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PALOMA SILVA RESENDE

DIVERSIDADE FUNCIONAL DE MÉDIOS E GRANDES MAMÍFEROS: PERSPECTIVAS MULTIESCALA EM PAISAGENS FRAGMENTADAS SOB AMEAÇAS ANTRÓPICAS

ILHÉUS – BAHIA
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Tese apresentada à Universidade Estadual de Santa Cruz, como parte das exigências para obtenção do título de Doutor em Ecologia e Conservação da Biodiversidade.
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Discente: Paloma Silva Resende
Orientador: Dr Ricardo Siqueira Bovendorp

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Paloma Silva Resende

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Ilhéus, 29 de maio de 2024

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meu irmão Mateus e ao meu Pai Dalmo.

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SUMÁRIO

DIVERSIDADE FUNCIONAL DE MÉDIOS E GRANDES MAMÍFEROS: PERSPECTIVAS MULTIESCALA EM PAISAGENS FRAGMENTADAS SOB AMEAÇAS ANTRÓPICAS

RESUMO

A compreensão dos processos que moldam as comunidades biológicas diante de diversas perturbações é crucial para a ecologia e a conservação ambiental. Os mamíferos desempenham papéis essenciais nos ecossistemas, como a dispersão de sementes e a regulação de populações de presas. No entanto, eles enfrentam diversas pressões, e sua biodiversidade vem sendo ameaçada em diferentes escalas pelas atividades antrópicas, incluindo mudanças no uso da terra principalmente para produção de alimento, perda e fragmentação de habitats, caça, reduzindo drasticamente suas populações. Muitos estudos têm mostrado os efeitos negativos das pressões antrópicas sobre a riqueza de espécies, porém os efeitos sobre outras dimensões da biodiversidade (e.g., funcional filogenética e genética) são menos exploradas, apesar de técnicas e abordagens mais modernas e foco, principalmente, em grandes escalas. Os índices de diversidade tradicionais (e.g., riqueza) não são suficientes para explicar a funcionalidade dos organismos nas comunidades. Portanto, investigando a diversidade funcional desses animais, podemos entender melhor a conexão entre aspectos fundamentais da biodiversidade e o funcionamento dos ecossistemas. Investigamos como a diversidade funcional de mamíferos responde a ameaças antrópicas (e.g. agricultura) em diferentes escalas (locais, regionais e global). Para isso, esta tese está dividida em três capítulos, os dois primeiros consistem em uma revisão de literatura, o primeiro a nível tropical e o segundo na Mata Atlântica. Especificamente, no capítulo um avaliamos os efeitos das perturbações antrópicas na diversidade funcional de mamíferos. Através de uma abordagem meta-analítica testamos a hipótese que a biodiversidade funcional ia ser negativamente afetada pelos distúrbios

antrópicos, relatamos a existência de padrões gerais e identificamos tendências e lacunas de conhecimento para os diferentes distúrbios, diferentes grupos de mamíferos terrestres (pequenos, médios e grandes) e entre os diferentes índices de diversidade funcional existentes. Descobriu-se um impacto negativo dessas perturbações na diversidade funcional, especialmente na riqueza funcional e na dispersão funcional. Isso sugere que as perturbações antropogênicas não apenas afetam a diversidade taxonômica, mas também reduzem a diversidade funcional dos mamíferos, o que provavelmente afetará o funcionamento dos ecossistemas e possivelmente a prestação de serviços ecossistêmicos. No segundo capítulo, testamos a hipótese que fragmentos maiores, menos defaunados e em áreas protegidas, a diversidade funcional de mamíferos de médio e grande porte seria maior, destacando o papel crucial das áreas protegidas na conservação da diversidade funcional dos mamíferos. Nossos resultados suportam nossa hipótese, demonstrando que fragmentos maiores em áreas protegidas tendem a ter maior diversidade funcional e menor defaunação. No terceiro capítulo, em um contexto local, realizamos um estudo na região sul da Bahia, Brasil. Com dados derivados de levantamento de mamíferos por armadilhas fotográficas, analisamos o impacto dos sistemas agroflorestais de cacau na diversidade funcional de mamíferos. Os resultados indicaram uma relação positiva entre a cobertura florestal no entorno das agroflorestas e a riqueza funcional, evidenciando o papel desses sistemas na manutenção da diversidade funcional em escala paisagística, e apontando que mesmo em áreas muito defaunadas, as agroflorestas ainda abrigam parte considerável da biodiversidade da região, servindo como refúgio para elas. Esses estudos destacam a complexidade das interações ecológicas e a necessidade de abordagens integradas de conservação para proteger a biodiversidade e os serviços ecossistêmicos, especialmente em ambientes perturbados como a Mata Atlântica.

Palavras-chave: Conservação da biodiversidade, Ameaças Antrópicas, Agrofloresta, Mata Atlântica, paisagens fragmentadas

FUNCTIONAL DIVERSITY OF MEDIUM AND LARGE MAMMALS: MULTI-SCALE PERSPECTIVES IN FRAGMENTED LANDSCAPES UNDER ANTHROPIC THREATS

ABSTRACT

An understanding of the processes that shape biological communities in the face of diverse disturbances is crucial for both ecology and environmental conservation. Mammals play essential roles in ecosystems, such as seed dispersal and regulation of prey populations. However, they face diverse pressures, and their biodiversity has been threatened at different scales by anthropogenic activities, including changes in land use mainly for food production, habitat loss and fragmentation, hunting, and drastically reducing their populations. A considerable number of studies have demonstrated the deleterious effects of anthropogenic pressures on species richness. However, the impact of these pressures on other dimensions of biodiversity, such as phylogenetic and genetic functional diversity, has been less extensively investigated, despite the advent of more sophisticated techniques and approaches, and a greater focus on large-scale phenomena. Traditional diversity indices, such as richness, are inadequate for explaining the functionality of organisms within communities. Consequently, by investigating the functional diversity of these animals, we can better comprehend the interconnections between fundamental aspects of biodiversity and the functioning of ecosystems. We examine how functional mammal diversity responds to anthropogenic threats (e.g., agriculture) at different scales (local, regional, and global). For this purpose, this thesis is

