. V., *et al*. 2021. Medium and large-sized mammals in Private Natural Heritage Reserves in the Quadrilátero Ferrífero of Minas Gerais, Brazil. Neotropical Biology and Conservation 16:383–396.

CROOKS, K. R., AND M.E. SOULÉ, 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400: 563–566.

FAHRIG, L., *et al*. 2019. Is habitat fragmentation bad for biodiversity? Biological Conservation 230:179–186.

FERREIRA, A. S., *et al.* 2020. Multi-scale mammal responses to agroforestry landscapes in the Brazilian Atlantic Forest: the conservation value of forest and traditional shade plantations. Agroforestry Systems 94:2331–2341.

FIGUEIREDO, M. D. S. L., *et al.* 2021. Tetrapod Diversity in the Atlantic Forest: Maps and Gaps. Pp. 185–204 in The Atlantic Forest (M.C.M. Marques and C.E.V. Grelle, eds.). Springer International Publishing, Cham.

GALETTI, M., *et al.* 2009. Priority areas for the conservation of Atlantic forest large mammals. Biological Conservation 142:1229-1241.

GALETTI, M., *et al.* 2021. Causes and Consequences of Large-Scale Defaunation in the Atlantic Forest. Pp. 297–324 in The Atlantic Forest (M.C.M. Marques and C.E.V. Grelle, eds.). Springer International Publishing, Cham.

HADDAD, N. M., *et al.* 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances 1:e1500052.

HSIEH, T. C., K. H. MA, AND A. CHAO. 2016. iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods in Ecology and Evolution 7: 1451-1456.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (eds.). 2012. Manual técnico da vegetação brasileira 2ª ed. Instituto Brasileiro de Geografia e Estatística-IBGE, Rio de Janeiro, Brasil.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE ICMBio (eds.). 2018. Livro Vermelho da Fauna Brasileira Ameaçada de Extinção. Brasilia, D. F., Brasil.

INTERNATIONAL UNION FOR CONSERVATION OF NATURE AND NATURAL RESOURCES. 2021. IUCN Red List categories. IUCN.

INVASIVE SPECIES SPECIALIST GROUP, ISSG. 2015. The Global Invasive Species Database.

KÉRY, M., AND J. A. ROYLE. 2015. Applied Hierarchical Modeling in Ecology: Analysis of Distribution, Abundance and Species Richness in R and BUGS.

KINDT, R., AND R. COE. 2005. Tree diversity analysis: a manual and software for common statistical methods for ecological and biodiversity studies. World Agroforestry Centre (ICRAF), Nairobi (Kenya).

LISTA DAS ESPÉCIES DA FAUNA AMEAÇADAS DE EXTINÇÃO NO ESTADO DE MINAS GERAIS. COPAM. 2010. Deliberação Normativa Conselho Estadual de Política Ambiental Nº 147. Diário do Executivo, Minas Gerais, Brasil.

MACKENZIE, D. I. AND W. L. KENDALL. 2002. How should detection probability be incorporated into estimates of relative abundance? Ecology 83:2387-2393.

MANDUJANO, S., AND L. A. PÉREZ-SOLANO. 2019. Fototrampeo en R: organización y análisis e datos. Instituto de Ecología AC, Xalapa, Veracruz, México.

DE MATOS, T. P. V., *et al*. 2021. Protected areas and forest fragmentation: sustainability index for prioritizing fragments for landscape restoration. Geology, Ecology, and Landscapes 5:19-31.

MYERS*, N., et al*. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

OLIVEIRA, R. F., A. R. DE MORAIS, AND L. C. TERRIBILE. 2020. Effects of landscape and patch attributes on the functional diversity of medium and large-sized mammals in the Brazilian Cerrado. Mammal Research 65:301-308.

OKSANEN, J., *et al*. 2013. Package 'vegan'. R Package. 254 pp.

PORFIRIO, G., *et al*. 2014. Medium to large size mammals of southern Serra do Amolar, Mato Grosso do Sul, Brazilian Pantanal. Check List 10(3): 473– 482.

PÜTTKER, T., *et al*. 2020. Indirect effects of habitat loss via habitat fragmentation: A cross-taxa analysis of forest-dependent species. Biological Conservation 241:108368.

QUINTELA, F. M., C. A. DA ROSA, AND A. FEIJÓ. 2020. Updated and annotated checklist of recent mammals from Brazil. Anais da Academia Brasileira de Ciências 92:e20191004.

R CORE TEAM 4.1.0. 2021. R: A language and environment for statistical computing. R for Statistical Computing, Vienna, Austria.

REGOLIN, A. L., *et al*. 2020. Spatial heterogeneity and habitat configuration overcome habitat composition influences on alpha and beta mammal diversity. Biotropica 52:969–980.

RIBEIRO, M. C., *et al*. 2009. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation 142:1141-1153.

ROVERO, F., AND D. SPITALE. 2016. Presence/absence and species inventory. Pp. 43-67 in Camera Trapping for Wildlife Research (F. Rovero and F. Zimmermann, eds.). Pelagic Publishing, U.K.

ROSA, C. A., *et al*. 2017. Alien terrestrial mammals in Brazil: current status and management. Biological Invasions 19:2101-2123.

SANTOS, K. K., G. S. M. PACHECO, AND M. PASSAMANI. 2016. Medium-sized and large mammals from Quedas do Rio Bonito Ecological Park, Minas Gerais, Brazil. Check List 12:1830.

SANTOS, F., *et al.* 2021. Site and species contribution to β-diversity in terrestrial mammal communities: Evidence from multiple Neotropical forest sites. Science of the Total Environment 789:147946.

DA SILVA, P. G., M. I. M. HERNÁNDEZ, AND J. HEINO. 2018. Disentangling the correlates of species and site contributions to beta diversity in dung beetle assemblages. Diversity and Distributions 24:1674-686.

Souza, Y., *et al.* 2019. Atlantic mammals: a data set of assemblages of medium- and large-sized mammals of the Atlantic Forest of South America. Ecology 100:e02785.

Srbek-Araujo, A. C., and A. G. Chiarello. 2005. Is camera-trapping an efficient method for surveying mammals in Neotropical forests? A case study in south-eastern Brazil. Journal of Tropical Ecology 21:121-125.

Steinbeiser, C. M., *et al*. 2019. Relative abundance and activity patterns explain method-related differences in mammalian species richness estimates. Journal of Mammalogy 100:192-201.

Tomczak, M., and Tomczak, E. 2014. The need to report effect size estimates revisited. An overview of some recommended measures of effect size. Trends in Sport Sciences, 1(21), 19–25.

Trolliet, F., *et al.* 2014. Use of camera traps for wildlife studies: a review. Biotechnologie, Agronomie, Société et Environnement 18:446–454.

Vilas Boas, A. H., *et al*. 2022. Survey of medium-and large-sized mammals in Atlantic Forest remnants of Conceição dos Ouros, Minas Gerais, Brazil. Biodiversity Data Journal 10:e82139.

Wearn, O.R., *et al*. 2017. Mammalian species abundance across a gradient of tropical land-use intensity: A hierarchical multi-species modelling approach. Biological Conservation 212:162 171.

Wearn, O. R., and P. Glover-Kapfer. 2019. Snap happy: camera traps are an effective sampling tool when compared with alternative methods. *Royal Society open science*, 6:181-748.

Whittaker, R. H. 1972. Evolution and measurement of species diversity. Taxon 21: 213–251.

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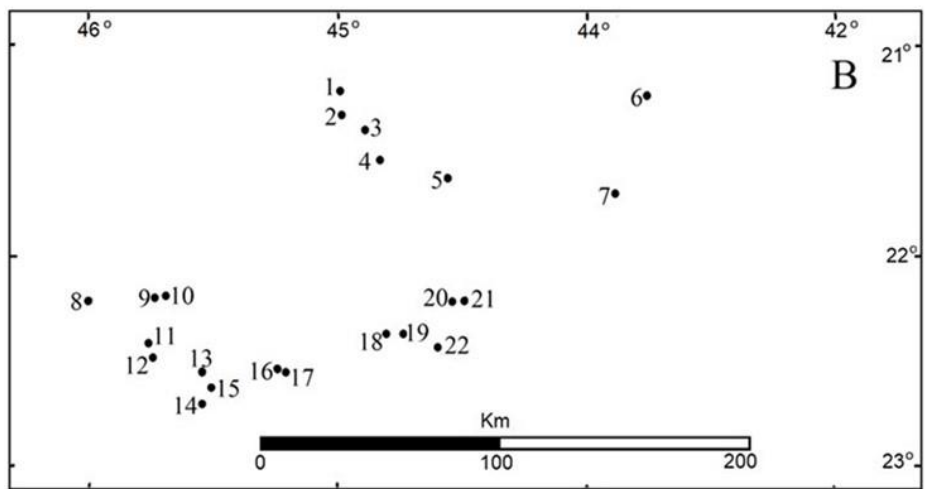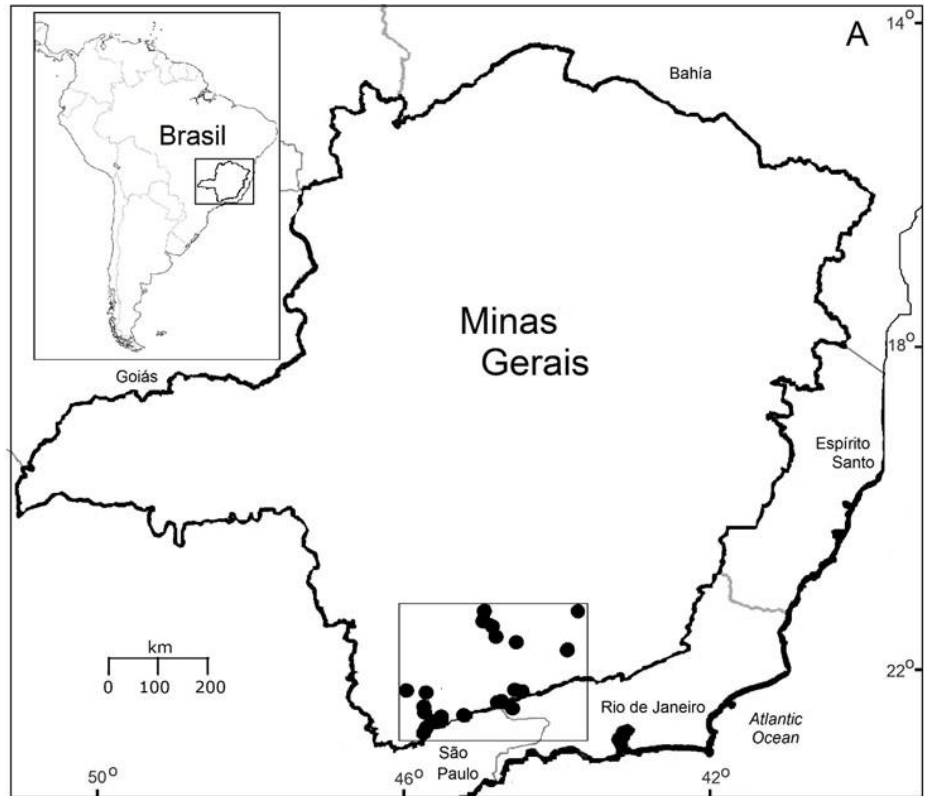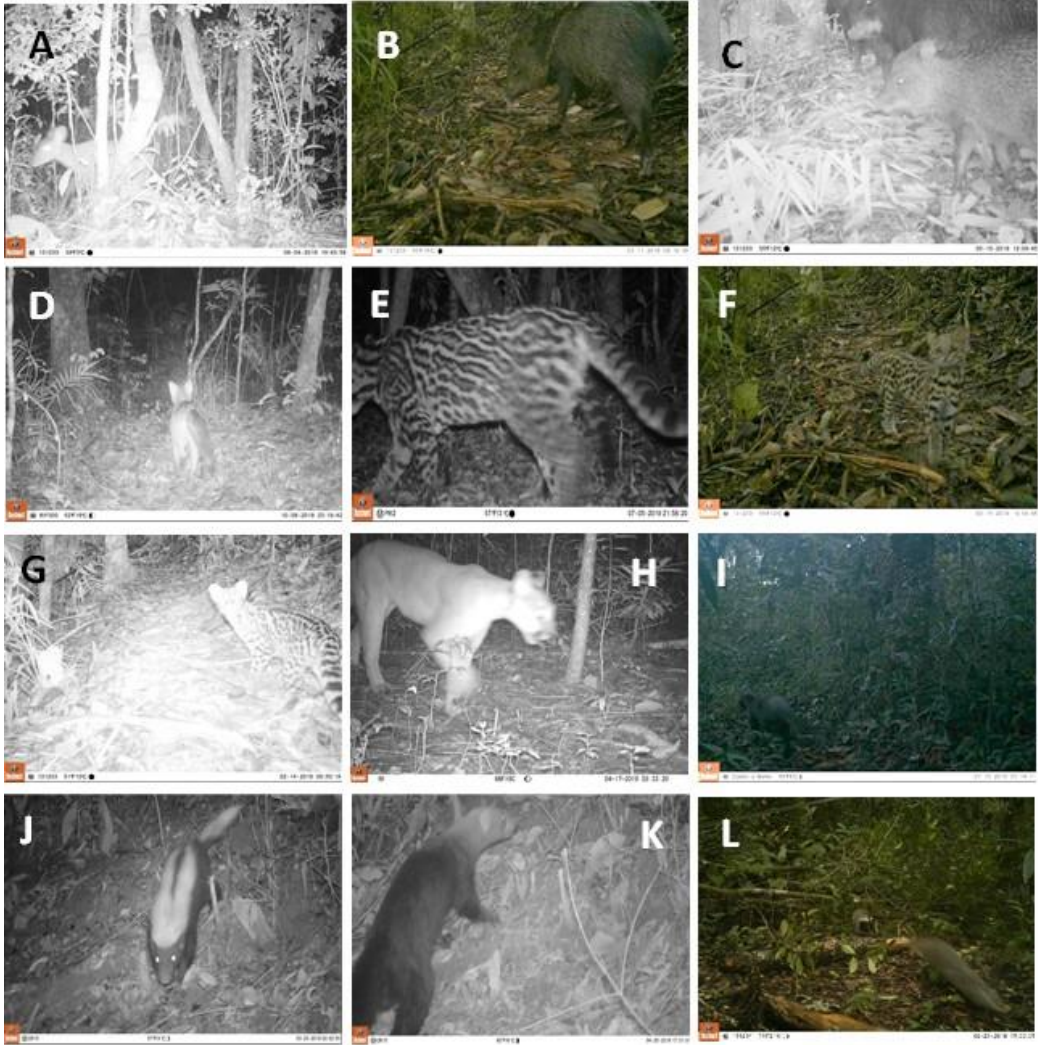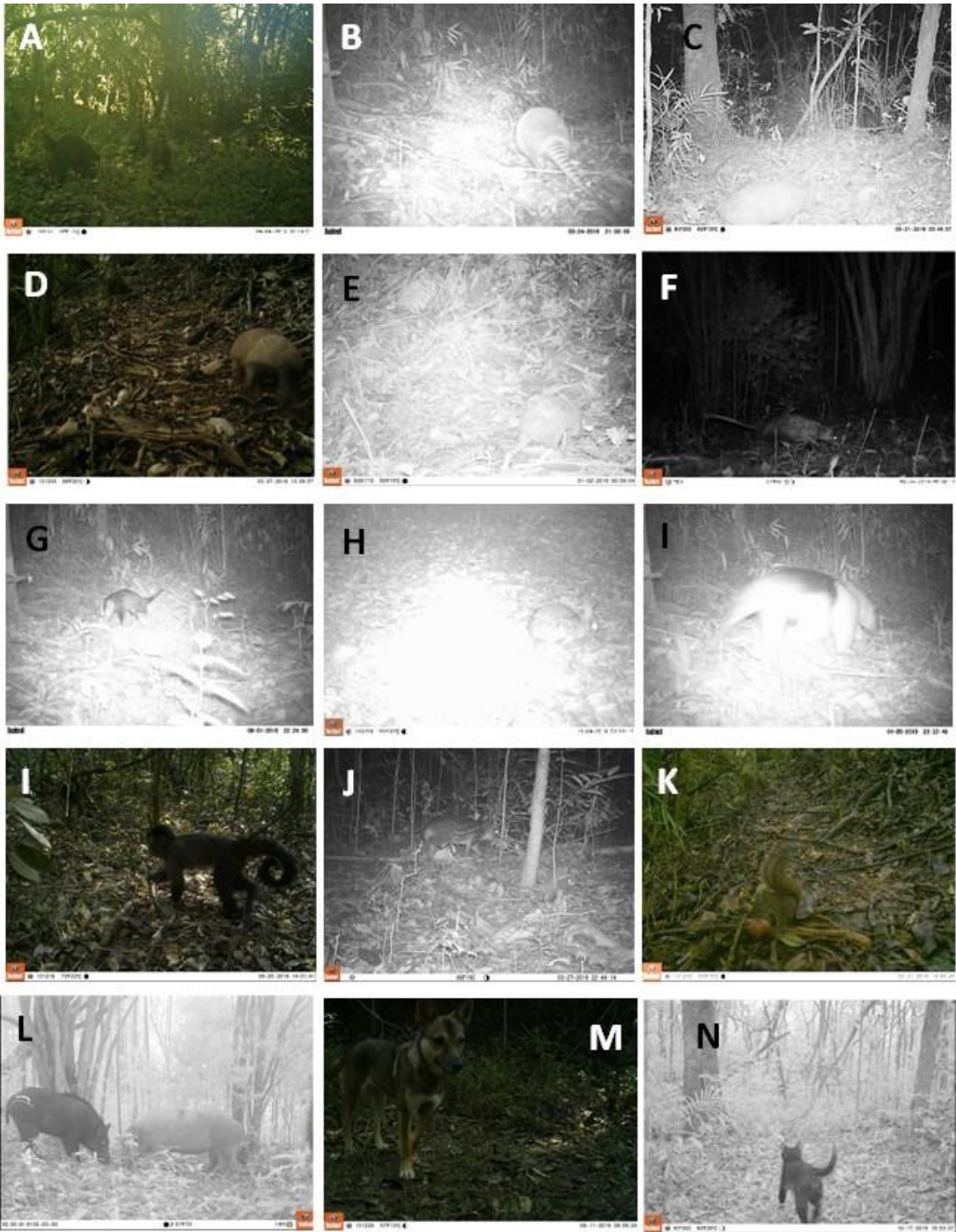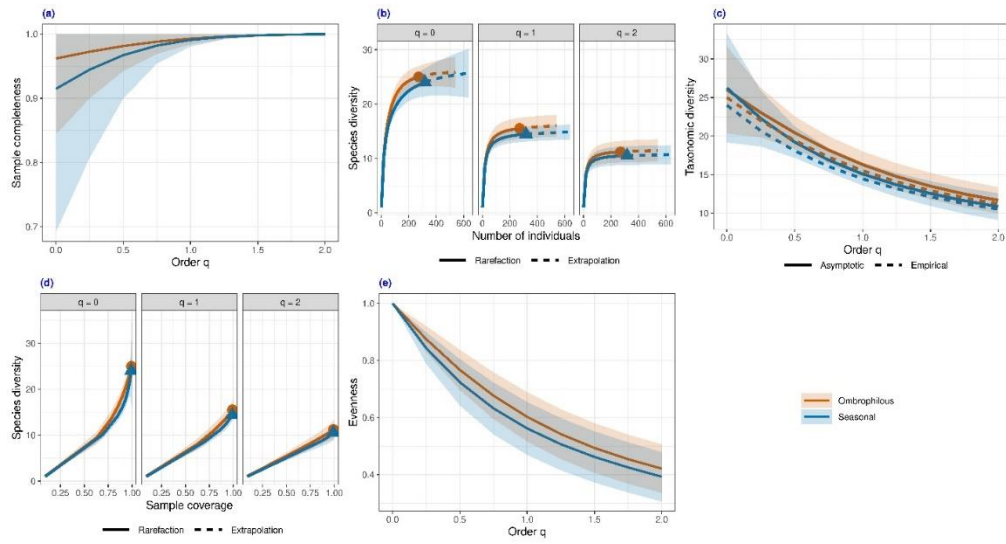
a) All mammal species

b) Native mammal species

Mammal assemblage (a)

Forest type (b)

Seasonal

Ombrophilous

$r^2 = 0.75$

D. aurita 1	*T. pecari* 17
C. paca 2	*C. semistriatus* 18
S. brasiliensis 3	*C. thous* 19
P. concolor 4	*C. unicinctus* 20
D. novemcinctus 5	*H. yagouaroundi* 21
E. barbara 6	*S. scrofa* 22
P. tajacu 7	*E. africanus* 23
L. guttulus 8	*E. sexcinctus* 24
C. l. familiaris 9	*D. septemcinctus* 25
S. aestuans 10	*F. silvestris* 26
L. pardalis 11	*T. tetradactyla* 27
D. albiventris 12	*B. taurus* 28
S. nigritus 13	*G. cuja* 29
Mazama sp 14	*E. ferus* 30
L. wiedii 15	*S. venaticus* 31
N. nasua 16	

Order	Family	Species	Common name	IUCN	ICMBIO	Minas Gerais COPAM	Species type
Artiodactyla	Bovidae	*Bos taurus*	Cattle	NA	NA	NA	Domestic
	Cervidae	*Mazama americana*	Red Brocket	DD	DD	NA	Native
		Mazama gouazoubira	Gray Brocket	LC	LC	NA	Native
	Suidae	*Sus scrofa*	Wild Boar	LC	NA	NA	Exotic
	Tayassuidae	*Pecari tajacu*	Collared Peccary	LC	LC	VU	Native
		Tayassu pecari	White-lipped Peccary	VU	VU	CR	Native
Carnivora	Canidae	*Canis lupus familiaris*	Domestic Dog	NA	NA	NA	Domestic
		Cerdocyon thous	Crab-eating Fox	LC	LC	NA	Native
		Speothos venaticus	Bush Dog	NT	VU	CR	Native
	Felidae	*Felis silvestris*	Domestic Cat	NA	NA	NA	Domestic
		Herpailurus yagouaroundi	Jaguarundi	LC	VU	NA	Native
		Leopardus guttulus	Northern Tiger Cat	VU	VU	VU	Native
		Leopardus pardalis	Ocelot	LC	LC	VU	Native
		Leopardus wiedii	Margay	NT	VU	EN	Native
		Puma concolor	Puma	LC	VU	VU	Native
	Mephitidae	*Conepatus semistriatus*	Striped Hog-nosed Skunk	LC	LC	NA	Native
	Mustelidae	*Eira barbara*	Tayra	LC	LC	NA	Native
		Galictis cuja	Lesser Grison	LC	LC	NA	Native
	Procyonidae	*Nasua nasua*	South American Coati	LC	LC	NA	Native
Cingulata	Dasypodidae	*Cabassous unicinctus*	Southern Naked-Tailed Armadillo	LC	LC	NA	Native
		Dasypus novemcinctus	Nine-Banded Armadillo	LC	LC	NA	Native
		Dasypus septemcinctus	Seven-Banded Armadillo	LC	LC	NA	Native
		Euphractus sexcinctus	Yellow Armadillo	LC	LC	NA	Native
Didelphimorphia	Didelphidae	*Didelphis albiventris*	White-eared Opossum	LC	LC	NA	Native
		Didelphis aurita	Brazilian Common Opossum	LC	LC	NA	Native
Lagomorphia	Leporidae	*Sylvilagus brasiliensis*	Tapeti	EN	LC	NA	Native
Perissodactyla	Equidae	*Equus asinus*	Asno	NA	NA	NA	Domestic
		Equus caballus	Hourse	NA	NA	NA	Domestic
Pilosa	Myrmecophagidae	*Tamandua tetradactyla*	Southern Tamandua	LC	LC	VU	Native
Primates	Cebidae	*Sapajus nigritus*	Black-horned Capuchin	NT	NT	EN	Native
Rodentia	Cuniculidae	*Cuniculus paca*	Agouti	LC	LC	NA	Native
	Sciuridae	*Sciurus aestuans*	Guianan Squirrel	LC	LC	NA	Native

Not apply (NA), Insufficient data-Know (DD), least concern (LC), vulnerable (VU), near threatened (NT), Endangered (EN) and critically endangered (CR).

Supplementary material 1.

Location and type of habitat in each of the landscapes in the Brazilian Atlantic Forest, in Minas Gerais (MG) and Rio de Janeiro (RJ).

Camera trap	Forest	Municipality	State	Latitude	Longitude	Altitude
1	Seasonal	Lavras	MG	-21,2289	-44,9719	951
2	Seasonal	Lavras	MG	-21,3319	-44,9855	1149
3	Seasonal	Ingai	MG	-21,4096	-44,8916	882
4	Seasonal	Luminárias	MG	-21,5488	-44,8304	1098
5	Seasonal	Minduri	MG	-21,6243	-44,5597	989
6	Seasonal	Barbacena	MG	-21,2394	-43,7533	1144
7	Seasonal	Lima Duarte	MG	-21,7072	-43,8846	1444
8	Seasonal	Pouso Alegre	MG	-22,2179	-45,9980	1046
9	Seasonal	Santa Rita do Sapucaí	MG	-22,2024	-45,7296	1040
10	Seasonal	Santa Rita do Sapucaí	MG	-22,1924	-45,6947	1014
11	Seasonal	Conceição dos Ouros	MG	-22,4137	-45,7658	1228
12	Seasonal	Conceição dos Ouros	MG	-22,4798	-45,7465	879
13	Seasonal	Piranguçu	MG	-22,5526	-45,5490	1078
14	Ombrophilous	Piranguçu	MG	-22,6145	-45,5482	1591
15	Ombrophilous	Piranguçu	MG	-22,5843	-45,5325	1614
16	Ombrophilous	Delfim Moreira	MG	-22,5350	-45,2427	1315
17	Ombrophilous	Delfim Moreira	MG	-22,5500	-45,2148	1368
18	Ombrophilous	Itamonte	MG	-22,3593	-44,8056	1560
19	Ombrophilous	Itamonte	MG	-22,3662	-44,7356	2081
20	Seasonal	Bocaina de Minas	MG	-22,2175	-44,5392	1257
21	Ombrophilous	Bocaina de Minas	MG	-22,2210	-44,4836	1383
22	Ombrophilous	Itatiaia	RJ	-22,4359	-44,6118	1070

Supplementary material 2.

Diversity of two forest in the Atlantic Forest in southeastern Minas Gerais, Brazil. Diversity of order 0 (q=0; species richness), diversity of order 1 (q=1; Shannon diversity), diversity of order 2 (q=2; Simpson diversity), and evenness among species abundances.

iNEXT 4 steps Summary

STEP 1. Sample completeness profiles

Assemblage	q = 0	q = 1	q = 2
Ombrophilous	0.96	0.99	1.00
Seasonal	0.91	0.99	1.00

STEP 2. Asymptotic analysis

Assemblage	Diversity	Observed	Estimator	S.E.	LCL	UCL
Ombrophilous	Species richness	25.00	26.00	2.91	25.00	31.70
Ombrophilous	Shannon diversity	15.52	16.30	0.94	14.46	18.14
Ombrophilous	Simpson diversity	11.23	11.67	0.91	9.89	13.45
Seasonal	Species richness	24.00	26.24	5.17	24.00	36.38
Seasonal	Shannon diversity	14.46	15.08	0.79	13.53	16.63
Seasonal	Simpson diversity	10.52	10.84	0.85	9.18	12.50

STEP 3. Non-asymptotic coverage-based rarefaction and extrapolation analysis

maxC = 0.998	q = 0	q = 1	q = 2
Ombrophilous	25.66	15.85	11.38
Seasonal	25.65	14.85	10.68

`STEP 4: Evenness among species abundances

Forest	Pielou J'	q = 1	q = 2
Ombrophilous	0.85	0.60	0.42
Seasonal	0.83	0.56	0.39

Notes

method = interpolated, observed, or extrapolated.
order = the diversity order of q (0,1,2).
qD = the estimated diversity of order q for a sample of size m.
SC = the estimated sample coverage for a sample of size m.
qD.LCL, qD.UCL = the bootstrap lower and upper confidence limits for the diversity of order q (value of 0.95).
SC.LCL, SC.UCL = the bootstrap lower and upper confidence limits for the expected sample coverage (value of 0.95).

Supplementary material 3.

Comparative Relative Abundance Index (average RAI) and naïve occupancy (NO) between mammals based on camera trap in the Atlantic Forest in southeastern Minas Gerais, Brazil. SD standard deviation. The sampling effort for the seasonal and ombrophilous forests was 1542 and 1314 days, respectively.

				Forest		
	Assemblage	Assemblage	Seasonal	Ombrophilous	Seasonal	Ombrophilous
Species	**RAIs ± SD**	**NO**	**RAIs ± SD**	**RAIs ± SD**	**NO**	**NO**
Equus ferus	0.04 ± 0.18	0.05	0.06 ± 0.22	0	0.07	0
Speothus venaticus	0.05 ± 0.24	0.05	0.08 ± 0.03	0	0.07	0
Felis silvestris	0.06 ± 0.19	0.05	0.16 ± 0.61	0	0.07	0
Bos taurus	0.06 ± 0.27	0.05	0	0.16 ± 0.45	0	0.12
Galictis cuja	0.10 ± 0.48	0.09	0	0.16 ± 0.29	0	0.25
Dasypus septemcinctus	0.10 ± 0.46	0.14	0.18 ± 0.37	0	0.21	0
Tamandua tetradactyla	0.11 ± 0.30	0.05	0.15 ± 0.58	0	0.07	0
Cabassous unicinctus	0.12 ± 0.39	0.14	0.24 ± 0.65	0.08 ± 0.22	0.14	0.12
Equus africanus	0.13 ± 0.62	0.05	0	0.36 ± 1.03	0	0.12
Euphractus sexcinctus	0.15 ± 0.56	0.09	0	0.33 ± 0.61	0	0.25
Sus scrofa	0.16 ± 0.63	0.09	0.06 ± 0.22	0.32 ± 0.9	0.07	0.12
Cerdocyon thous	0.18 ± 0.54	0.09	0.16 ± 0.61	0.26 ± 0.72	0.07	0.12
Herpailurus yagouaroundi	0.20 ± 0.64	0.09	0	0.44 ± 1.02	0	0.25
Conepatus semistriatus	0.28 ± 0.73	0.14	0.29 ± 0.77	0.25 ± 0.71	0.14	0.12
Sapajus nigritus	0.37 ± 1.74	0.27	0.76 ± 1.26	0.08 ± 0.22	0.36	0.12
Didelphis albiventris	0.41 ± 0.76	0.18	0.95 ± 1.88	0	0.29	0
Nasua nasua	0.44 ± 1.07	0.27	0.28 ± 0.57	0.65 ± 1.02	0.21	0.38
Tayassu pecari	0.47 ± 1.20	0.05	0	1.02 ± 2.88	0	0.12
Mazama sp	0.51 ± 1.05	0.23	0.36 ± 1.35	0.65 ± 0.95	0.07	0.50
Leopardus wiedii	0.6 ± 1.55	0.18	0	1.20 ± 1.54	0	0.50
Leopardus pardalis	0.81 ± 1.64	0.36	0.85 ± 1.83	0.73 ± 1.36	0.29	0.50
Sylvilagus brasiliensis	0.82 ± 2.43	0.09	2.38 ± 8.91	0.36 ± 1.03	0.07	0.12
Canis lupus familiaris	1.08 ± 2.55	0.32	1.46 ± 3.14	0.43 ± 0.62	0.29	0.38
Puma concolor	1.11 ± 1.74	0.41	2.40 ± 7.55	0.33 ± 0.49	0.43	0.38
Sciurus aestuans	1.16 ± 1.88	0.18	0.72 ± 2.41	0.98 ± 2.63	0.14	0.25
Leopardus guttulus	1.29 ± 1.31	0.36	0.47 ± 1.07	2.23 ± 2.16	0.21	0.62
Dasypus novemcinctus	1.47 ± 4.24	0.27	1.87 ± 5.11	0.76 ± 2.16	0.36	0.12
Eira barbara	1.65 ± 6.03	0.68	1.08 ± 1.41	1.65 ± 1.13	0.57	0.88
Pecari tajacu	1.65 ± 7.10	0.41	0.81 ± 1.54	1.76 ± 2.36	0.29	0.62
Cuniculus paca	2.35 ± 3.73	0.45	1.83 ± 2.57	3.26 ± 5.3	0.43	0.50
Didelphis aurita	4.55 ± 7.66	0.55	4.70 ± 8.28	4.28 ± 6.97	0.50	0.62