divided into three chapters. The first two consist of a literature review, the first at the tropical level and the second in the Atlantic Forest. In particular, chapter one assesses the impact of anthropogenic disturbances on mammalian functional diversity. A meta-analytical approach was employed to test the hypothesis that functional biodiversity would be negatively affected by anthropogenic disturbances. This approach also served to report the existence of general patterns and identify trends and knowledge gaps for the different groups of terrestrial mammals (small, medium, and large) and among the different indices of functional diversity. The results indicated a negative impact of these disturbances on functional diversity, particularly in regard to functional richness and functional dispersion. This indicates that anthropogenic disturbances not only impact taxonomic diversity but also reduce mammalian functional diversity, which is likely to affect ecosystem functioning and potentially ecosystem service delivery. In the second chapter, we tested the hypothesis that larger fragments, less defaunated, and in protected areas, the functional diversity of medium and large mammals would be greater. This highlighted the crucial role of protected areas in the conservation of functional diversity of mammals. The results of this study support the hypothesis that larger fragments in protected areas tend to have greater functional diversity and less lag. In the third chapter, we conducted a study in the southern region of Bahia, Brazil, in a local context. The data derived from mammal surveys conducted using camera traps were analyzed to assess the impact of cocoa agroforestry systems on the functional diversity of mammals. The results indicated a positive relationship between forest cover around agroforests and functional richness, thereby underscoring the role of these systems in maintaining functional diversity at the landscape scale. Furthermore, the findings revealed that even in areas with high soil lagunation, agroforestry still serves as a refuge for a significant portion of the region's biodiversity. These studies underscore the intricacy of ecological interactions and

the necessity for integrated conservation strategies to safeguard biodiversity and ecosystem services, particularly in degraded ecosystems such as the Atlantic Forest.

Keywords: Biodiversity Conservation, Anthropogenic Threats, Agroforestry, Atlantic Forest, Fragmented Landscapes

INTRODUÇÃO GERAL

A crescente pressão exercida pelas populações humanas em expansão, a demanda cada vez maior por recursos naturais e, portanto, a conversão de muitos habitats naturais em paisagens fragmentadas, têm causado impactos severos na biodiversidade global (Cisneros et al. 2015). Os impactos antrópicos incluem a agricultura, caça, exploração madeireira e, especialmente, a perda e fragmentação de habitats, que são reconhecidos como fortes preditores da perda de diversidade de mamíferos (Gonzalez-Suarez et al. 2013, Brodie et al. 2021). Embora diversos estudos documentem os efeitos de distúrbios antrópicos na perda de espécies (Lyra-Jorge et al. 2009, Dotta & Verdade 2011, Ferreira et al. 2020), dimensões adicionais, como a diversidade filogenética e funcional, ainda são pouco exploradas.

A compreensão da diversidade funcional é essencial para entender a relação entre organismos e suas funções nos ecossistemas, fornecendo informações cruciais para avaliar os impactos antropogênicos nos processos ecossistêmicos (Safi et al. 2011, Mouillot et al. 2013). Enquanto a extinção de espécies pode ser causada por diversos fatores, não há consenso sobre quais ameaças antrópicas causam declínios na diversidade funcional (Brodie et al. 2021). A fragmentação de habitats pode atuar como um filtro, permitindo a persistência de um espectro limitado de características funcionais (Edwards et al. 2014).

Embora os mamíferos desempenhem funções ecológicas vitais, como dispersão de sementes, predação e regulação populacional, além de atuarem como reservatórios de zoonoses e vetores de doenças (Ahumada et al. 2011), estudos que relacionam a diversidade funcional dos mamíferos a distúrbios antrópicos ainda são poucos e revelam resultados heterogêneos (Flynn et al. 2009, Edwards et al. 2014, Magioli et al. 2016, Bovendorp et al. 2019, de la Sancha et al. 2020). A heterogeneidade dos resultados pode estar relacionada à ampla gama de distúrbios antropogênicos que afetam os mamíferos em diferentes regiões (Ahumada et al. 2011, Edwards et al. 2014, Brodie et al. 2021).

A região tropical apresenta grande destaque quando abordamos sua grande riqueza de espécies, padrão já amplamente reconhecido. Porém, quando o assunto é a diversidade funcional, esse padrão tem ganhado destaque principalmente nas últimas duas décadas (Safi et al. 2011, Feng et al. 2020). As regiões temperadas historicamente apresentam um tempo maior de ocupação humana, expondo assim as espécies a maior intensidade de pressão antrópica, sendo provável que as espécies sensíveis já tenham passado por um filtro ambiental, enquanto em regiões tropicais esse processo é mais recente, fazendo com que as comunidades sofram mais com as pressões antrópicas atuais (Newbold et al. 2020).

Características ecológicas das espécies, como especializações alimentares, área de vida, e sensibilidade térmica também pode influenciar a forma como as espécies respondem as pressões antrópicas (Dotta & Verdade 2011, Pacifici et al. 2017, Newbold Id et al. 2018). Em particular, a região tropical tem um grau de sazonalidade menor do que os biomas temperados, e as espécies que habitam essas áreas demonstraram maior sensibilidade às alterações no uso do solo e climáticas, pois evoluíram para tolerar a gama mais estreita de condições climáticas (Williams et al. 2020).

Mesmo com os crescentes estudos a respeito das ameaças a biodiversidade em grandes escalas, ainda existem lacunas que precisam de ser abordadas para compreender melhor como reduzir a tendência decrescente da biodiversidade (Newbold et al. 2020). Além disso, mudanças nas condições ambientais após distúrbios podem afetar a abundância de diferentes espécies, com algumas espécies sendo mais afetadas do que outras. Essas mudanças podem afetar a abundância de espécies que desempenham funções únicas nos ecossistemas, o que pode prejudicar serviços ecossistêmicos (Mouillot et al. 2013). Portanto, é crucial compreender como diferentes distúrbios antrópicos afetam a diversidade funcional dos mamíferos em diferentes paisagens.

A Mata Atlântica é considerada um dos hotspots para conservação mundial, e é uma das maiores florestas tropicais das Américas. O bioma apresenta condições ambientais bastante diversas e ainda abriga grandes quantidades de espécies de plantas e animais, sendo boa parte endêmica (Myers et al. 2000, Ribeiro et al. 2009). Devido ao processo avançado de fragmentação, a vegetação restante são, em sua maioria áreas menores que 50 hectares, circundadas por cidades, grandes áreas de cultivos e pastagens, isolando assim os fragmentos de floresta entre matrizes variada (Ribeiro et al. 2009, Lima & Mariano-Neto 2014). Esse processo de fragmentação, juntamente com outras pressões como caça, levou a uma perda de espécies, principalmente às de maior porte, processo conhecido como defaunação (Dirzo et al. 2014). Essa perda pode ocorrer tanto em nível global, quando uma espécie é totalmente extinta; local, quando uma espécie deixa de ocorrer somente em uma região; ou funcional, que é quando uma espécie tem sua abundância muito reduzida e deixa de exercer sua função (Galetti et al. 2021).

A região Sul do estado da Bahia compreende uma área importante para conservação da Mata Atlântica (Martini et al., 2007). Nesta região há grandes áreas de agrofloresta de cacau (*Theobroma cacao*) conhecidas regionalmente como cabrucas (Figura 1), bem como outros importantes cultivos, como café (*Coffea arabica*), banana (*Musa* sp.), seringueira (*Hevea brasiliensis*), e entre outros, compondo um mosaico de paisagem (Manfred Willy & Carlos Gama-Rodrigues, 2012). As cabrucas são áreas onde as árvores de cacau são plantadas em cultivos sombreados por floresta nativa, e armazenam uma importante parcela da biodiversidade local. Essas áreas fornecem um ambiente propício para entender como a comunidade de mamíferos de médio e grande porte se comporta em ambientes fragmentados e com constante manejo da vegetação (Nájera & Simonetti 2010).

Figura 1: Agrofloresta de cacau no município de Ilhéus sul da Bahia.

Considerando a atual fragmentação da Mata Atlântica, os mamíferos são um importante grupo a ser estudado, principalmente no contexto de paisagens fragmentadas e áreas agroflorestais. Os fragmentos de mata isolados associados aos impactos humanos resultam em grandes níveis de defaunação na Mata Atlântica, afetando principalmente vertebrados de grande porte (Canale et al. 2012, Galetti et al. 2017).

Logo, este estudo busca compreender através da análise da diversidade funcional: 1) quais distúrbios antrópicos exercem maior pressão nos mamíferos da região tropical, 2) como a comunidade de mamíferos de médio e grande porte responde ao processo de fragmentação da Mata Atlântica e 3) como essa comunidade responde ao ambiente agroflorestal (áreas de cabrucas). Dado que estas agroflorestas de cacau ainda albergam muitas espécies vegetais e animais nativos, a diversidade funcional é uma medida mais sensível às mudanças ambientais, e, assim, traz informações ecológicas mais mecaniscistas e de funcionamento dos ecossistemas (Cianciaruso et al. 2009), ressaltando a importância desses ambientes para conciliar a produção agrícola com a redução dos danos ambientais (Foley et al. 2005). Para abordar essas questões, esta tese foi dividida em três capítulos:

O primeiro capítulo, intitulado "A meta-analysis of the effects of anthropogenic disturbances on tropical mammal functional diversity", relatamos a existência de padrões gerais de como a diversidade funcional dos mamíferos nos trópicos responde a perturbações antropogênicas e identificamos tendências e lacunas de conhecimento com base em uma revisão sistemática da literatura. Além disso, utilizamos uma abordagem meta-analítica, para avaliar os efeitos gerais e fatores que podem contribuir para a idiossincrasia dos resultados observados em estudos anteriores, incluindo a região de estudo, o grupo de mamíferos estudado (pequenos, médios e grandes), os possíveis efeitos das abordagens metodológicas (ou seja, diferentes índices), e o tipo de perturbação antrópica. Desde a perda e fragmentação de habitat até a caça, esses distúrbios têm sido identificados como fatores-chave na diminuição da diversidade funcional dessas populações. Embora muitos estudos tenham documentado os efeitos dessas perturbações na perda de espécies, a compreensão da diversidade funcional ainda é limitada e requer uma análise mais aprofundada.

O segundo capítulo, "Functional defaunation of the Atlantic forest: The functional diversity of medium and large mammals and their relationship with habit loss and fragmentation", compilamos dados secundários publicados de estudos de mamíferos de médio a grande porte em toda a Mata Atlântica para determinar o grau de defaunação funcional para este bioma e avaliar qual tamanho de fragmento conseguiu manter a diversidade funcional dos mamíferos de médio e grande porte na Mata Atlântica e o papel das áreas protegidas na manutenção desse aspecto da biodiversidade. Espera-se que este capítulo contribua para uma compreensão mais profunda dos efeitos da fragmentação da Mata Atlântica, bioma altamente fragmentado e sujeito a uma série de ameaças antrópicas, na diversidade funcional dos mamíferos.

Por fim, o terceiro capítulo, "Functional diversity of medium and large mammals in areas of cocoa agroforestry in southern Bahia", tem como tem como objetivo avaliar a influência local e em nível de paisagem das agroflorestas de cacau no sul da Bahia, na diversidade funcional de mamíferos de médio e grande porte, além do efeito modulador da defaunação de assembleias de mamíferos. As agroflorestas de cacau na Bahia, representam um contexto único onde a agricultura coexiste com remanescentes florestais, desempenhando um papel fundamental na conservação da biodiversidade regional. No entanto, as práticas de manejo inadequadas podem comprometer essa contribuição, destacando a importância de compreendermos como as atividades agrícolas impactam a diversidade funcional e quais medidas podem ser adotadas para promover uma coexistência sustentável entre agricultura e conservação. Espera-se que este capítulo forneça informações cruciais para o desenvolvimento de estratégias de manejo realistas para garantir a manutenção das funções ecológicas importantes desempenhadas pelas agroflorestas.

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CAPÍTULO I:

A META-ANALYSIS OF THE EFFECTS OF ANTHROPOGENIC DISTURBANCES ON TROPICAL MAMMAL FUNCTIONAL DIVERSITY

Artigo aceito para publicação na Mammal Review

A meta-analysis of the effects of anthropogenic disturbances on tropical mammal functional diversity

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Abstract

1. Understanding the processes that shape biological communities under a variety of perturbations is a central challenge in ecology and conservation. Mammals contribute to critical functional processes of an ecosystem, such as seed dispersal to maintain forest carbon stocks.

2. The analysis of functional diversity, which measures the range and value of the ecological traits of organisms, provides critical information to understanding the link between biodiversity and ecosystem functioning.

3. A growing number of studies have investigated the effects of anthropogenic disturbances on mammalian functional diversity, however their results are very heterogeneous.

4. Here, we conduct a comprehensive meta-analysis of the effects of such anthropogenic disturbances on mammalian functional diversity in the tropics. We highlight major trends and analyze the influence of the type of anthropogenic disturbance, subgroups, and the functional diversity index used/applied.