ARTICLE 2

Effect of habitat loss and landscape fragmentation on the native, specialist, generalist, and exotic mammalian communities in the southeastern Atlantic Forest of Minas Gerais

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Abstract

The fragmented Brazilian Atlantic Forest is an ideal study system to understand the impacts of habitat loss and fragmentation, habitat amount, and connectivity in richness of the mammal communities and the beta diversity. We propose 1) Evaluate how the amount of habitat and the size of the core area of vegetation present in different fragments of the Atlantic Forest determine the richness of native, specialists, generalists, and exotic species, performing a multiscale analysis. 2) Evaluate the influence of habitat amount, path size, area of focal fragment, structural connectivity, and functional area on the richness of the mammal species, native, specialist, generalist and exotic and 3) Perform a beta diversity analysis to know the turnover and homogenization between communities in the Atlantic Forest. We conducted our study in 22 landscapes located in the southern Brazilian Atlantic Forest in 15 municipalities with native forest. We surveyed medium- and large-sized mammals (≥1 kg) in each landscape with one camera trap at each sampling point between January 2019 to March 2020. With the sampling effort of 3096 effective camera traps/day, we identified 33 mammal species, belonging to 25 genera, nine orders, and 17 families. Of the species recorded, most are native to the Atlantic Forest (82%), the rest not native (18%). The applied multi-model inference by Akaike information criterion (AICc), applied to complete models built as: richness mammal on native, specialist, generalist, or exotic mammal ~ patch size + area of the focal fragment + structural connectivity + functional connectivity + habitat amount – best scale + core area – best scale. Based on these results, the occurrence the species in the groups of mammals presented differences. Only specialist species respond positively to the amount of habitat and the core area at the scale of 3000 m, and the exotic species negatively at the scale 1000 m. Finally, the group of generalist and native species did not respond to the amount of habitat and percentage of the core area. We found that each group of mammals responds differently to the landscape metrics. For native and specialist species, with a positive effect, the functional connectivity. Indicating a possible minimum critical functional connectivity threshold to ensure their occurrence. It is important to mention that when combining the metrics, when averaging the models, the specialist species showed a significant influence of functional connectivity, corroborating that the effect of the amount of habitat in specialist mammals does not fulfill only the species-area hypothesis. Additionally, we found a high beta diversity and highlighting the homogenization of species existing in the sampled areas. The total beta diversity between sites (100 randomizations) (β SOR) was 0.90±0, species substitution (turnover β STU) was 0.85±0 and, species nesting (β SNE) was 0.04±0. This is confirmed because most of the species recorded in the area presented distributions restricted to few landscapes, low relative abundances, or locally extinctions, probably by the habitat fragmentation, presence of geographical barriers and changes in environmental conditions. Therefore, we found that only the specialist species responds positively to functional connectivity and to detect the effect we need considering species groups, like native, specialist, generalist, and exotic species. These results highlight the importance of promoting functional connectivity between forest fragments and increasing the -stepping stones- to favor the conservation of the mammalian species and reduce the extinction of specialist species in the Brazilian Atlantic Forest of Minas Gerais.

Keywords: camera trapping, fragmentation, habitat loss, mammal communities, multi-model inference, species richness

Introduction

Changes in landscape configuration and habitat loss are the leading causes of biodiversity loss worldwide (Fahrig et al., 2019), influence the species richness (Norris et al., 2010; Maseko et al., 2016), and have a pernicious impact on the survival of species (Fahrig, 2003). Therefore, to monitor and conserve biodiversity, it is crucial the scientists and resource managers must assess changes in species composition in response to anthropogenic impacts (Devarajan et al., 2020). However, although land use change is the root cause of the extinction crisis, the links between habitat change and biodiversity loss are not yet fully understood (Semper-Pascual et al., 2021). Even when there is evidence that habitat loss is an essential driver of extinction, the impact of habitat fragmentation remains debatable (Fahrig 2017; Fahrig et al., 2019; Fletcher 2018; Semper-Pascual et al., 2021; Teixido et al*.,* 2020) and their consequences for the functioning and resilience of ecosystems are still largely unknown (Sitters et al., 2016). Moreover, although predicting and managing ecological patterns and processes of animal communities in fragmented landscapes is crucial, standardized and large-scale analyses are still lacking (Püttker et al., 2020).

From a landscape perspective, four possible hypotheses can explain the structure and dynamics of a community and shape diversity characteristics: (1) the size of the focal patch (Patch Area Hypothesis) (Fahrig, 2013); (2) the amount of focal habitat in a landscape (Habitat Amount Hypothesis) (Fahrig, 2013; Martin, 2018); (3) the amount of focal habitat in a landscape and the configuration of habitat patches (Habitat Configuration Hypothesis) (Villard & Metzger, 2014); and finally, (4) composition and configuration, where more heterogeneous landscapes support greater species diversity (Multi-Habitat Hypothesis) (Presley et al., 2019). For some authors, the reduction in connectivity (Fahrig, 2003) and the edge effect (Santos & Telleria, 2006) are decisive. However, landscape metrics such as edge effects and connectivity have received little attention in the Atlantic Forest (Teixido et al., 2020). Therefore, it is premature and risky to dismiss habitat fragmentation as a significant force driving species extinction in tropical forest landscapes (Püttker et al., 2020).

Variations in the fragmentation level, habitat amount, and connectivity, modify the mammal community composition (Palmerin et al., 2018) and the beta diversity values (Wearn et al., 2016). However, this changes across fragmented landscapes remains poorly understood (Palmerin et al., 2018). Consequently, we must increase our efforts to clarify these information gaps (Ehlers et al., 2020; Palmerin et al., 2018; Regolin et al., 2020; Socolar et al., 2015) promoting studies multiscale, necessary to understand the dynamics of communities (Presley et al., 2019), and the degree of homogenization among mammal communities (Palmerin et al., 2018).

The Brazilian Atlantic Forest is an ideal study system to understand the impacts of habitat loss and fragmentation in natural areas (Ribeiro et al., 2009). The remnants of the Atlantic Forest are isolated, which affects the number of species that can survive within the fragments (Beca et al., 2017). The combined effects of these factors result in high levels of defaunation throughout the Atlantic Forest (Galetti et al., 2016), particularly the loss of large vertebrates, which have implications for forest composition and ecological cascades (Beca et al., 2017).

Our main goal was to examine spatial patterns on the mammalian richness, particularly (a) evaluate through a multiscale analysis the effect of the habitat amount and core areas in the mammalian richness in native, specialists, generalists, and exotic species; (b) determine how the habitat amounts, core areas, patch size, area of the focal fragment, structural connectivity, and functional area, determine the richness of native, specialists, generalists and exotic species; and (c) know what is the turnover and homogenization of mammal species between sites, establishing the mammals beta-diversity. We expect to observe negative impacts of habitat loss and fragmentation on the richness of native and specialist mammal species. Furthermore, we anticipate a neutral effect on the generalist and exotic species. Lastly, we expect low species turnover and high homogenization among landscapes.

Materials and Methods

Mammal sampling

We conducted our study in 28 landscapes located in the southern Brazilian Atlantic Forest, in 15 municipalities of Minas Gerais and one of Rio de Janeiro (46°0'W 43°0'W; 23°0'S 21°0'S) (Figure 1; Supplementary material 1) covering an area of 22,014 km^2 approximately. The selection of landscapes was based on satellite images provided by the Google Earth Pro software and on updated maps of the remaining forest fragments made available by the SOS Atlantic Forest Institute (2013/2014), having as selection criteria, a priori, the presence of native forest, and a distance between landscapes greater than 2.85 km (Figure 1; Supplementary material 1s).

Each landscape corresponds to fragments of closed-canopy native forest, surrounded by agricultural or urban matrices, with no recorded occurrence of fire and/or logging. The landscapes presented elevations ranging from 887 m to 2,087 m a.s.l. The lower elevations are predominantly humid temperate sites with dry winters and hot summers (Cwa type), while the mountainous areas have dry winters and rainy and moderately hot summers (Cwb type) (Instituto Brasileiro de Geografia e Estatística IBGE, 2012).

Regarding mammalian sampling, we surveyed medium- and large-sized mammals (≥1 kg) using a single sampling station in each landscape with one camera trap at each sampling

point (Bushnell® HD Bushnell Outdoor Products, California, USA). At different times between January 2019 to March 2020, the camera trap stations operated continuously 24 hours per day for an average of 4.3 months in each landscape. We recorded the occurrence of all mammal species considered as independent records of the photographs with a minimum of a 24-hour interval. The traps were placed 20 cm above the ground and operated for 24 hours daily.

The sampling effort was 3096 effective camera traps/day, and 589 independent camera trap events, were organized using the Wild.ID Program 0.9.31 (Conservation International, 2018). We identified the species at the lowest taxonomic level possible, grouping the records of *Mazama americana* and *Mazama gouazoubira*, as *Mazama* sp., due to the difficulty of differentiating both species. We got 21.000 photographs and identified 3567 records of medium and large-sized mammals (≥1 kg of body weight).

Classification of the different groups of mammals

Mammal species found in the area were classified based on the literature (IUCN 2016; Olivieira 2020, Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) into the following groups: (1) native species - SpNat ~ includes all species present in the assemblage of Atlantic Forest mammals in each landscape; (2) habitat specialist mammals – SpEs ~ considering natural forest-dependent species; (3) non-habitat-specialist mammals – SpNEs ~ included generalist or tolerant species to anthropic activities and, finally, (4) exotic mammals – SpEx ~ considering exotic and domestic species in the Atlantic Forest (Table 1).

Mammalian richness

We conducted descriptive analyses of mammal community richness using the TEAM library program 1.7.R for Windows (Rovero and Spitale 2016). To evaluate the effectiveness of the sampling method, we included all the native species and generated a sample-based rarefaction with a 95 % confidence interval using the non-parametric richness estimator Jackknife 1 with the Biodiversity R package (Kindt and Coe 2005). We chose this estimator because it is one of the most precise techniques to reduce the bias of the estimated values (Moreno et al. 2001).

We obtained the gamma diversity and compare the mammalian richness between fragments with the R package iNEXT. 4 steps (https://chao.shinyapps.io/iNEXT_4steps) we compute the rarefaction, interpolation, and extrapolation curves based on abundance data (Chao et al., 2020). We employed 100 bootstraps and 95% confidence interval. We used the mammal richness exclusively of the landscapes whose sample coverage was greater than 80 %. Therefore, the final analysis included 22 landscapes (Figure 1; Supplementary Material 2s).

Landscape selection and metrics

The landscape metrics were provided by the Laboratory of Spatial Ecology and Conservation (LEEC) at UNESP Rio Claro, São Paulo, Brazil (Supplementary material 1s). They are 1. Patch size (Patch_Area): Corresponds to each clump of vegetation. 2. Area of the focal fragment (Area_f): This is equivalent to the patch size but discards corridors of vegetation and the structural connectivity through corridors and branches. 3. Structural connectivity (CoEs): This represents how much vegetation is structurally connected to a patch. 4. Functional connectivity (Con_fun): It is a functionally connected area. 5. Habitat amount (HA), and 6. Core area (CA): Proportion of habitat present in each area considering three buffer sizes, 1000 m, 2000 m, and 3000 m, to evaluate the effect of metrics through a multi-scale analysis around the centroids of each sampled landscape (Supplementary Material 1s).

Effect of landscape variables on mammalian species richness

Generalized Linear Models (GLMs) were used to analyze the data (Porras et al., 2016; Loureiro et al., 2020; Maseko et al., 2020; Püttker *et al*., 2020). The residual showed a Poisson distribution therefore the "log" link function was used (m=glm (y ~ x...., family = Poisson, data).

Multimodel inference by Akaike information criterion (AIC)

The Akaike's Information Criterion (AIC) (Akaike, 1987; Norris et al., 2010; Linley et al., 2020) corrected for small samples (AICc) was used to find the most parsimonious model. We calculate the AICc Delta values (Δ AICc) and the weight of each model (wAICc) (Anderson and Burnham, 2004) with the Tools for General Maximum Likelihood Estimation package (Ben Bolker, 2021).

We compared three simple models non-nested, for each group of mammals. We created one model for each buffer, with the aim of evaluating the effect of landscape metrics through a multi-scale analysis. Additionally, we obtained a summary of the coefficients for each model about the habitat amount and core areas, with and without null model. Afterward, we selected the best buffer and used it to build the full models in order to assess the effect of landscape metrics on the richness of each group of mammals.

We adjusted a complete model for each group as follows Richness mammal on native specialist, generalist, or exotic mammal ~ patch size + area of the focal fragment + structural connectivity + functional connectivity + habitat amount – best scale + core area – best scale. In addition, we include the null model, which represents the absence of effect, in the list of competing models. For model simplification, we use the collinearity of the variables in the regression models, with the Variance Inflation Factor (VIF) considering a VIF<3 as satisfactory (Gross, 2003).

The models that were considered most parsimonious were those with values with Δ

AICc < 2 (Anderson & Burnham 2004). Then, we average the models using the full and subset (conditional) methods. Subsequently, we calculated the goodness-of-fit measures of the best-valued model(s) for each response variable and performed model(s) diagnoses. Subsequently, we calculated the goodness-of-fit measures of the best-valued model(s) for each response variable and performed model(s) diagnoses. To generate and compare the final GLMs, we used the MuMIn (Bartoń 2019), Tidyverse (Wickham 2019), Caret (Kuhn and Johnson 2013), and Broom (Robinson and Hayes 2020) libraries. Finally, we graph the best models and the coefficients using the MuMIn, Data.table, and Effects libraries.

Results

1. *Mammalian Richness*

The specific richness of medium and large mammals was 33 species, belonging to 25 genera, nine orders, and 17 families. The Orders Carnivora and Artiodactyla were the most represented, with five and four families, respectively. The Order Rodentia was represented by two families, while Cingulata, Didelfimorphia, Lagomorpha, Perissodactyla, Pilosa, and Primates were represented by only one family each. Of the total species, 82% were native to the Atlantic Forest, while the remaining species were non-native (Figure 2; Table 1).

Among the species recorded, *Sylvilagus brasiliensis* is threatened (EN), *Leopardus wiedii* is near threatened (NT), *Sapajus nigritus*, *Leopardus guttulus*, and *Tayassu pecar*i are considered vulnerable (VU), the rest of the species are considered of least concern (LC), based on the IUCN List of Endangered Species (Soto-Werschitz et al. 2023). The data records for *Mazama americana* and *Mazama gouazoubira* were excluded from the analysis because it was difficult to differentiate between landscapes. The species accumulation curve approached the asymptote (30 ± 0). However, according to Jackknife 1 analysis, the estimated species richness for the study area was 35 ± 2 species. Therefore, we found 94 % of the estimated species in the area.

2. *Multiscale analysis*

Each group of mammals presented particularities about the best models (Table 2; Supplementary Material 3s). Without the null model, the native and specialist species, presented a positive effect on mammal richness using the analysis scale with a buffer of 3000 m, as habitat and core area percentages increased (Table 2a; Figure 3; Supplementary Material 3s). Unlike the generalist and exotic species, showed a negative effect when the analysis scale decreased at 1000 m (Table 2a; Figure 3; Supplementary Material 3s). We did not identify any issues with the residuals of the constructed models in any of the groups (Supplementary Material 4s).

However, included the null model, only the specialist species presented a positive effect on mammal richness positively related to the amount of habitat and percentage of the core area,

while the exotic species respond negatively at 1000 m (Table 2b; Figure 3; Supplementary Material 3s). Finally, the group of generalist and native species did not respond to the amount of habitat and percentage of the core area to any scale (Table 2b; Figure 3; Supplementary Material 3s) because in these two cases, the best model was the null. We did not identify any issues with the residuals of the constructed models in any of the groups (Supplementary Material 4s).