5. Our results indicate a negative effect of anthropogenic disturbances on mammalian functional diversity, particularly on functional richness (FRic) and functional dispersion (FDis). Habitat isolation was the stressor with the strongest effect, while agriculture and urbanization showed a positive link with functional diversity.

6. These results indicate that anthropogenic disturbances not only affect taxonomic diversity, but also reduce the functional diversity of mammals, which is likely to affect ecosystem functioning and possibly ecosystem service provision.

Keywords: Functional traits, mammalian, tropical regions, habitat isolation, ecological functions.

Running head: Anthropic effect in mammal's functional diversity

Introduction

Growing human populations and the increasing demand for natural resources have severely impacted biodiversity, with many natural habitats included in the mosaics of land converted to human use (Cisneros et al. 2015). Agriculture, hunting, logging, and especially habitat loss and fragmentation, are known to be strong predictors of loss of mammalian diversity (Gonzalez-Suarez et al. 2013, Brodie et al. 2021). Several studies have documented the effects of anthropogenic disturbances on species loss (Chiarello 1999, Umetsu & Pardini 2006, Lyra-Jorge et al.2009, Dotta & Verdade 2011), but other dimensions, such as phylogenetic and functional diversity, are still poorly addressed.

Knowledge of functional diversity provides essential information for understanding the relationship between organisms and their functions in the ecosystem. It is therefore considered important for assessing the anthropogenic impacts on ecosystem processes. The position and amount of functional space occupied by species, for example, can be related to the use of environmental resources, such as food, territory and sexual partners, composing different dimensions of functional diversity. Each species has a unique set of traits that are associated with one or more functions. Thus, if a species is negatively affected by some disturbance, its functions may also be affected, providing a different response compared to traditional measurements such as species richness (Safi et al.2011, Mouillot et al. 2013). Species extinction can be caused by a variety of factors. However, there is no consensus about which anthropogenic threats cause declines in functional diversity (Brodie et al. 2021). Changes in environmental conditions after disturbance can act as a filter, allowing only a narrow spectrum of traits to persist (Edwards et al. 2014).

A growing number of studies have identified functional diversity as a crucial tool for assessing ecosystem processes. The development of indices that measure functional traits and express species distribution in a multidimensional space (Petchey & Gaston 2006, Villéger et al. 2008) is driven by the need to quantify the facet of diversity related to the numerous complementary components of the functional structure of communities. However, the relationship between these indices is not well established. Some are highly correlated, and there is still no consensus on the ideal ones to use (Mouchet et al. 2010). The choice of the index can influence the outcome of the analysis. Ideally, the use of a combination of indices that address these complementary characteristics would allow a more complete assessment of the situation (Mouchet et al. 2010).

Despite the important ecological functions of mammals, such as seed dispersal, predation and population regulation, and their role as parasite reservoirs and disease vectors (Ahumada et al. 2011), studies relating mammalian functional diversity to anthropogenic disturbances are still scarce and reveal heterogeneous results (Edwards et al. 2014). This heterogeneity may be related to the fact there is a wide range of different anthropogenic disturbances that affect mammals in different regions (Ahumada et al. 2011, Edwards et al. 2014). Furthermore, distinct species are known to respond differently to disturbances, with some species being more affected than others. Changes in the environment can affect the abundance of distinct species. Those that perform unique functions in ecosystems are of particular interest in this context. If human-induced disturbances affect species with these characteristics or significantly reduce their abundance in the community, ecosystem function is more likely to be impaired (Mouillot et al. 2013).

Here, we report the existence of general patterns of how mammalian functional diversity responds to anthropogenic disturbances and identify trends and knowledge gaps based on a systematic review of the literature. Using a meta-analytic approach, we assessed the general effects and factors that can contribute to the idiosyncrasy of the results observed in previous studies, including study region, mammalian group studied, the possible effects of the methodological approaches (i.e., different indices), and the type of anthropogenic disturbance. We expected that:

I. Functional diversity would be negatively related to anthropogenic disturbances (however, we predicted different responses depending on the particular disturbance).

II. More negative impacts would occur on medium and large mammals because of their larger home ranges and higher vulnerability to anthropogenic disturbances, especially stressors associated with habitat loss and fragmentation (Magioli et al. 2021).

III. Functional richness metrics would show stronger negative responses to anthropogenic disturbances compared to other metrics because they can efficiently discriminate assembly rules implicit in the community structure, independent of species richness (Mouchet et al. 2010, Luck et al. 2013).

IV. More negative effects would be associated with habitat loss and fragmentation, hunting, and logging than with other anthropogenic disturbances (e.g., urbanization), which have already been shown to be detrimental to different dimensions of biodiversity (Ahumada et al. 2011). Conversely, agriculture has been found to have varying impacts, depending on the type of management (Flynn et al. 2009).

Methods

2.1 Data collection

We conducted our literature search for studies that have examined the relationship between anthropogenic disturbances and any indices that denote mammalian functional diversity using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to search for papers (Moher et al. 1999). We searched the Web of Science and Scopus databases for peer-reviewed scientific papers using the following search terms: ("functional diversity") AND ("mammal*") AND ("disturbance" OR "degradation" OR "conversion" OR "alteration" OR "fragmentation" OR "disturbance" OR "habitat loss" OR "agriculture" OR "hunting" OR "poaching"). A second search was conducted using only the terms "functional diversity" AND "mammals" to further increase the number of studies. The terms were searched in the title, abstract, keywords, and main text. To supplement our dataset, we performed a search of grey literature studies in Google Scholar, including thesis and dissertations, using the search terms "functional diversity" AND "mammals.”

The inclusion criteria included studies that: 1. Reported effects of anthropogenic disturbances compared to control areas (areas that, according to the authors, have not suffered from anthropogenic disturbances, generally protected areas or continuous forests) or examined effects across a gradient of disturbances on functional diversity. 2. Provided sufficient data for meta-analysis (i.e., statistical test values and sample sizes). A total of 556 scientific articles were found (245 in Web of Science and 311 in Scopus). Of these, 229 were eliminated because they were duplicates and 290 because they did not address the topic of interest. Of the remaining 37 articles that related functional diversity to anthropogenic disturbances, 11 did not have the necessary data for meta-analysis. Subsequently, six thesis or dissertations and three articles were added to the references based on a Google Scholar search. Therefore, the final meta-analysis included 35 studies that assessed the effects of anthropogenic disturbances on mammalian functional diversity (Appendix S1 and Appendix S2).

The studies were published between 2011 and 2022 (Figure 1). In general, they used more than one index and/or examined the effects of more than one anthropogenic disturbance. We considered each outcome to be independent, resulting in 35 studies with 147 effect sizes. The effect size is a statistical parameter used to compare the results of different studies on the same scale (Koricheva et al. 2013); that is, the number of comparisons that measure the variable of interest (in this case, we had 147 comparisons that measured the anthropogenic impacts on mammalian functional diversity).

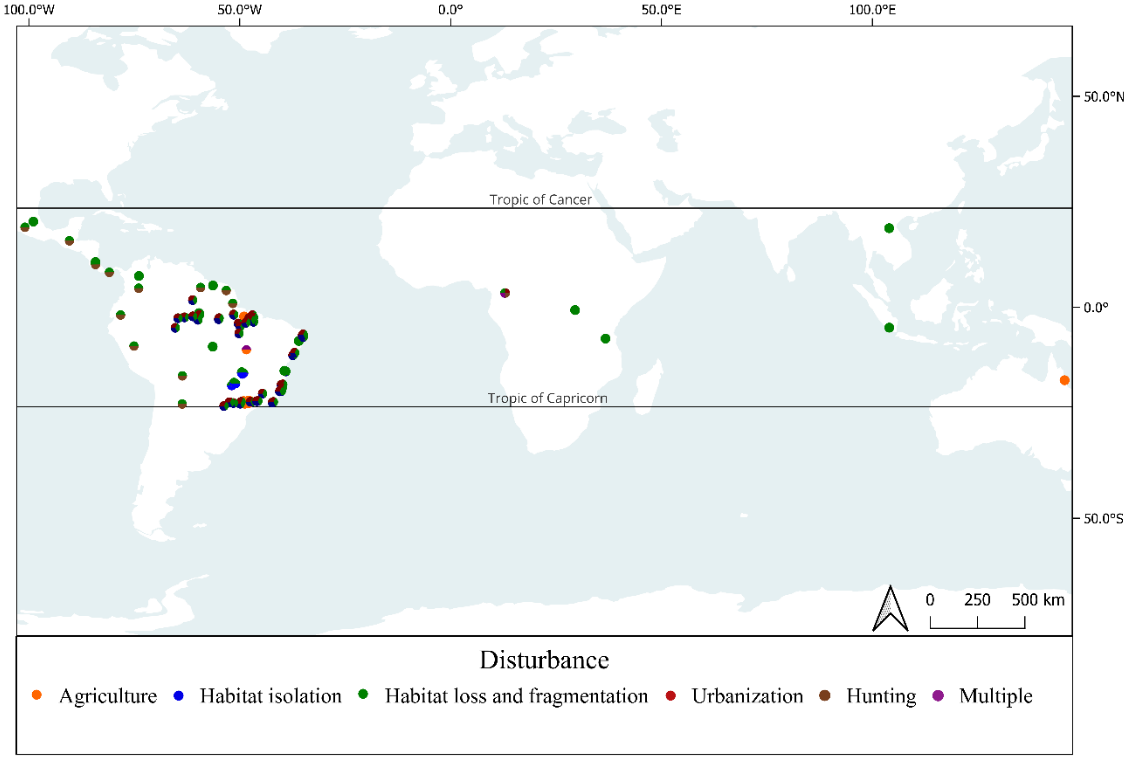

Figure. 1. Geographic distribution of tropical sites that were included in the meta-analysis. Solid circles are color-coded according to the threat reported in each study (see legend). For more information, see Table S2 of the supplementary material.

2.2. Data extraction

From each study that compared the disturbed and control areas, we extracted the sample size (sample sites in each study), mean functional diversity index, and error estimates (standard error or variance) for each treatment. For studies that evaluated anthropogenic disturbances (Table 1, e.g., agriculture, hunting, habitat loss, and fragmentation), we extracted the sample size and the correlation coefficient (r). If the authors reported the data only in figures, we used ImageJ or GetData Graph Digitizer to extract the values. We also collected information on the region where the study was conducted (tropical or temperate), the functional diversity index used (e.g., functional richness, functional dispersion), the group of terrestrial mammals evaluated (bats, small, medium, and large mammals; or all mammals) (Chiarello 2000, Paglia et al. 2012).

Table 1. Subgroups were used to explore the heterogeneity of responses to studies of anthropogenic disturbances on mammalian functional diversity. Due to sample size issues, we were unable to include all categories of index type and anthropogenic disturbance. Therefore, each subgroup analysis is limited to a subset of studies and comparisons.

Subgroup	Categories (n. of studies/n. of comparisons)
1. Group	1.1 All mammals (6/30) All non-aquatic mammals, regardless of the group. 1.2 Bats (5/19) Volant mammals. 1.3 Medium and large (11/61) Mammals weighing more than 1 kg. 1.4 Small mammals (5/14) Mammals weighing less than 1 kg.
2. Index	2.1 Functional diversity (FD) (8/25) 2.2 Functional dispersion (FDis) (9/30) 2.3 Functional divergence (FDiv) (5/11) 2.4 Functional evenness (FEve) (7/15) 2.5 Functional richness (FRic) (8/11) 2.6 Rao's quadratic entropy (RaoQ) (6/18)
3. Disturbance	3.1 Agriculture (7/21) Studies evaluating the impact of agricultural production systems, pasture and agrosilvopastoral practices. 3.2 Habitat loss and fragmentation (18/77) Studies that evaluated the effects of the reduction in the amount of habitat in the landscape or the size of the fragments. 3.3 Habitat isolation (4/5) Studies that evaluated the effects of fragment isolation or connectivity metrics. 3.4 Hunting (3/8) Studies that evaluated the effect of hunting. 3.5 Urbanization (3/4) Studies that evaluated the effects of urban sprawl. 3.6 Multiple (2/3) When the study considered more than one type of anthropogenic disturbance but did not distinguish the effects separately.