 3. Effect of landscape characteristics on species richness

The Best Models suggest that the variables with the most significant impact on species richness for each group are as follows: 1) Native and specialist species are primarily affected by functional connectivity; 2) The richness of generalist species is linked to a null model, therefore their richness is not significantly affected by any of the variables analyzed; and 3) the richness of exotic species are negatively impacted by the amount of habitat at a 1000 m scale (Table 3; Supplementary material 5s). We found that functional connectivity has a positive effect on the mammal richness of native and specialist species, while a negative effect for the exotic species on the smallest scale (Figure 4; Supplementary material 6s).

We analyzed the models in each group and observe that are other parsimonious models with the delta value with a $\Delta < 2$, therefore, we calculate the Average Models for each group. The most parsimonious models are for the 1) Native species $\sim$ functional connectivity (P = 0.05) + patch area (P = 0.07); 2) Specialist species $\sim$ functional connectivity (P = 0.03) + habitat amount 3000 m (P = 0.05) + patch Area (P = 0.06); 3) Generalist species $\sim$ model null + habitat amount 1000 m (P = 0.1) + core area 1000 m (P = 0.2), and in this last group, 4) Exotic species only one variable influenced the species richness, habitat amount 1000 m (Table 4; Supplementary material 6s). Therefore, the Full Average Model did not show significant values for any mammal group, and in the Conditional Models we only observed significant differences in the case of functional connectivity, for the specialist species groups (Table 4). No problems were detected in the residuals of the built models in any of the groups (Supplementary Material 7s).

4. Beta-Diversity

The beta diversity between the landscape communities (comparison pair by pair) showed a high beta diversity, highlighting the homogenization of species across the sampled areas. The total beta diversity between sites was 0.90±0 (β SOR), the species substitution was 0.85±0 (turnover β STU) and, the species nesting was 0.04±0 (β SNE) (Figure 5).

Discussion

The gamma diversity in this study indicates that according to the first-order jackknife, the overall sampling effort was sufficient to represent the community of medium and large

terrestrial mammals in the study area (94%). Therefore, the gamma diversity in this study was remarkably like other studies, indicating that the sampling was adequate to represent the community of medium and large terrestrial mammals in the Atlantic Forest of Minas Gerais (Bogoni et al., 2016, 2017, 2018; Rios et al., 2021; Souza et al., 2019).

The alfa diversity indicates that each landscape presents a different subset of medium and high sized mammals, although the Atlantic Forest regionally retains a set of representative species on the ecosystem. The defaunation of forest mammals is severe and is occurring in most forest fragments in the Atlantic Forest that we have studied, as it happens in other areas of the Atlantic Forest (Rios et al., 2021). The number of species between landscapes varied between two and 14, confirm the most species recorded in the area presented restricted distributions to few landscapes and low relative abundances (Soto-Werschitz et al., 2023). We found high beta diversity between landscapes, characterized by a high turnover and extremely low homogenization of species. Probably likely a consequence of habitat loss and fragmentation, the anthropogenic conditions and other factors that increase the species dispersion and probability of both the gain and loss of mammal species between landscapes (Bogoni et al., 2017). Therefore, analyzing gamma diversity does not allow us to perceive the true extent of biodiversity loss and fragmentation, then we need analyzed the alfa and beta diversity too, to create effective species conservation strategies.

The mammal richness in the area reflects that species diversity is dominant by mesocarnivores and generalist species (Soto-Werschitz et al., 2023) reinforcing that habitat loss and fragmentation are principal drivers of local extinction of large sized mammals (Fahrig, 2003; Semper-Pascual et al., 2021). Our results indicate that fragmented landscapes in the southeastern of Minas Gerais, retained an impoverished subset of the original assemblage of medium to large sized mammals, but regionally safeguarded a regional mammal fauna. Overall, these findings underscore the urgent need for conservation efforts that address the root causes of habitat loss and fragmentation to preserve the remaining biodiversity in the region.

Our multiscale analysis showed that performing this type of analysis allows us to find thresholds on species richness groups. The native species presented a positive influence of the percentage of habitat on the richness, but the value is not significant. Obviously, this is because the response to the effect of specialist species is masked. When analyzing the groups of mammals separately, only the specialist responded positively to the habitat amount hypothesis, and significantly at scale of 3000 m. On the contrary, the increase in the habitat amount had a negative impacted on the generalist and exotic richness, but only was significant to exotic species at the scale of 1000 m, indicating a possible minimum critical habitat amount threshold to ensure their occurrence. The exotic species showed only the structural connectivity have a

positive effect on its richness, but the value was not significant. Therefore, only the specialist species respond to the habitat amount hypothesis. This result confirms the report by Chiarello (1999) and Pardini et al., (2010), who uncovered a plausible effect of forest cover on specialist's species.

We found that each group of mammals responds differently to the landscape metrics too. The best model for native and specialist species, with a positive effect, was functional connectivity. Both groups of species appear to be using connectivity to move between different forest patches, and probably increment in generalist species the possibility to traverse different matrices. Therefore, they were more sensitive to the effect of fragmentation than to the habitat amount, path size, area of the focal fragment, structural connectivity, or functional area.

It is important to mention that when combining the metrics, and when averaging the models, the specialist species showed a significant influence of functional connectivity, corroborating that the effect of the amount of habitat in specialist mammals is more important that the species-area hypothesis. Therefore, to favor conservation strategies for specialist and generalist mammal species, we need to increase connectivity between forest remnants through of ecological corridors and stepping-stones along the Atlantic Forest that help maintains the functional landscape connectivity.

The overall direction of our results may contribute to better understanding medium- to large-bodied mammal diversity patterns and variations in the landscapes of the Atlantic Forest. We reinforce that negative habitat fragmentation in the specialist species richness, in disagreement with Faring who affirmed that the effects of habitat fragmentation are predominantly positive (Fahrig, 2017, 2019) but matches with Püttker et al. (2020), Fletcher Jr. et al. (2018). Finally, our findings have important implications for research and conservation for mammals in fragmented landscapes to high scale in the Atlantic Forest of Minas Gerais.

Acknowledgments

References

AKAIKE, H. (1987). Factor analysis and AIC. In Selected papers of hirotugu akaike (pp. 371-386). Springer, New York, NY.

ANDERSON, D., & BURNHAM, K. 2004. Model selection and multi-model inference. Second. NY: Springer-Verlag, 63 (2020), 10.

BECA, G., et al., 2017. High mammal species turnover in forest patches immersed in biofuel plantations. Biological Conservation 210 (2017) 352–359.

BASELGA, A. ORME, C.D.L. 2012. Betapart: An R package for the study of beta diversity. Methods Ecology and Evolution 3, 808–812.

BOGONI, J.A., et al. 2017. What would be the diversity patterns of medium- to large-bodied mammals if the fragmented Atlantic Forest was a large metacommunity? Biological Conservation 211, 85–94.

BOLKER, B. 2014. Maximum likelihood estimation and analysis with the Bbmle package. R package version, 1, 17.

CHAO, A., et al. 2020. Quantifying sample completeness and comparing diversities among assemblages. Ecological Research 35(2), 292-314.

CHIARELLO, A.G., 1999. Effects of fragmentation of the Atlantic Forest on mammal communities in south-eastern Brazil. Biol. Conservation 89, 71–82.

CONSERVATION INTERNATIONAL. 2018. Wild.ID 0.9.31. San Diego Supercomputer Center. U.S.A.

Deverajan K., T. L. Morelli & S. Tenan. 2020. Multispecies occupancy models: review, roadmap, and recommendations. Ecography 43:1-13.

EHLERS SMITH, Y.C., Ehlers Smith, D.A., Ramesh, T., Downs, C.T., 2017. The importance of microhabitat structure in maintaining forest mammal diversity in a mixed land-use mosaic. Biodiversity and Conservation 26:2361–2382.

FAHRIG, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution and Systematics 34: 487-515.

FAHRIG, L. 2013. Rethinking patch size and isolation effects: the habitat amount hypothesis. Journal of Biogeography 40:1649–1663.

FAHRIG, L. 2017. Ecological Responses to Habitat Fragmentation Per Se. Annual Review of Ecology, Evolution, and Systematics 48:1–23.

FAHRIG, L. Arroyo-Rodríguez, V. Bennett, J.R. et al., 2019. Is habitat fragmentation bad for biodiversity? Biological Conservation 230, 179–186.

FLETCHER, R. J. R. K. DIDHAM, C. B. LEITED, et al. 2018. Is habitat fragmentation good for biodiversity? Biological Conservation 226:9-15.

GALETTI, M, H. CAMARGO, T. SIQUEIRA, A. KEUROGHLIAN et al. 2015. Diet Overlap and Foraging Activity between Feral Pigs and Native Peccaries in the Pantanal. PLoS ONE 10(11): e0141459.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (eds.). 2012. Manual técnico da vegetação brasileira 2a edição revista e ampliada. Instituto Brasileiro de Geografia e Estatística-IBGE, Rio de Janeiro, Brasil.

KINDT, R., AND COE, R. 2005. Tree diversity analysis: a manual and software for common statistical methods for ecological and biodiversity studies. World Agroforestry Centre (ICRAF), Nairobi (Kenya).

MASEKO, M. S., et. al. 2020. Effects of habitat-patch size and patch isolation on the diversity of forest birds in the urban-forest mosaic of Durban, South Africa. Urban Ecosystems, 23(3), 533-542.

MORENO, C. E. 2001. Métodos para medir la biodiversidad. M&T–Manuales y Tesis SEA, vol. 1. Zaragoza, 84 pp.

NORRIS D. F. MICHALSKI & C. A. PÉRES. 2010. Habitat patch size modulates terrestrial mammal activity patterns in Amazonian Forest fragments. 2010. Journal of Mammalogy 91(3):551–560.

PALMEIRIM, A. F., M. BENCHIMO, J. C. MORANTE-FILHO, M. V. VIEIRA & C. A. PERES. 2018. Ecological correlates of mammal β-diversity in Amazonian land-bridge islands: from small-to large-bodied species. Diversity and Distributions 24:1109–1120.

PARDINI, R., et al., 2010. Beyond the fragmentation threshold hypothesis: regime shifts in biodiversity across fragmented landscapes. PLoS One 5, 1–10.

PRESLEY, S. J., L. M. CISNEROS, T. B. KLINGBEIL & M. R. WILLIG. 2019. Landscape ecology of mammals. Journal of Mammalogy, 100(3):1044–1068.

PORRAS P., L. B. VAZQUEZ, R. SARMIENTO-AGUILAR, D. DOUTERLUNGNE & D. VALENZUELA-GALVÁN. 2016. Influence of human activities on some medium and large-sized mammals' richness and abundance in the Lacandon Rainforest. Journal for Nature Conservation 34 (2016) 75–81.

PÜTTKER, T., R. CROUZEILLESB, M. ALMEIDA-GOMESC, M. SCHMOELLERD, et al. 2020. Indirect effects of habitat loss via habitat fragmentation: A cross-taxa analysis of forest-dependent species. Biological Conservation 241: 108368.

REGOLIN A. L., M. C. RIBEIRO, F. MARTELLO, G. LEAL, J. SPONCHIADO, et al. 2020. Spatial heterogeneity and habitat configuration overcome habitat composition influences on alpha and beta mammal diversity. Biotrópica 52: 2:970–982.

RIBEIRO, M.C., METZGER, J.P., MARTENSEN, A.C., PONZONI, F.J., HIROTA, M. M. 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation 142: 1141–1153.

RIOS, E., BENCHIMOL, M., De VLEESCHOUWER, K., & CAZETTA, E. 2022. Spatial predictors and species' traits: evaluating what really matters for medium-sized and large mammals in the Atlantic Forest, Brazil. Mammal Review, 52(2), 236-251.

ROVERO, F., AND SPITALE D. 2016. Presence/absence and species inventory. Pp. 43-67 in Camera Trapping for Wildlife Research (eds F. Rovero and F. Zimmermann). Pelagic Publishing, U.K.

SANTOS T., TELLERÍA J.L. 2006. Pérdida y fragmentación del hábitat: efecto sobre la conservación de las especies. Ecosistemas 2: 3-12.

SEMPER-PASCUAL A., et al. 2021. How do habitat amount and habitat fragmentation drive time-delayed responses of biodiversity to land-use change? Proc. R. Soc. B 288: 20202466.

SITTERS H., A. YORK, M. SWAN, F. CHRISTIE & DI STEFANO. 2016. Opposing Responses of Bird Functional Diversity to Vegetation Structural Diversity in Wet and Dry Forest. PLoS ONE 11(10): e0164917.

SOCOLAR, J.B., J. J. GILROY, W.E. KUNIN, D.P. EDWARDS. 2015. How should beta-diversity inform biodiversity conservation? Trends Ecol. Evol. 31, 67–80.

TEIXIDO A., S. R. A. GONÇALVES, G.J. FERNÁNDEZ-ARELLANO, T. J. WESLEY, et al. 2020. Major biases and knowledge gaps on fragmentation research in Brazil: Implications for conservation. Biological Conservation 251: 108749.

VILLARD, M-A. & J. P. METZGER. 2014. Beyond the fragmentation debate: a conceptual model to predict when habitat configuration really matters. J. Appl. Ecol. 51:309–18.

Figures

Figure 1. Study area showing the location of the landscape sampled with the camera traps in the southeastern Brazilian Atlantic Forest of Minas Gerais.
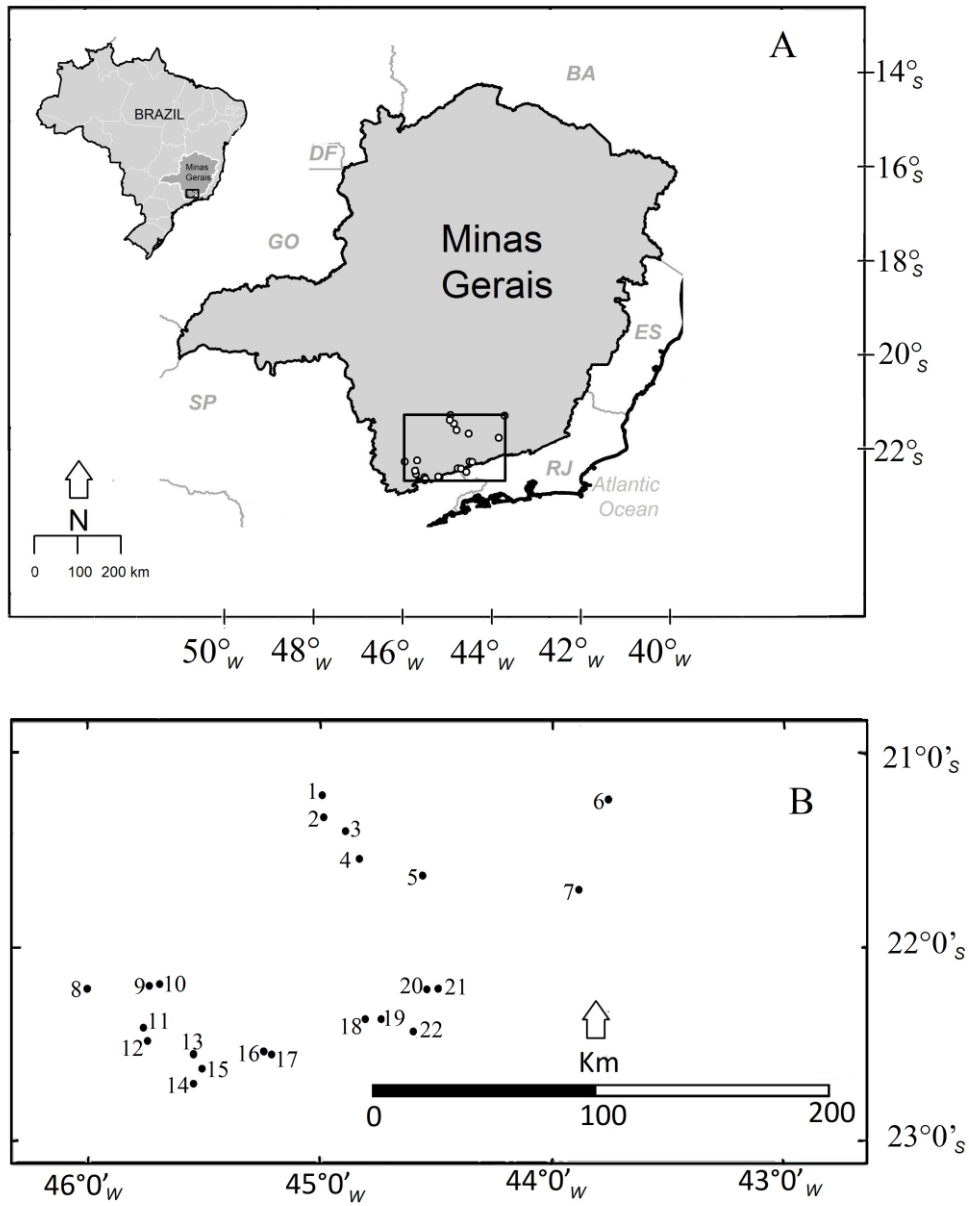
Figure 2. Number of Orders, Families, Genera and Species in the study area.

Figure 3. Linear relationship observed in the best models obtained from the multiscale analysis in terms of habitat amount (HA) and core areas (CA). Predicted values, 95% confidence intervals.
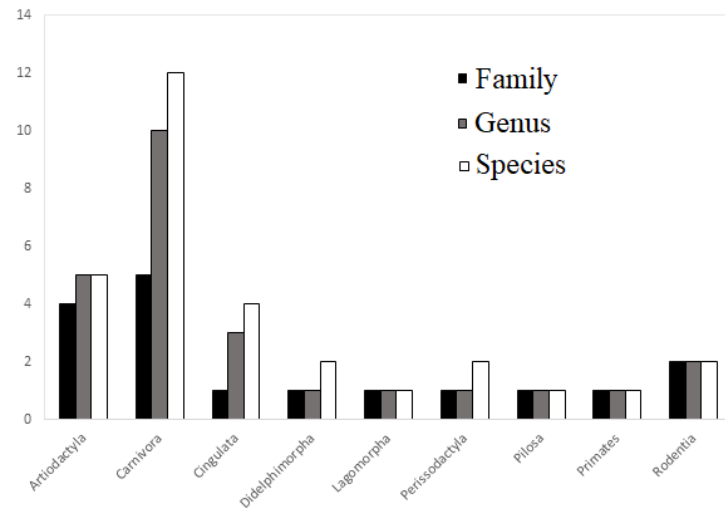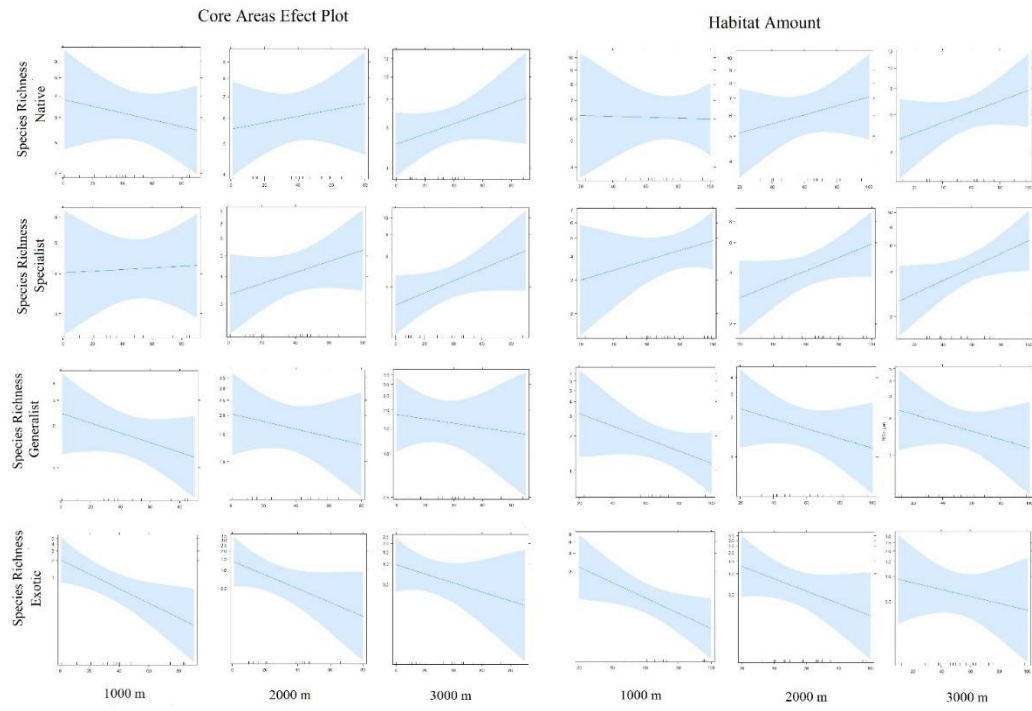
Figure 4. Linear relationship observed in the best models obtained from the multiscale analysis in terms of the analysis of effect of landscape characteristics on species richness.
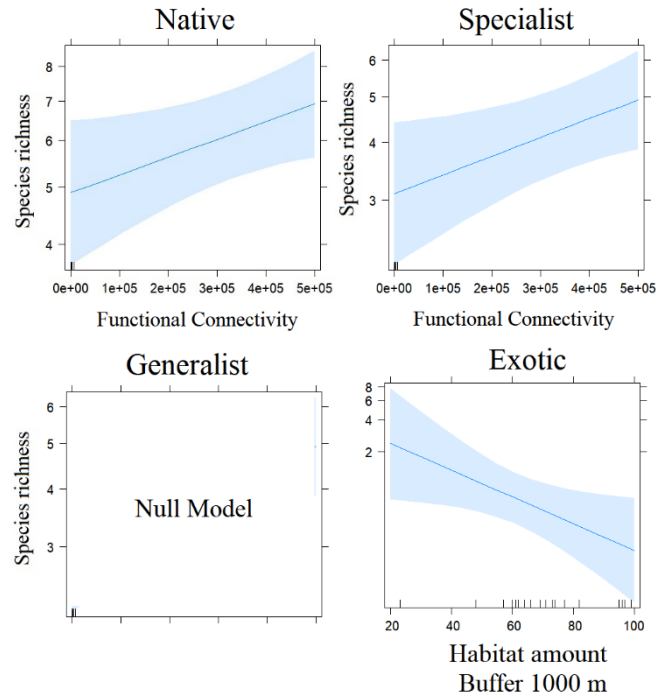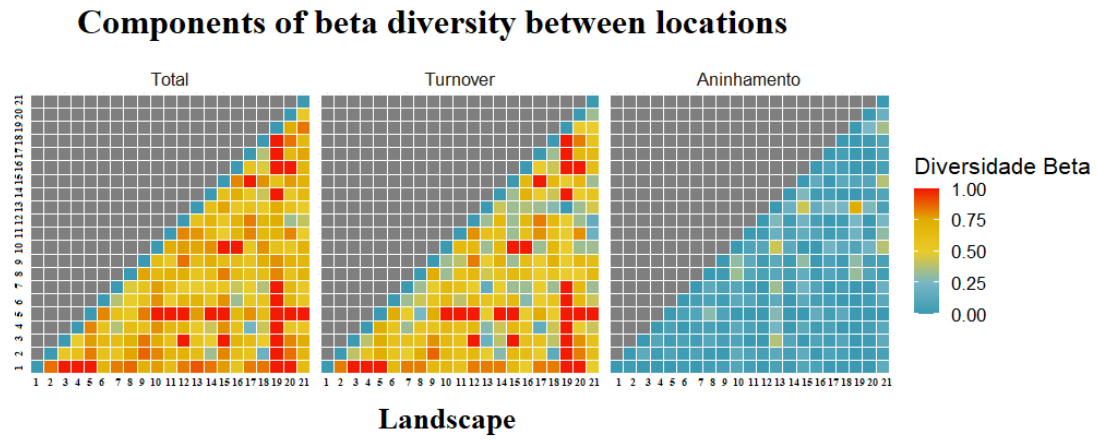
Figure 5. Partition of the diversity β that represents the turnover, the nesting components and the sum of both values between landscapes.

Components of beta diversity between locations

Tables

Table 1. Species classification as native species (SpNat), specialist species (SpSpe), and, generalist species (SpGen), and exotic species (SpEx). Sources: IUCN, Olivieira et. al. 2020, ICMBio-Brazil.

Order	Family	Species	SpNat	SpSpe	SpGen	SpEx
Artiodactyla	Bovidae	*Bos taurus*				*
	Cervidae	*Mazama americana*	*	NA		
		Mazama gouazoubira		NA		
	Suidae	*Sus scrofa*	*			*
	Tayassuidae	*Pecari tajacu*	*	*		
		Tayassu pecari	*	*		
Carnivora	Canidae	*Canis lupus familiaris*				*
		Cerdocyon thous			*	
		Speothos venaticus	*	*		
	Felidae	*Felis silvestris*	*			*
		Herpailurus yagouaroundi	*	*		
		Leopardus guttulus	*	*		
		Leopardus pardalis	*	*		
		Leopardus wiedii	*	*		
		Puma concolor	*	*		
	Mephitidae	*Conepatus semistriatus*	*		*	
	Mustelidae	*Eira barbara*	*	*		
		Galictis cuja	*	*		
	Procyonidae	*Nasua nasua*	*	*		
		Procyon cancrivorous	*		*	
Cingulata	Dasypodidae	*Cabassous unicinctus*	*		*	
		Dasypus novemcinctus	*	*		
		Dasypus septemcinctus	*		*	
		Euphractus sexcinctus	*		*	
Didelphimorphia	Didelphidae	*Didelphis aurita*	*		*	
		Didelphis albiventris			*	
Lagomorphia	Leporidae	*Sylvilagus brasiliensis*		*		
Perissodactyla	Equidae	*Equus asinus*				*
		Equus caballus	*			*
Pilosa	Myrmecophagidae	*Tamandua tetradactyla*	*			
Primates	Cebidae	*Sapajus nigritus*	*			
Rodentia	Cuniculidae	*Cuniculus paca*	*	*		
	Sciuridae	*Sciurus aestuans*			*	

Table 2. Multiscale comparison and Best Models for native, specialist, generalist and exotic mammals considered the habitat amount (HA) and core areas (CA) in the Brazilian Atlantic Forest in the southeastern of Minas Gerais.

a) Best Models excluding the Null Model

	Habitat amount					**Core Area**			
	Native	Specialist	Generalist	Exotic		Native	Specialist	Generalist	Exotic
Intercept	1.469***	0.831**	1.394**	1.439	Intercept	1.625***	1.144***	0.887**	0.737
	(0.260)	(0.322)	(0.601)	(0.837)		(0.165)	(0.202)	(0.337)	(0.480)
HA3000	0.006	0.010*			CA3000	0.005	0.008		
	(0.004)	(0.005)				(0.004)	(0.005)		
HA1000			-0.012	-0.028**	CA1000			-0.008	-0.030**
			(0.008)	(0.013)				(0.006)	(0.012)
Log Likelihood	-45.941	-41.468	-29.761	-19.069	Log Likelihood	-46.072	-42.083	-30.058	-17.888
AICc	96.550	87.603	64.188	42.805	AICc	96.810	88.833	64.783	40.443
Delta	0.000	0.000	0.000	0.000	Delta	0.000	0.000	0.000	0.000
Weight	0.509	0.562	0.469	0.690	Weight	0.479	0.569	0.469	0.808
Num.obs.	21	21	21	21	Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1   ***p<0.01; **p<0.05; *p<0.1

b) Best Models including the Null Model

	Habitat amount					**Core Area**			
	Native	Specialist	Generalist	Exotic		Native	Specialist	Generalist	Exotic
Intercepto	1.800***	0.831**	0.511***	1.439	Intercepto	1.800***	1.144***	0.511***	0.737
	(0.089)	(0.322)	(0.169)	(0.837)		(0.089)	(0.202)	(0.169)	(0.480)
HA3000		0.010*			CA3000		0.008		
		(0.005)					(0.005)		
HA1000				-0.028**	CA1000				-0.030**
				(0.013)					(0.012)
Log Likelihood	-46.900	-41.468	-30.814	-19.069	Log Likelihood	-46.900	-42.083	-30.814	-17.888
AICc	96.010	87.603	63.839	42.805	AICc	96.010	88.833	63.839	40.443
Delta	0.000	0.000	0.000	0.000	Delta	0.000	0.000	0.000	0.000
Weight	0.400	0.449	0.358	0.552	Weight	0.417	0.386	0.429	0.741
Num.obs.	21	21	21	21	Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1   ***p<0.01; **p<0.05; *p<0.1

Table 3. Best Models for each group of mammals and summary of the coefficients.

Best Models				
	Model 1	**Model 2**	**Model 3**	**Model 4**
(Intercept)	1.589***	1.130***	0.511***	1.439*
	(0.143)	(0.180)	(0.169)	(0.837)
Com_fun	0.000**	0.000**		
	(0.000)	(0.000)		
Q1000o				-0.028**
				(0.013)
Log Likelihood	-44.812	-40.954	-30.814	-19.069
AICc	94.290	86.575	63.839	42.805
Delta	0.000	0.000	0.000	2.361
Weight	0.286	0.309	0.269	0.164
Num. obs.	21	21	21	21

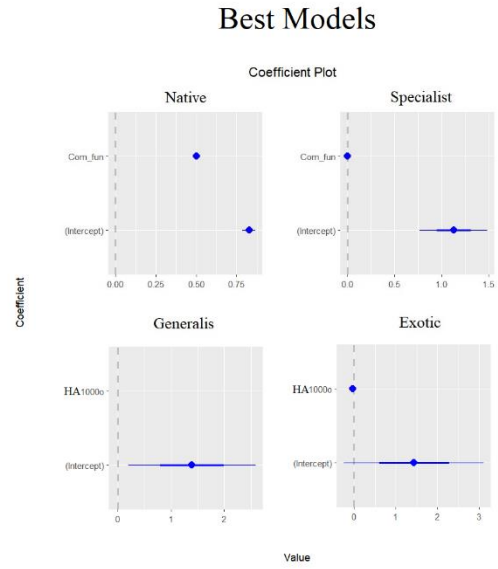***p < 0.01; **p < 0.05; *p < 0.1

Best Models

Table 4. Average and conditional models for each group of mammals of the analysis of effect of landscape characteristics on species richness.

Native

Model-averaged coefficients:
(Full average)

	Estimate	Std. Error	Adjusted SE	zvalue	Pr(>|z|)
(Intercept)	1.659e+00	1.453e-01	1.526e-01	10.873	<2e-16 ***
Com_Fun	2.689e-07	3.984e-07	4.064e-07	0.662	0.508
Patch_Area	1.004e-06	1.831e-06	1.867e-06	0.538	0.591
Co_Es	4.790e-07	1.387e-06	1.419e-06	0.338	0.736

(Conditional average)

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	1.659e+00	1.453e-01	1.526e-01	10.873	<2e-16 ***
Com_Fun	6.903e-07	3.416e-07	3.648e-07	1.892	0.0585 .
Patch_Area	3.413e-06	1.782e-06	1.903e-06	1.794	0.0728 .
Co_Es	3.162e-06	2.052e-06	2.191e-06	1.443	0.1490

Specialist

Model-averaged coefficients:
(Full average)

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	1.073e+00	2.723e-01	2.848e-01	3.769	0.000164 ***
Com_Fun	4.307e-07	5.441e-07	5.545e-07	0.777	0.437333
HA3000o	2.880e-03	5.378e-03	5.473e-03	0.526	0.598776
Patch_Area	1.107e-06	2.169e-06	2.207e-06	0.502	0.615988

(Conditional average)

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	1.073e+00	2.723e-01	2.848e-01	3.769	0.000164 ***
Com_Fun	9.284e-07	4.195e-07	4.480e-07	2.072	0.038234 *
HA3000o	1.038e-02	5.140e-03	5.489e-03	1.891	0.058668 .
Patch_Area	4.280e-06	2.146e-06	2.292e-06	1.867	0.061865 .