2.3 Meta-analysis

a) Effect size

We used two approaches to calculate effect sizes, following common procedures in meta-analyses of diversity data (Hillebrand 2016, Kinlock et al. 2018). When a study compared functional diversity between a control site and a degraded site, Hedge's d was calculated from the difference in values between the two categories. The d-value was obtained from a measure of the mean, deviation, or standard error provided in the article for the control and treatment groups. The d-value was then converted to a zr-value, which is a measure of the effect size for continuous data, using a web calculator (www.psychometrica.de/effect_size.html). If a study reported correlation or other basic statistical test results, such as Z-scores, Student's t, F, or R^2 statistics assessing functional diversity and anthropogenic disturbance, the significance values and test statistics of these metrics were converted to correlation coefficients (Koricheva et al. 2013). Therefore, we converted the correlation coefficients to the zr-values.

b) Meta-analytical models and moderators

After computing individual effect sizes, we assessed the overall effect size along with the corresponding 95% confidence intervals utilizing a multilevel meta-analytic model implemented with the 'rma.mv' function from the 'metafor' package (Viechtbauer 2010) in the R software (R Core Team, 2023). This model is generally chosen when individual effect sizes are not independent. By relaxing the assumptions of independence inherent in fixed-effect and random-effect models, we could specify random effects, especially in scenarios involving multiple effect sizes from the same study (Koricheva et al.2013, Nakagawa et al. 2017). Thus, we incorporated study identity and effect size within each study as random factors to estimate variations between and within studies, respectively [R syntax: random = list (~1|Study ID/individual effect ID)] (Felix et al. 2023). Positive z-values in this context denote an increase in functional diversity in a degraded environment, while negative values indicate a decrease. Effects were considered non-significant if the confidence intervals overlapped zero.

To investigate the effect of explanatory variables on effect sizes, we formed subgroups and used a meta-analysis of mixed-effects models to explore the heterogeneity of study responses to anthropogenic disturbance of mammal functional diversity with three moderators: i. Taxonomic group (small mammals and bats; medium and large mammals; and a third subgroup with unspecific combinations including all types of non-aquatic mammals, which we called "all mammals"). We classified medium and large mammals as those weighing more than 1 kg (Chiarello 2000, Paglia et al. 2012). ii: Functional diversity index (functional diversity, functional dispersion, functional divergence, Rao quadratic entropy, functional richness, and functional uniformity). iii: The type of anthropogenic disturbance studied (agriculture, habitat isolation, habitat loss and fragmentation, urbanization, hunting, and multiple if more than one anthropogenic disturbance was considered). We decided not to include comparisons from a single study in order to obtain more robust estimates (Table 1). Therefore, some indices (functional originality, mean closest taxon distance, standardized mean distance from the closest taxon, functional specialization, mean paired distance, mean paired functional distance, mean closest taxon functional distance) and types of anthropogenic disturbances (defaunation, large dam construction, local extinction, logging) were not used in the analyses of the respective moderators.

c) Publication bias

We checked for possible publication bias as well as the strength of our results using funnel plots and Egger's regression test (statistical approach) (Egger et al. 1997). When the intercept of our regression model was greater than 0, this indicated asymmetry of the data. For significant results, we also used Rosenthal's fail-safe number (FSN) to calculate the number of studies with nonsignificant effect sizes that would need to be included in our analyses to make our results nonsignificant (Rosenthal 1979, Rosenberg

2005, Fragkos et al. 2014). To compare the zr between different groups of studies, we used heterogeneity analysis (Q statistic) to test the homogeneity of categorical groups with respect to effect sizes using a random effects model (Koricheva et al. 2013). In complementation, we estimated I^2 to test heterogeneity across studies in the models. This statistic indicates the percentage of variation due to data heterogeneity rather than chance (Higgins et al. 2003). All analyses were performed in R (R Core Team, 2023), using the Metafor package (Viechtbauer 2010).

Results

Of the 147 effect sizes calculated, most were measured in the tropics (n = 124), while temperate regions were underrepresented (n = 23). Because we found few studies in temperate region that met our inclusion criteria, we decided to focus our analyses only on tropical regions, with 124 effect sizes. These studies investigated medium and large mammals (n = 61), small mammals (n = 14), bats (n= 19) and all mammals (n = 30). The functional diversity indexes that were most studied were functional dispersion (n=30), functional diversity (n=25), Rao quadratic entropy (n = 18), functional evenness (n = 15), functional richness, and functional divergence, both with (n=11). Habitat loss and fragmentation (n = 77), agriculture (n = 21), multiple factors (n = 3), hunting (n = 8), habitat isolation (n = 5), and urbanization (n = 4) were the most common anthropogenic disturbances.

The overall mean effect size for all 124 comparisons was (zr = -0.12, [CI 95: -0.28; 0.04], Fig. 2), which indicated that anthropogenic disturbances had a negative but not significant effect on the functional diversity of mammals when all metrics were combined. Total heterogeneity was high and significant (Q = 797.15; p <0.001), and the heterogeneity due to random effect within and between studies was moderate (within study estimates = 0.08, square root = 0.29, I^2 = 38.38%; between study estimates = 0.13, square root =0.36, 56.51%).