Generalist

Model-averaged coefficients:
(Full average)

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	0.907236	0.554939	0.575141	1.577	0.115
HA 1000o	-0.004248	0.007684	0.007902	0.538	0.591
CA 1000o	-0.002001	0.004741	0.004896	0.409	0.683

(Conditional average)

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	0.907236	0.554939	0.575141	1.577	0.115
HA 1000o	-0.012464	0.008417	0.008989	1.387	0.166
CA 1000o	-0.007902	0.006491	0.006931	1.140	0.254

Exotic

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Supplementary material

Supplementary material 1s. Location of each fragment in the Brazilian Atlantic Forest, in Minas Gerais (MG) and Rio de Janeiro (RJ) (Modified from Soto-Werschitz *et al.* 2023), and landscape metrics in the study area provided by UNESP's Laboratory of Spatial Ecology and Conservation (LEEC) in Rio Claro, São Paulo, Brazil.

Fragment	Municipality	State	Latitude	Longitude	Altitude	Patch_Area	Area_f	CoEs	Com_fun	Habitat amount %			Core area %		
										Q1000m	Q2000m	Q3000m	AN1000m	AN2000m	AN3000m
1	Lavras	MG	-21,229	-44,972	951	25	6	19	57	23	16	12	1	1	0
2	Lavras	MG	-21,332	-44,986	1149	417	128	289	5593	60	33	31	36	13	7
3	Ingai	MG	-21,41	-44,892	882	NA	18	590	9588	36	25	25	5	2	1
4	Luminárias	MG	-21,549	-44,83	1098	234	155	79	290	57	41	29	29	16	9
5	Minduri	MG	-21,624	-44,56	989	2309	1436	873	5887	95	80	62	85	66	46
6	Barbacena	MG	-21,239	-43,753	1144	229	132	97	1253	74	42	31	54	20	11
7	Lima Duarte	MG	-21,707	-43,885	1444	5421	140	5281	535546	71	47	46	38	15	10
8	Pouso Alegre	MG	-22,218	-45,998	1046	1023	723	300	1487	96	70	57	84	47	33
9	Santa Rita do Sapucaí	MG	-22,202	-45,73	1040	1948	1318	630	2129	73	66	48	54	44	29
10	Sta. Rita do Sapucaí	MG	-22,192	-45,695	1014	185	164	21	247	64	46	39	38	21	20
11	Conceição dos Ouros	MG	-22,414	-45,766	1228	629	595	34	649	99	67	53	93	54	39
12	Conceição dos Ouros	MG	-22,48	-45,747	879	1838	1290	548	2319	82	58	50	74	49	33
13	Piranguçu	MG	-22,553	-45,549	1078	2428	946	1482	535546	69	47	38	48	21	14
14	Piranguçu	MG	-22,615	-45,548	1591	108736	1760	106976	535546	69	71	73	29	39	41
15	Piranguçu	MG	-22,584	-45,533	1614	108736	1760	106976	535546	62	62	64	21	36	41
16	Delfim Moreira	MG	-22,535	-45,243	1315	108736	15228	93508	535546	77	68	69	42	43	43
17	Delfim Moreira	MG	-22,55	-45,215	1368	108736	15228	93508	535546	66	75	76	32	41	47
18	Itamonte	MG	-22,359	-44,806	1560	91783	60361	31422	535546	97	82	75	83	59	54
19	Itamonte	MG	-22,366	-44,736	2081	91783	60361	31422	535546	99	95	90	93	78	73
20	Bocaina de Minas	MG	-22,218	-44,539	1257	91783	27	91756	535546	48	40	50	11	10	17
21	Bocaina de Minas	MG	-22,221	-44,484	1383	492	232	260	535546	61	50	57	40	25	32
22	Itatiaia	RJ	-22,436	-44,612	1070	91783	60361	31422	535546	95	97	98	74	82	88

Patch size (Patch_Area); Area of the focal fragment (Area_f); Structural connectivity (CoEs); Functional area (A_fun); Habitat amount (Q); Core area (AN)

Supplementary material 2s. Rarefaction and extrapolation curves for each landscape created with the INEXT program. The graphics present the coverage of the samples (X axis) and species richness (Y axis).
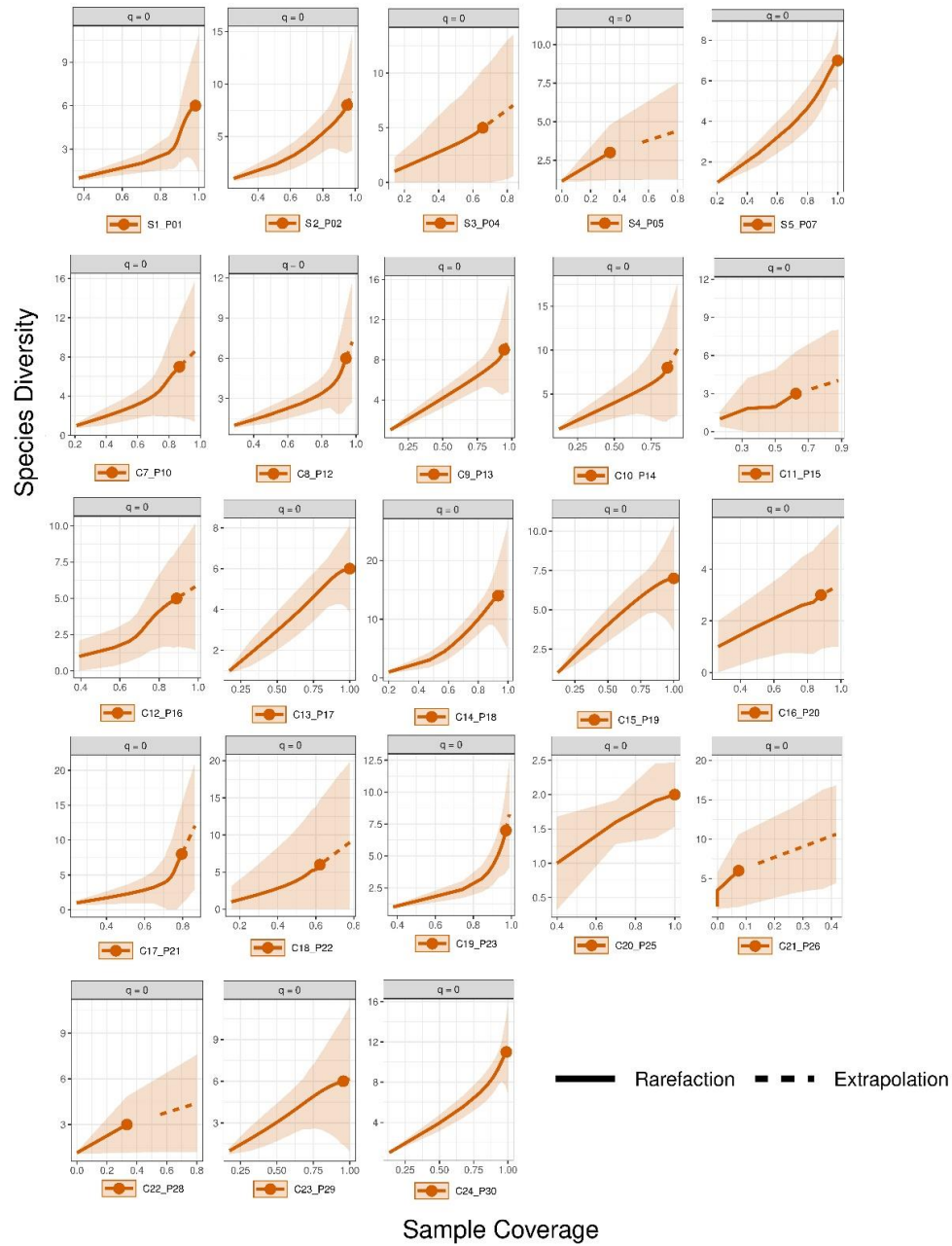
Supplementary material 3s. Multiscale comparison of simplified models for native, specialist, generalist and exotic mammals included and excluded the null model for the habitat amount (HA) and core areas (CA) in the Brazilian Atlantic Forest in the southeastern of Minas Gerais. (a) Models with null model and (b) Models without null model.

(a) Best Models including the Null Model

Native — Habitat amount

	Model 1	Model 2	Model 3	Model 4
Intercept	1.800*** (0.089)	1.469*** (0.260)	1.555*** (0.286)	1.826*** (0.354)
HA3000		0.006 (0.004)		
HA2000			0.004 (0.004)	
HA1000				-0.000 (0.005)
Log Likelihood	-46.900	-45.941	-46.483	-46.897
AICc	96.010	96.550	97.634	98.461
Delta	0.000	0.539	1.623	2.450
Weight	0.400	0.305	0.178	0.117
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Native — Core Area

	Model 1	Model 2	Model 3	Model 4
Intercept	1.800*** (0.089)	1.625*** (0.165)	1.921*** (0.185)	1.713*** (0.177)
CA3000		0.005 (0.004)		
CA1000			-0.002 (0.003)	
CA2000				0.002 (0.004)
Log Likelihood	-46.900	-46.072	-46.628	-46.735
AICc	96.010	96.810	97.923	98.136
Delta	0.000	0.800	1.913	2.125
Weight	0.417	0.279	0.160	0.144
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Specialist — Habitat amount

	Model 1	Model 2	Model 3	Model 4
Intercept	0.831** (0.322)	0.862** (0.357)	1.421*** (0.107)	0.975** (0.452)
HA3000	0.010* (0.005)			
HA2000		0.009 (0.005)		
HA1000				0.006 (0.006)
Log Likelihood	-41.468	-42.060	-43.498	-42.958
AICc	87.603	88.786	89.206	90.583
Delta	0.000	1.183	1.603	2.980
Weight	0.449	0.248	0.201	0.101
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Specialist — Core Area

	Model 1	Model 2	Model 3	Model 4
Intercept	1.144*** (0.202)	1.421*** (0.107)	1.194*** (0.219)	1.391*** (0.230)
CA3000	0.008 (0.005)			
CA2000			0.006 (0.005)	
CA1000				0.001 (0.004)
Log Likelihood	-42.083	-46.072	-46.628	-46.735
AICc	88.833	89.206	90.167	91.641
Delta	0.000	0.373	1.334	2.808
Weight	0.386	0.321	0.198	0.095
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Generalist — Habitat amount

	Model 1	Model 2	Model 3	Model 4
Intercept	0.511*** (0.169)	1.394** (0.601)	1.009* (0.503)	0.924* (0.458)
HA1000		-0.012 (0.008)		
HA2000			-0.009 (0.008)	
HA3000				-0.008 (0.008)
Log Likelihood	-30.814	-29.761	-30.293	-30.366
AICc	63.839	64.188	65.252	65.399
Delta	0.000	0.350	1.413	1.560
Weight	0.358	0.301	0.177	0.164
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Generalist — Core Area

	Model 1	Model 2	Model 3	Model 4
Intercept	0.511*** (0.169)	0.887** (0.337)	0.717** (0.320)	0.623** (0.301)
CA1000		-0.008 (0.006)		
CA2000			-0.006 (0.008)	
CA3000				-0.004 (0.008)
Log Likelihood	-30.814	-30.058	-30.543	-30.717
AICc	63.839	64.783	65.752	66.100
Delta	0.000	0.944	1.913	2.262
Weight	0.429	0.268	0.165	0.138
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Exotics — Habitat amount

	Model 1	Model 2	Model 3	Model 4
Intercept	1.439 (0.837)	-0.480* (0.277)	0.657 (0.770)	0.017 (0.744)
HA1000	-0.028** (0.013)			
HA2000			-0.020 (0.014)	
HA3000				-0.009 (0.014)
Log Likelihood	-19.069	-21.314	-20.227	-21.071
AICc	42.805	44.838	45.120	46.810
Delta	0.000	2.033	2.315	4.005
Weight	0.552	0.200	0.174	0.075
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Exotics — Core Area

	Model 1	Model 2	Model 3	Model 4
Intercept	0.737 (0.480)	0.328 (0.480)	-0.480* (0.277)	-0.027 (0.471)
CA1000	-0.030** (0.012)			
CA2000		-0.026 (0.015)		
CA3000				-0.015 (0.014)
Log Likelihood	-17.888	-19.616	-21.314	-20.699
AICc	40.443	43.899	44.838	46.065
Delta	0.000	3.456	4.395	5.622
Weight	0.741	0.132	0.082	0.045
Num.obs.	21	21	21	21

***p<0.01; **p<0.05; *p<0.1

Supplementary material 4s. Analysis of the residuals in each model obtained for each group of mammalian species. Habitat amount (Q), core area (AN).

(b) **Best Models excluding the Null Model**

Native	Habitat amount		
	Model 1	Model 2	Model 3
Intercept	1.469***	1.555***	1.826***
	(0.260)	(0.286)	(0.354)
HA3000	0.006		
	(0.004)		
HA2000		0.004	
		(0.004)	
HA1000			-0.000
			(0.005)
Log Likeliho	-45.941	-46.483	-46.897
AICc	96.550	97.634	98.461
Delta	0.000	1.084	1.911
Weight	0.509	0.296	0.196
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Native	Core Area		
	Model 1	Model 2	Model 3
Intercept	1.625***	1.921***	1.713***
	(0.165)	(0.185)	(0.177)
CA3000	0.005		
	(0.004)		
CA1000		-0.002	
		(0.003)	
CA2000			0.002
			(0.004)
Log Likelihood	-46.072	-46.628	-46.735
AICc	96.810	97.923	98.136
Delta	0.000	1.113	1.326
Weight	0.479	0.274	0.247
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Specialist	Habitat amount		
	Model 1	Model 2	Model 3
Intercept	0.831**	0.862**	0.975
	(0.322)	(0.357)	(0.452)
HA3000	0.010*		
	(0.005)		
HA2000		0.009	
		(0.005)	
HA1000			0.006
			(0.006)
Log Likeliho	-41.468	-42.060	-42.958
AICc	87.603	88.786	90.583
Delta	0.000	1.183	2.980
Weight	0.562	0.311	0.127
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Specialist	Core Area		
	Model 1	Model 2	Model 3
Intercept	1.144***	1.194***	
	(0.202)	(0.219)	
CA3000	0.008		
	(0.005)		
CA2000		0.006	
		(0.005)	
CA1000			0.001
			(0.004)
Log Likelihood	-42.083	-42.750	-43.487
AICc	88.833	90.167	91.641
Delta	0.000	1.334	2.808
Weight	0.569	0.292	0.140
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Generalist	Habitat amount		
	Model 1	Model 2	Model 3
Intercept	1.394**	1.009*	0.924*
	(0.601)	(0.503)	(0.458)
HA1000	-0.012		
	(0.008)		
HA2000		-0.009	
		(0.008)	
HA3000			-0.008
			(0.008)
Log Likeliho	-29.761	-30.293	-30.366
AICc	64.188	65.252	65.399
Delta	0.000	1.064	1.211
Weight	0.469	0.275	0.256
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Generalist	Core Area		
	Model 1	Model 2	Model 3
Intercept	0.887**	0.717**	0.623*
	(0.337)	(0.320)	(0.301)
CA1000	-0.008		
	(0.006)		
CA2000		-0.006	
		(0.008)	
CA3000			-0.004
			(0.008)
Log Likelihood	-30.058	-30.543	-30.717
AICc	64.783	65.752	66.100
Delta	0.000	0.969	1.318
Weight	0.469	0.289	0.243
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Exotics	Habitat amount		
	Model 1	Model 2	Model 3
Intercept	1.439	0.657	0.017
	(0.837)	(0.770)	(0.774)
HA1000	-0.028**		
	(0.013)		
HA2000		-0.020	
		(0.014)	
HA3000			-0.009
			(0.014)
Log Likeliho	-19.069	-20.227	-21.071
AICc	42.805	45.120	46.810
Delta	0.000	2.315	4.005
Weight	0.690	0.217	0.093
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1