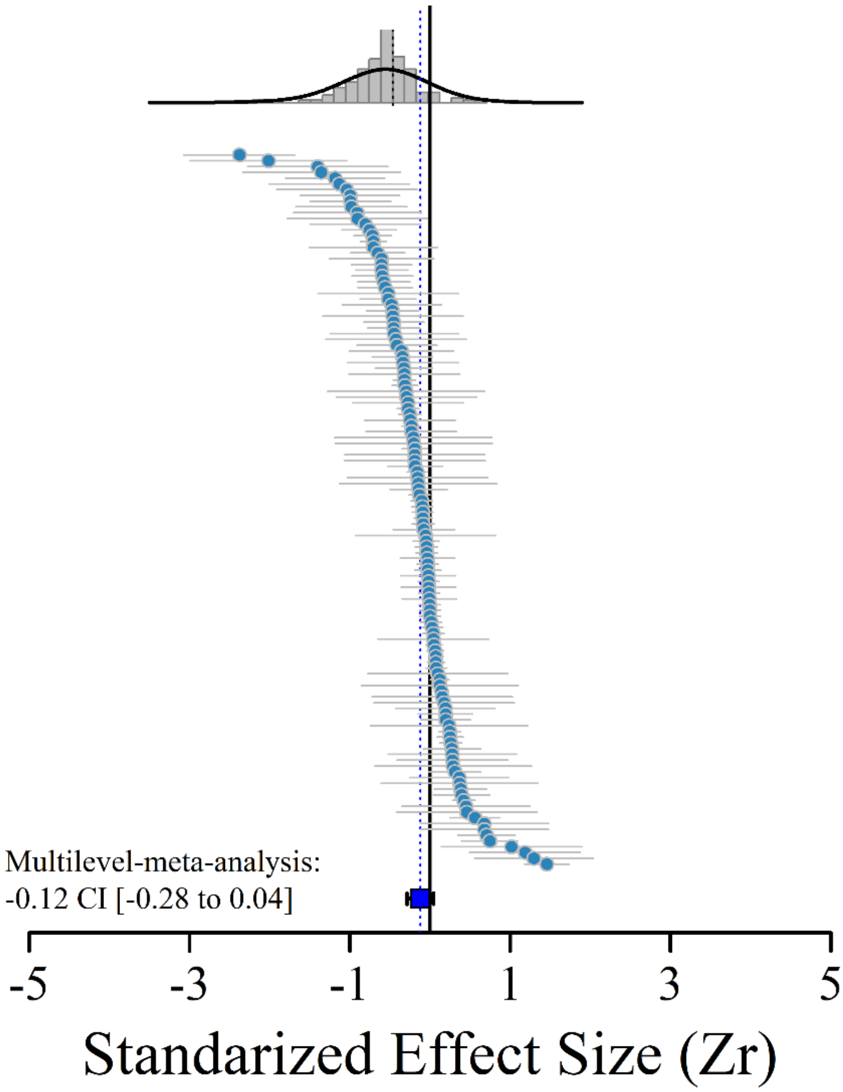

Figure. 2. Forest plot of the 124 effect size estimates in all studies examined. At the top of the histogram is the distribution of effect size. Horizontal grey lines indicate a 95% confidence interval (CI) of the individual effect size. The blue square near the bottom is the estimated overall weighted mean effect based on a multilevel meta-analytic model.

The effect size analysis based on different moderators revealed negative outcomes of mammalian functional diversity for some metrics. We found a significant negative effect of anthropogenic disturbances on functional diversity for studies performed for all mammals (-0.42 [CI 95: -0.76; -0.07]), and among studies that used functional richness (-0.40 [CI 95: -0.72; -0.08]) and functional dispersion (-0.31 [CI 95: -0.59; -0.03]).

Finally, among the anthropogenic disturbance types investigated, only habitat isolation negatively affected functional diversity (-0.61 [CI 95: -1.03; -0.18]). For the remaining mammal groups and disturbance variables, there were no substantial differences between areas with more or less anthropogenic disturbance. We found non-significant differences in heterogeneity for most moderators, indicating homogeneity among the parameters used (Fig. 3).

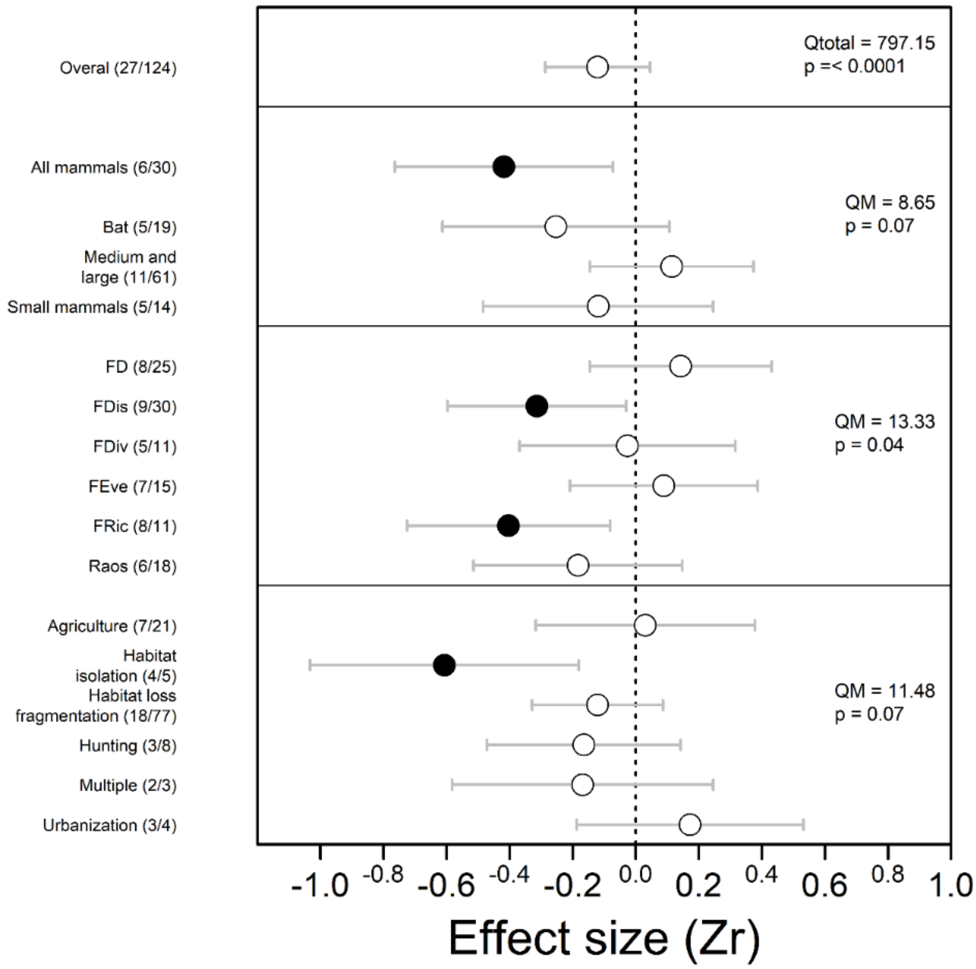

Figure. 3. Effect size estimates based on multilevel meta-analytic model. Here, we compare the effect size based on the moderators used. If the confidence interval includes

zero, we consider the effect to be not significant (white circles), while the black circles represent the significant effect size (confidence intervals that do not overlap zero). QM represents the statistical test of heterogeneity between groups of studies. On the left, the categories of each group are presented with the number of studies and individual comparisons in parentheses.

For the moderators, we found non-significant differences in heterogeneity, indicating homogeneity among the parameters used (Taxonomic group: QM = 8.65, p = 0.07; Functional diversity index: QM = 13.33, p = 0.04; Type of anthropogenic disturbance: QB = 11.48, p = 0.07). The Rosenthal fail-safe number (FSN) for all mammals (370 studies), functional richness (76 studies), functional dispersion (425 studies), and habitat isolation (39 studies) was large, relative to the number of independent comparisons included in the meta-analysis (30 studies, 11 studies, 30 studies, and 5 studies, respectively), indicating the strength of our results. We did not find evidence of publication bias from visual inspection of funnel plots (effect size versus sample size). There was a lack of relationship between effect size and publication year (Appendix S3). Egger's test intercept was less than 0 (Appendix S4), which reinforces the absence of publication bias and indicates the strength of our results.