Exotics	Core Area		
	Model 1	Model 2	Model 3
Intercept	0.737	0.328	-0.027
	(0.480)	(0.480)	(0.471)
CA1000	-0.030**		
	(0.012)		
CA2000		-0.026	
		(0.015)	
CA3000			-0.015
			(0.014)
Log Likelihood	-17.888	-19.616	-20.699
AICc	40.443	43.899	46.065
Delta	0.000	3.456	5.622
Weight	0.808	0.144	0.049
Num.obs.	21	21	21

***p<0.01; **p<0.05; *p<0.1
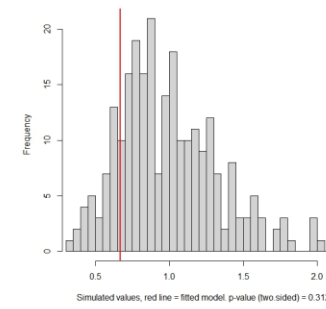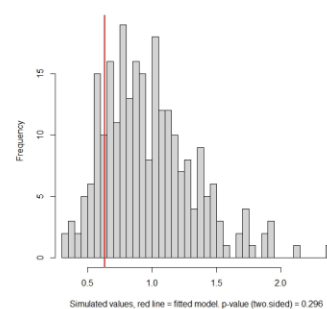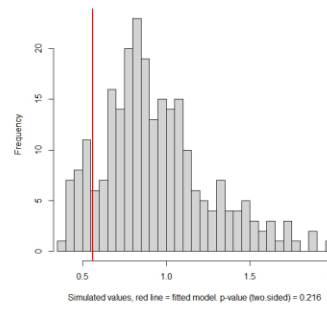
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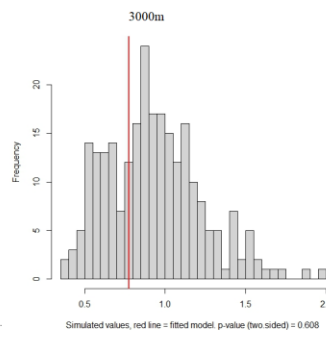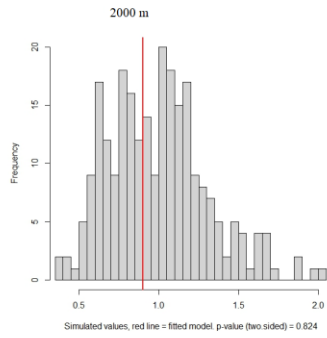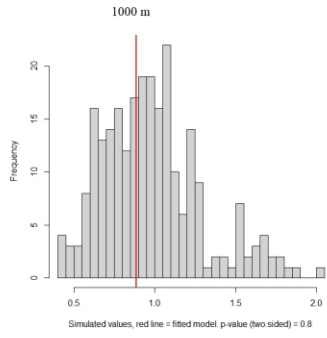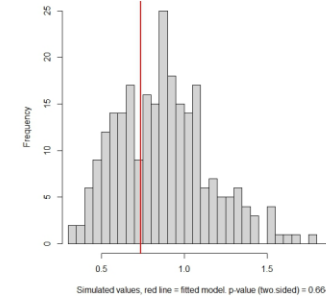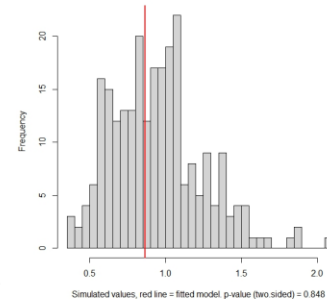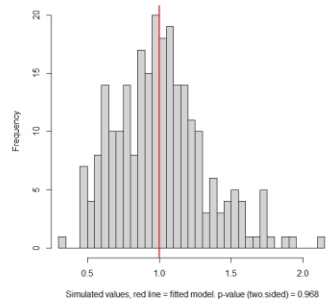
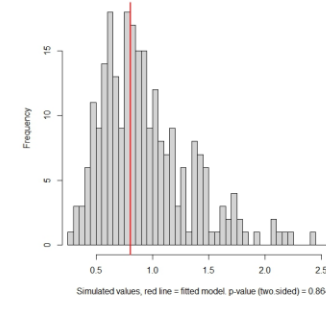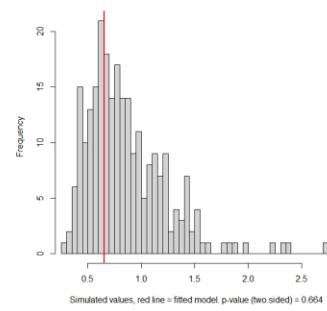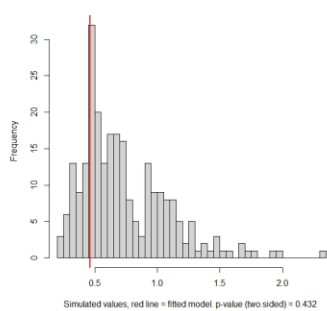Supplementary material 5s. Comparisons models for each group of mammals of the analysis of effect of landscape characteristics on species richness.

Variables that influence the richness

Native

	Model 1	Model 2	Model 3	Model 4	Model 5
(Intercept)	1.589***	1.653***	1.800***	1.734***	1.587***
	(0.143)	(0.122)	(0.089)	(0.102)	(0.143)
Com_fun	0.000*				0.000
	(0.000)				(0.000)
Patch_Area		0.000*			0.000
		(0.000)			(0.000)
Areaf				0.000	0.000
				(0.000)	(0.000)
Log Likelihood	-44.812	-45.093	-46.900	-45.923	-44.589
AICc	94.290	94.852	96.010	96.513	99.677
Delta	0.000	0.562	1.721	2.224	5.387
Weight	0.388	0.293	0.164	0.128	0.026
Num. obs.	21	21	21	21	21

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Specialist

	Model 1	Model 2	Model 3	Model 4	Model 5
(Intercept)	1.130***	0.831**	1.232***	1.421***	0.919**
	(0.180)	(0.322)	(0.151)	(0.107)	(0.373)
Com_fun	0.000**				0.000
	(0.000)				(0.000)
Q3000o		0.010*			0.005
		(0.005)			(0.008)
Patch_Area			0.000*		0.000
			(0.000)		(0.000)
Log Likelihood	-40.954	-41.468	-41.539	-43.498	-40.640
AICc	86.575	87.603	87.744	89.206	91.781
Delta	0.000	1.028	1.168	2.631	5.206
Weight	0.400	0.239	0.223	0.107	0.030
Num. obs.	21	21	21	21	21

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Generalist

	Model 1	Model 2	Model 3	Model 4	Model 5
(Intercept)	0.511***	1.394**	0.887**	0.484**	1.934*
	(0.169)	(0.601)	(0.337)	(0.192)	(0.929)
Q1000o		-0.012			-0.026
		(0.008)			(0.024)
AN1000o			-0.008		0.005
			(0.006)		(0.019)
Areaf				0.000	0.000
				(0.000)	(0.000)
Log Likelihood	-30.814	-29.761	-30.058	-30.766	-28.907
AICc	63.839	64.188	64.783	66.200	68.315
Delta	0.000	0.350	0.944	2.361	4.476
Weight	0.348	0.292	0.217	0.107	0.037
Num. obs.	21	21	21	21	21

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Exotic

	Model 1	Model 2	Model 3	Model 4	Model 5
(Intercept)	1.439	-0.312	-0.816*	-0.919*	0.806
	(0.837)	(0.293)	(0.419)	(0.502)	(1.145)
Q1000o	-0.028**				-0.026
	(0.013)				(0.018)
Areaf		-0.000			-0.000
		(0.000)			(0.000)
Patch_Area			0.000		0.000
			(0.000)		(0.000)
Com_fun				0.000	0.000
				(0.000)	(0.000)
Log Likelihood	-19.069	-20.439	-20.509	-20.549	-16.961
AICc	42.805	45.544	45.685	45.765	47.922
Delta	0.000	2.740	2.881	2.960	5.117
Weight	0.557	0.142	0.132	0.127	0.043
Num. obs.	21	21	21	21	21

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Supplementary material 6s. Linear relationship observed in the best models obtained from the multiscale analysis in terms of the analysis of effect of landscape characteristics on species richness.
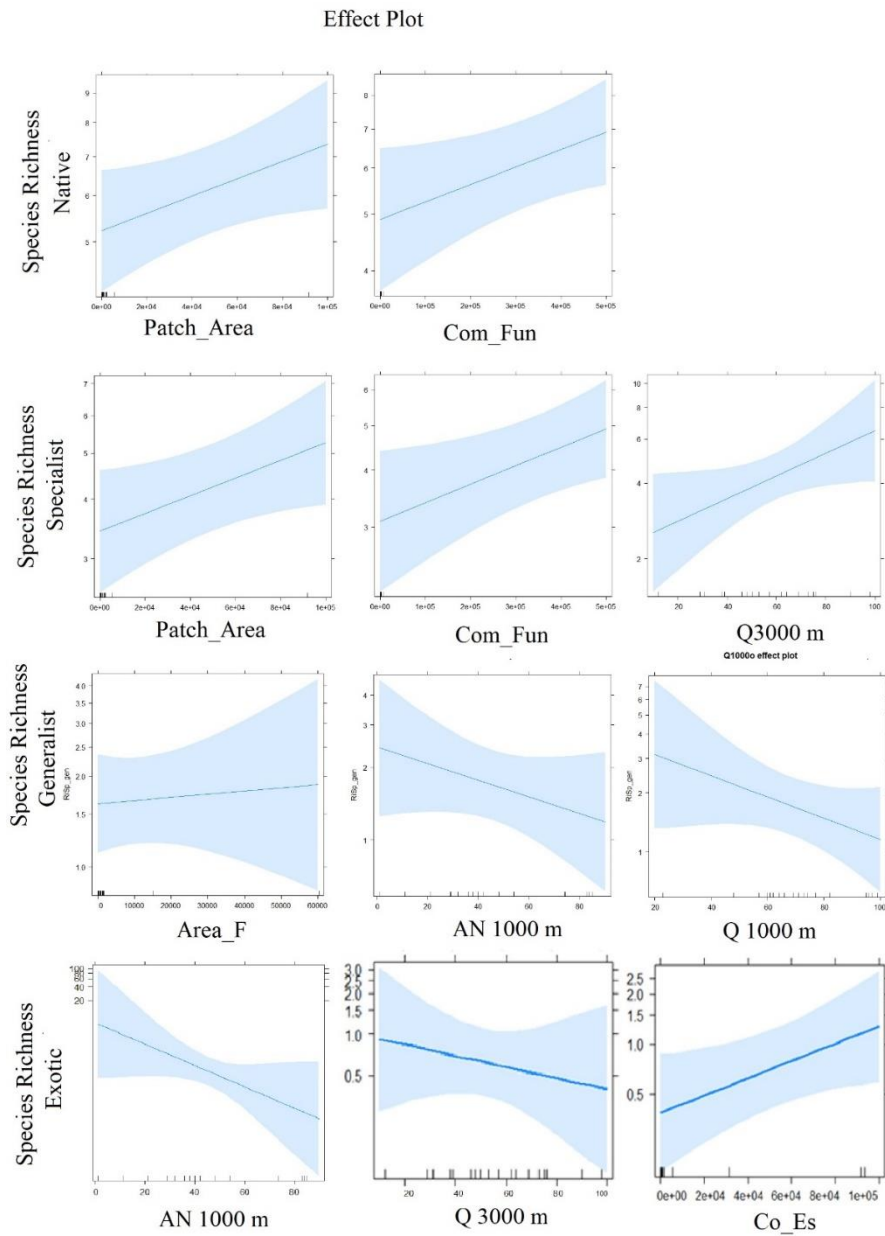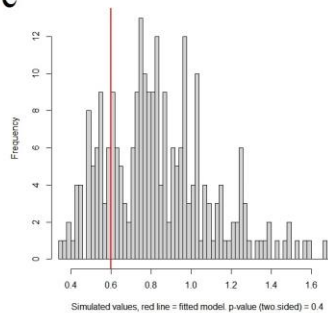
Supplementary material 7s. Analysis of the residuals in each model obtained for each group of mammalian species.

Nonparametric dispersion test via SD of residuals fitted vs. simulated
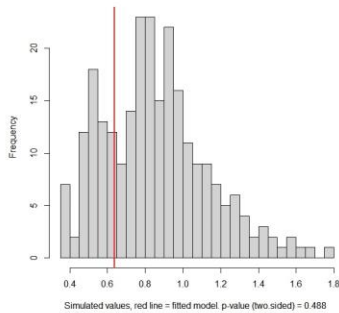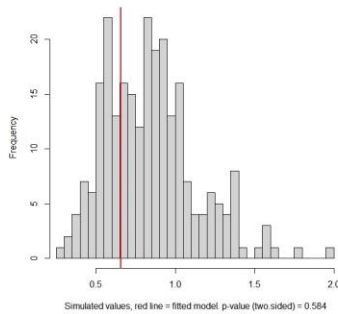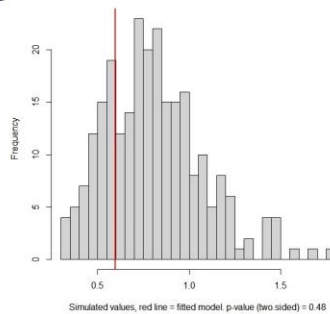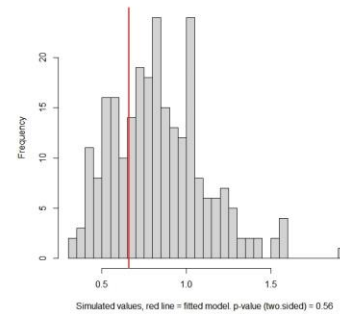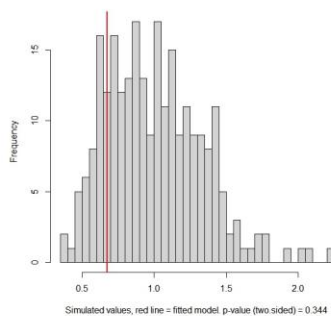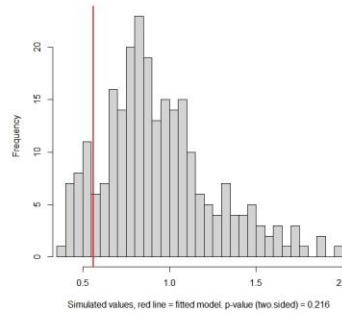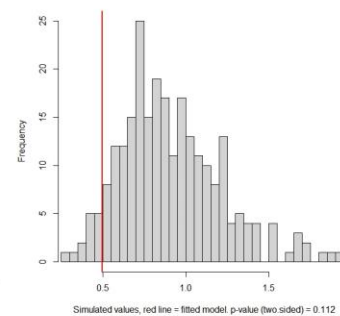
ARTICLE 3

Short Communication

First record of the bush dog *Speothos venaticus* in the Atlantic Forest of Minas Gerais, Brazil

ALEJANDRA SOTO-WERSCHITZ, SALVADOR MANDUJANO and MARCELO PASSAMANI

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Abstract The bush dog *Speothos venaticus* is a highly social Neotropical canid categorized globally on the IUCN Red List as Near Threatened, as Vulnerable in Brazil and as Critically Endangered in Minas Gerais and the Atlantic Forest as a result of human pressure. As part of the monitoring of this mammal, during January 2019–March 2020 we placed one camera trap in each of 22 forest fragments in various landscapes in 15 municipalities of the state of Minas Gerais and one municipality of the state of Rio de Janeiro. On average, each camera trap was active for 4.3 months in each fragment. In a total of 2,856 trap-days we obtain the first record of *S. venaticus* in Minas Gerais, south-eastern Brazil, c. 2 km from Serra de Santa Rita Mítzi Brandão Biological Reserve. This record provides information on the northernmost distribution of *S. venaticus* in the Atlantic Forest and highlights the importance for this species of forest remnants in a fragmented landscape. Further monitoring of this area should be a priority, to increase knowledge regarding the distribution of this species and for developing conservation strategies appropriate to these fragmented landscapes.

The bush dog *Speothos venaticus* occurs in Central and South America (DeMatteo & Loiselle, 2008), is a strict carnivore (Beisiegel & Zuercher, 2005; Lima et al., 2009) and is considered the most social and smallest Neotropical canid (Azevedo et al., 2016; Oliveira et al., 2018). Previous research has examined the conservation status, distribution and ecological requirements of this species (DeMatteo & Loiselle, 2008; Ferreira et al., 2015; Jorge et al., 2018; Lima et al., 2015; Michalski, 2010; Oliveira, 2009). Nevertheless, because of the elusive behaviour, low density, fragmented occurrence and large home range of the bush dog, the species biology is poorly understood (DeMatteo & Kochanny, 2004; Michalski & Pérez, 2005; Lima et al., 2012, 2015; Oliveira et al., 2018; Jorge et al., 2018). Consequently, it is necessary to increase our knowledge of this species (Azevedo et al., 2016; Oliveira et al., 2018; Tiepolo et al., 2016; Jorge et al., 2018) and its distribution (DeMatteo & Loiselle, 2008).

The bush dog is categorized as Near Threatened globally on the IUCN Red List (DeMatteo et al., 2011), as Vulnerable on the Brazilian National List and as Threatened in several Brazilian states (Jorge et al., 2018). In the Atlantic Forest the bush dog is categorized as Critically Endangered (Jorge et al., 2018), with a few records in the states of São Paulo (Beisiegel, 2009), Paraná (Fusco-Costa & Ingberman, 2013; Tiepolo et al., 2016), Santa Catarina, Rio Grande do Sul (Fick et al., 2021) and Mato Grosso do Sul, in the Atlantic Forest and the Cerrado ecotone (Teribele et al., 2012). In the state of Minas Gerais the bush dog is categorized as Critically Endangered (COPAM, 2010; Jorge et al., 2018) and was considered probably extinct (Costa, 1998) until records of the species were obtained in the north and west of the state (Azevedo et al., 2016; Ferreira et al., 2015; Silva et el., 2022). Here we report the first record of the bush dog in southern Minas Gerais, the current northernmost known occurrence of this species in the Brazilian Atlantic Forest.

We conducted this study in 22 fragments in various landscapes in 16 municipalities in south-eastern Minas Gerais (Fig. 1). During January 2019–March 2020 we placed a single camera trap (Bushnell HD, Bushnell Outdoor Products, California, USA) in each fragment for a mean of 4.3 months, at altitudes of 887–2,087 m. The lowlands are predominantly humid, whereas the mountainous sites have dry or rainy winters. The temperature range in this region is 12.2–19.8°C and the annual total precipitation range is 1,476–2,175 mm (Instituto Brasileiro de Geografia e Estatística, 2012). We contemplate the protocols established for camera trapping proposed by Rovero & Spitale (2016) and Sharma et al. (2020).

After 2,856 trap-days we obtained two photographs of one bush dog (×Plates 1) in the municipality of Santa Rita do Sapuçaí (Fig. 1) at 7.40 on 20 May 2019. The image is not clear but typical characteristics of the species can be distinguished such as its short legs and tail, typical leg shape and elongated, cylindrical and thick body. We obtained five independent assessments from Brazilian carnivore specialists that this image was of a bush dog. The nearest known records are 725 and 739 km north (Fig. 1). The survey effort was less than that required to detect the bush dog in other localities, where recording the species required 4,818 (Beisiegel, 2009), 4,112 (Fusco-Costa & Ingberman, 2013), 6,000, 7,000, 27,000 (Ferreira et al., 2015), 4,036 (Azevedo et al., 2016) and 15,888 trap-days (Oliveira et al., 2018).

We recorded the bush dog in a fragment of the seasonal forest at an altitude of 1,014 m, with an area of 164 ha, structural connectivity of 21 ha, and a patch size of 185 ha. The fragment is next to Serra de Santa Rita Mítzi Brandão Biological Reserve (2 Km), one conservation unit and water recharge region, with seven main springs on its slope, and the Sapucaí River. The bush dog would be using area as a corridor towards areas with greater availability of forest cover and water. Considering the biological knowledge gaps and the importance of this record, designating a long-term monitoring project for the bush dog in this area would increase our knowledge about the species to use as a flagship species to promote increased connectivity in the Atlantic Forest through corridors and stepping-stones that favors animal dispersal among fragmented populations, considering the surrounding matrix.

Author contributions Study design: ASW, MP; fieldwork: MP; data processing and analysis: ASW, SM, MP; writing: ASW, MP, SM.

Conflicts of interest None.

Ethical standards This research followed ethical procedures for conducting camera-trapping (Sharma et al., 2020), the cameras only recorded photographs of wildlife, and this research otherwise abided by the *Oryx* guidelines on ethical standards.
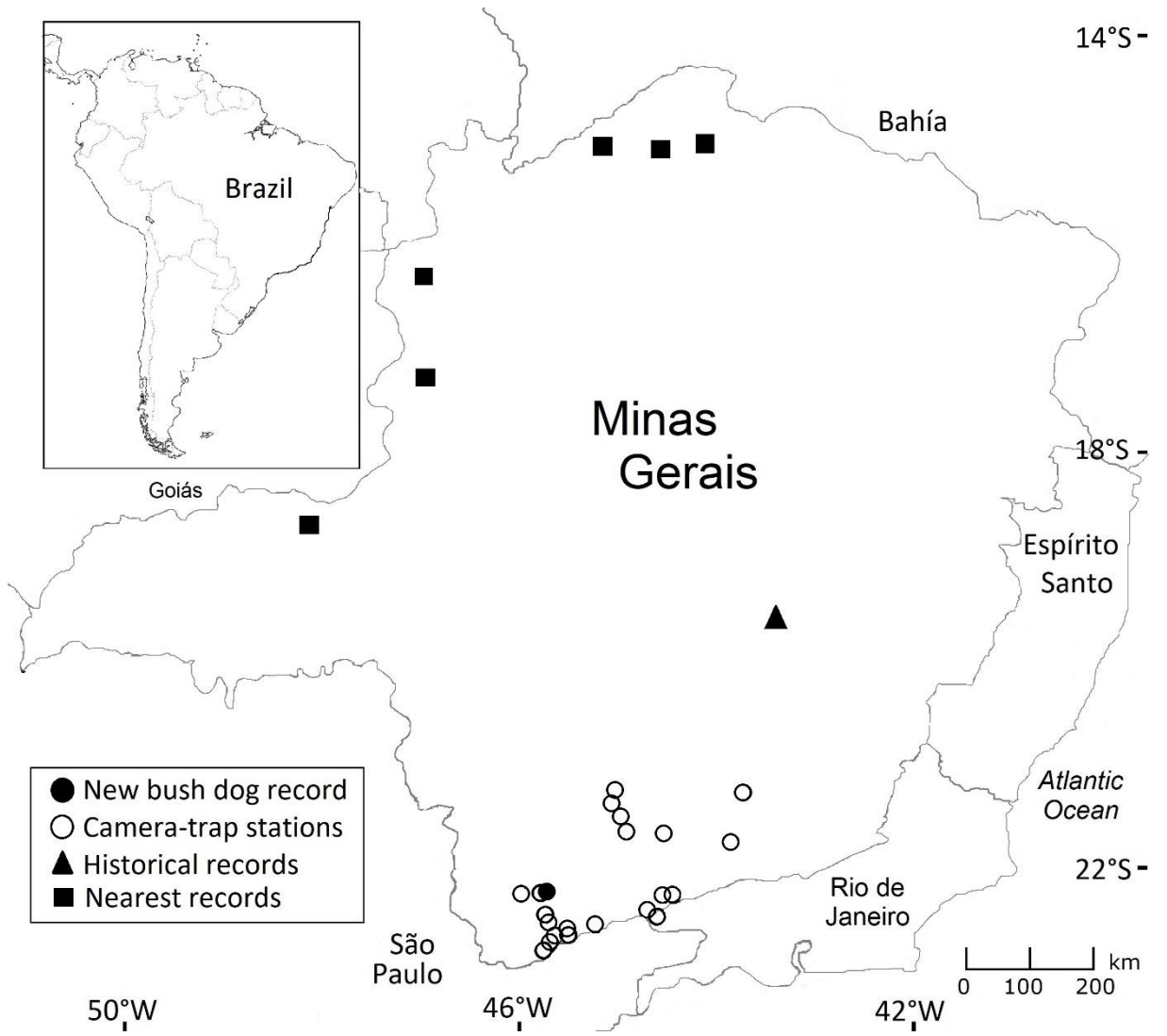
Data availability Not applicable.

References

Azevedo, F.C., Lemos, F.G., Costa, A.N., Rocha, D.G. & Freitas Junior, M.C. (2016) New-record of the bush dog *Speothos venaticus* in a human-altered landscape in west Minas Gerais, Brazil. *Bioscience Journal*, 32, 1324–1330.

Beisiegel, B.D.M. (2009) *First camera trap record of bush dogs* Speothos venaticus *at the state of São Paulo, Brazil*. canids.org/canidnews/12/Bush_dogs_in_Sao_Paulo.pdf [accessed March 2022].

Beisiegel, B.D.M. & Zuercher, G.L. (2005) *Speothos venaticus. Mammalian Species*, 783, 1–6.

COPAM (2010) *Lista das Espécies da Fauna Ameaçadas de Extinção no Estado de MG*. Deliberação Normativa Conselho Estadual de Política Ambiental No 147. Diário do Executivo, Minas Gerais, Brazil.

Costa, C.M.R. (1998) *Speothos venaticus*. In *Livro Vermelho das Espécies Ameaçadas de Extinção da Fauna de Minas Gerais* (eds A.B.M. Machado, G.A.B. Fonseca, R.B. Machado, L.M.S. Aguiar & L.V. Lins), pp. 105–107. Fundação Biodiversitas, Belo Horizone, Brazil.

DeMatteo, K. & Kochanny, C.O. (2004) Determining an effective and safe radio-tracking collar for bush dogs (*Speothos venaticus*). *Canid News*, 7, 1-5.

DeMatteo, K. & Loiselle, B.A. (2008) New data on the status and distribution of the bush dog (*Speothos venaticus*): evaluating its quality of protection and directing research efforts. *Biological Conservation*, 141, 2494–2505.

DeMatteo, K., Michalski, F. & Leite-Pitman, M.R.P. (2011) *Speothos venaticus*. In *The IUCN Red List of Threatened Species* 2011. dx.doi.org/10.2305/IUCN.UK.2011-2.RLTS.T20468A9203243.en.

Ferreira, G.B., Oliveira, M.J.R., Paula, R.D.C., Rodrigues, F.H.G. & Carmo, É.D.C. (2015) Regionally extinct species rediscovered: the bush dog *Speothos venaticus* in Minas Gerais, southeastern Brazil. *Oryx*, 49, 60–63.

Fick, A., Hendgen, A.C., Kunzler, D.C. & da Silva, L.G. (2021) Primeiro registro do cachorro-vinagre *Speothos venaticus* (Carnivora, Canidae) para a Mata Atlântica do estado do Rio Grande do Sul, sul do Brasil. *Biotemas*, 34, 1–6.

Fusco-Costa, R. & Ingberman, B. (2013) Records of the bush dog *Speothos venaticus* in a continuous remnant of coastal Atlantic Forest in southern Brazil. *Oryx*, 47, 105–108.

Instituto Brasileiro de Geografia e Estatística (ed.) (2012) *Manual Técnico da Vegetação Brasileira*, 2nd edition. Instituto Brasileiro de Geografia e Estatística (IBGE), Rio de Janeiro, Brazil.

DELETE THIS REF.:Jorge, R.P.S., Beisiegel, B.D.M., Lima, E.D.S., Jorge, M.L.D.S.P., Leite-Pitman, M.R.P. & de Paula, R.C. (2013) Avaliação do risco de extinção do cachorro-vinagre *Speothos venaticus* (Lund, 1842) no Brasil. *Biodiversidade Brasileira*, 1, 179–190.

Jorge, R.P.S., Beisiegel, B.D.M., Lima, E.D.S., Jorge, M.L.D.S.P., Leite-Pitman, M.R.P. & de Paula, R.C. (2018) *Speothos venaticus* (Lund, 1842). In *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Volume II Mamíferos* (eds A.G. Chiarello, L.M.S. de Aguiar, R. Cerquera, F.R. de Melo, F.H.G. Rodrigues & V.M.F. da Silva), pp. 783–784. ICMBio/MMA Brasília, Federal District, Brazil.

Lima, E.S., DeMatteo, K.E., Jorge, R.S., Jorge, M.L.S., Dalponte, J.C., Lima, H.S. & Klorfine, S.A. (2012) First telemetry study of bush dogs: home range, activity and habitat selection. *Wildlife Research*, 39, 512–519.

Lima, E.S., Jorge, R.S.P. & Dalponte, J.C. (2009) Habitat use and diet of bush dogs, *Speothos venaticus*, in the northern Pantanal, Mato Grosso, Brazil. *Mammalia*, 73, 13–19.

Lima, E.S., Jorge, M.L.S., Jorge, R.S. & Morato, R.G. (2015) The bush dog *Speothos venaticus*: area requirement and habitat use in cultivated lands. *Oryx*, 49, 64–70.

Lund, P.W. (1842) Blik paa brasiliens dyreverden för Sidste Jordomvaeltning. *Det Kongelige Danske Videnskabernes Selskbas Naturvidenskabelige og Mathematiske Afhandlinger*, 9, 137–208.

Michalski, F. (2010) The bush dog *Speothos venaticus* and short-eared dog *Atelocynus microtis* in a fragmented landscape in southern Amazonia. *Oryx*, 44, 300–303.

Michalski, F. & Peres, C.A. (2005) Anthropogenic determinants of primate and carnivore local extinctions in a fragmented forest landscape of southern Amazonia. *Biological Conservation*, 124, 383–396.

OLIVEIRA, T.G. (2009) Distribution, habitat utilization and conservation of the Vulnerable bush dog *Speothos venaticus* in northern Brazil. *Oryx*, 43, 247–253.

OLIVEIRA, T.G., MICHALSKI, F., BOTELHO, A.L., MICHALSKI, L.J., CALOURO, A.M. & DESBIEZ, A.L. (2018) How rare is rare? Quantifying and assessing the rarity of the bush dog *Speothos venaticus* across the Amazon and other biomes. *Oryx*, 52, 98–107.

ROVERO, F. & SPITALE, D. (2016) Presence/absence and species inventory. In *Camera Trapping for Wildlife Research* (eds F. ROVERO & F. ZIMMERMANN), pp. 43–67. Pelagic Publishing, London, UK.

SHARMA, K., FIECHTER, M., GEORGE, T., YOUNG, J., ALEXANDER, J.S., BIJOOR, A. et al. (2020) Conservation and people: towards an ethical code of conduct for the use of camera traps in wildlife research. *Ecological Solutions and Evidence*, 1, e12033.

SILVA, P. M., SERAFIM, G. T., ROCHA, E. C., FONSECA, A. P. E., & FERREIRA, O. A. (2022). A rare record of bush dogs (*Speothos venaticus*) in a peri-urban area of Cerrado in Minas Gerais State, Brazil. Multi-Science Journal, 5, 26-29.

TERIBELE, R., CONCONE, H.V.B., GODOY, M., BIANCHI, R.C., SANTOS, J.C.C., MAURO, R.A. et al. (2012) New records for bush dog in Mato Grosso do Sul, Brazil. *Canid News*, 15, 1–4.

TIEPOLO, L.M., QUADROS, J. & PITMAN, M.R.P.L. (2016) A review of bush dog *Speothos venaticus* (Lund, 1842) (Carnivora, Canidae) occurrences in Paraná State, subtropical Brazil. *Brazilian Journal of Biology*, 76, 444–449.

FIG. 1. Locations of the camera traps and of record of bush dog *Speothos venaticus* in this study, historical record (Lund, 1842), and nearest current records (Azevedo et al., 2016; Ferreira et al., 2015; Silva et al., 2022) in Minas Gerais, Brazil.

PLATE 1 The two photographs of the bush dog *Speothos venaticus* obtained at Santa Rita do Sapuçaí, in Minas Gerais, Brazil.

Bushnell (M) 131224 53°F11°C ○ 05-20-2019 07:40:04

Bushnell (M) 131224 53°F11°C ○ 05-20-2019 07:40:05

VIDEO

Selfies na Mata Atlântica.............https://www.youtube.com/watch?v=w8RrVmnwDCU