Discussion

Based on our results, we accept predictions I and III. Our findings demonstrate that anthropogenic disturbances generally reduce the functional diversity of mammals, particularly when assessing functional richness (FRic). However, we did not find any specific results related to medium and large mammals, habitat loss and fragmentation, hunting, or logging. We will discuss each topic in detail below.

We found that anthropogenic disturbances tend to negatively affect the functional diversity of mammals. Given that similar patterns of diversity loss have already been observed for other facets of diversity (i.e., taxonomic, phylogenetic, and genetic diversity) (Lino et al. 2019, Brodie et al. 2021, Romero-Muñoz et al. 2021), demonstrating that in disturbed environments, not only are individual species lost, but also functional attributes and broader ecological functions.

Our research revealed that a significant number of studies have been conducted in tropical regions, with a relative gap in temperate regions. To improve the evaluation of this topic, it is necessary to conduct new studies, particularly in regions such as Europe and the United States, which have not yet been evaluated. There is a consensus that tropical regions are hosts to the greatest species richness on the planet, but the same pattern is not clear when observing functional diversity (Feng et al. 2020), although there is a correlation between species richness and functional diversity that is not linear. The pattern of functional diversity is related to the way species have colonized the planet over time, with biological traits shaped by processes such as speciation, extinction, and dispersal, among others, making it complex to understand (Davies et al. 2008, Safi et al. 2011). At a certain point, the increase in the number of species stabilizes functional diversity because of the increase in redundant functions (Safi et al.2011). Although numerous species perform redundant functions in tropical regions, they face greater anthropogenic threats, rendering these communities more susceptible to loss of functional diversity.

We found that the effects were most significant when all mammals were evaluated together. Contrary to our expectations, a positive trend was observed, but with non-significant effects for medium and large mammals when evaluated separately from the other groups. This result should be interpreted with caution, since some anthropogenic disturbances, such as hunting, which can have an important effect on reducing the functional diversity of mammals (Brodie et al. 2021), have been poorly studied because of the practical difficulty in quantifying these effects (Arévalo-Sandi et al.2018, Laméris et al. 2020). In contrast, we found a trend towards a negative effect on the functional diversity of small mammals in the most degraded areas. In general, because of their smaller body size, these animals have a lower dispersal capacity, often depend only on the resources available in vegetation fragments, and are more affected by anthropogenic disturbances, which are mainly influenced by landscape characteristics such as the size of the natural vegetation fragments and reduced landscape connectivity (Bovendorp et al. 2019, de la Sancha et al.2020, Palmeirim et al. 2021). As forest areas decline, small mammals gradually go extinct. However, this extinction may not necessarily reduce functional diversity because other species with redundant attributes can take over their ecological functions (Palmeirim et al. 2021). The presence of medium and large mammals can also influence the functional diversity of small mammals, as shown in a study in the Atlantic Forest, a highly fragmented biome where areas with greater richness of medium and large mammals had a lower functional diversity of small mammals, but this functional diversity increased according to forest patch size (Bovendorp et al. 2019).

The use of functional diversity indices along perturbation gradients can reveal the most direct effects on the community structure (Cornwell et al. 2006). Currently, there is a wide variety of functional diversity indices (Villéger et al. 2008), each of which captures different aspects of the functional space. We observed that the indices respond differently to anthropogenic disturbances. Consistent with our predictions, anthropogenic disturbances caused a significant reduction in functional richness, since this index measures the volume of functional space occupied by all species in the community (Villéger et al.2008). Thus, in highly disturbed environments, there is a filtering of species through the filtering of traits, causing a reduction in this functional diversity dimension. In disturbed areas, the amount of functional space occupied by species is smaller, and existing resources are used inefficiently (Mouillot et al.2013). Additionally, anthropogenic disturbance was found to have a negative impact on functional dispersion (FDis), which measures the abundance distribution in a species' characteristic functional space. This suggests that areas with greater anthropogenic disturbance have greater resource competition, potentially reducing the occurrence and abundance of species. Therefore, niche complementarity may play a role in mitigating these effects (Mason et al.2013).

We also found that habitat isolation had a negative effect on mammalian functional diversity, with results similar to those found for birds (Matuoka et al. 2020), where continuous forests in more connected landscapes had greater functional diversity. Connectivity between areas also allows greater gene flow and increases the availability of habitats, increasing the number of available resources, whereas smaller and more isolated fragments have a limited number of available niches, often supporting a limited number of functional traits (Magioli et al.2015, Ehlers Smith et al. 2020).

Although they showed a positive trend, the evaluation of agriculture and urbanization did not yield significant results. It is important to mention that although there were no apparent negative effects, other factors like crop type and land use intensity (which were not assessed in this study) could impact these findings (Etard et al. 2022). Etard (2022) also found a similar pattern with no significant results for mammals. However, there was a decrease in FRic in both intensely used areas and those with little use, but no reduction overall. Additionally, there was a trend of functional improvement in mammal communities in agricultural and urban regions, contrary to our expectations. Further research indicated that disturbed areas have a higher chance of non-native and functionally novel species colonization, which could potentially offset any local functional decline. Furthermore, these areas can enhance the resource availability from crops, thereby increasing the likelihood of synanthropic species occupying them (Etard et al. 2022).

This meta-analysis provides valuable information on how anthropogenic threats are affecting mammalian functional diversity, demonstrating the importance of using complementary indices, and in particular, the effect of habitat isolation. Overall, we observed that mammalian functional diversity can change under anthropogenic pressures, allowing a better understanding of which threats are causing changes and where they are most intense. Understanding species responses and possible threat patterns can be a powerful basis for conservation planning and management. Future work should be based on direct measurements of organism characteristics in communities under different land use management practices at different landscape scales and should seek to assess characteristics of specific ecosystem processes. It is also important for studies to evaluate how these anthropogenic disturbances affect different groups of mammals, since they play important ecological roles, and even if there is a substitution of functions, this may be accompanied by a simplification of communities.

Data Availability Statement

The data supporting the conclusions of this study are openly available on "Mendeley Data": V4, doi: 10.17632/wrrwnkb4yk.4

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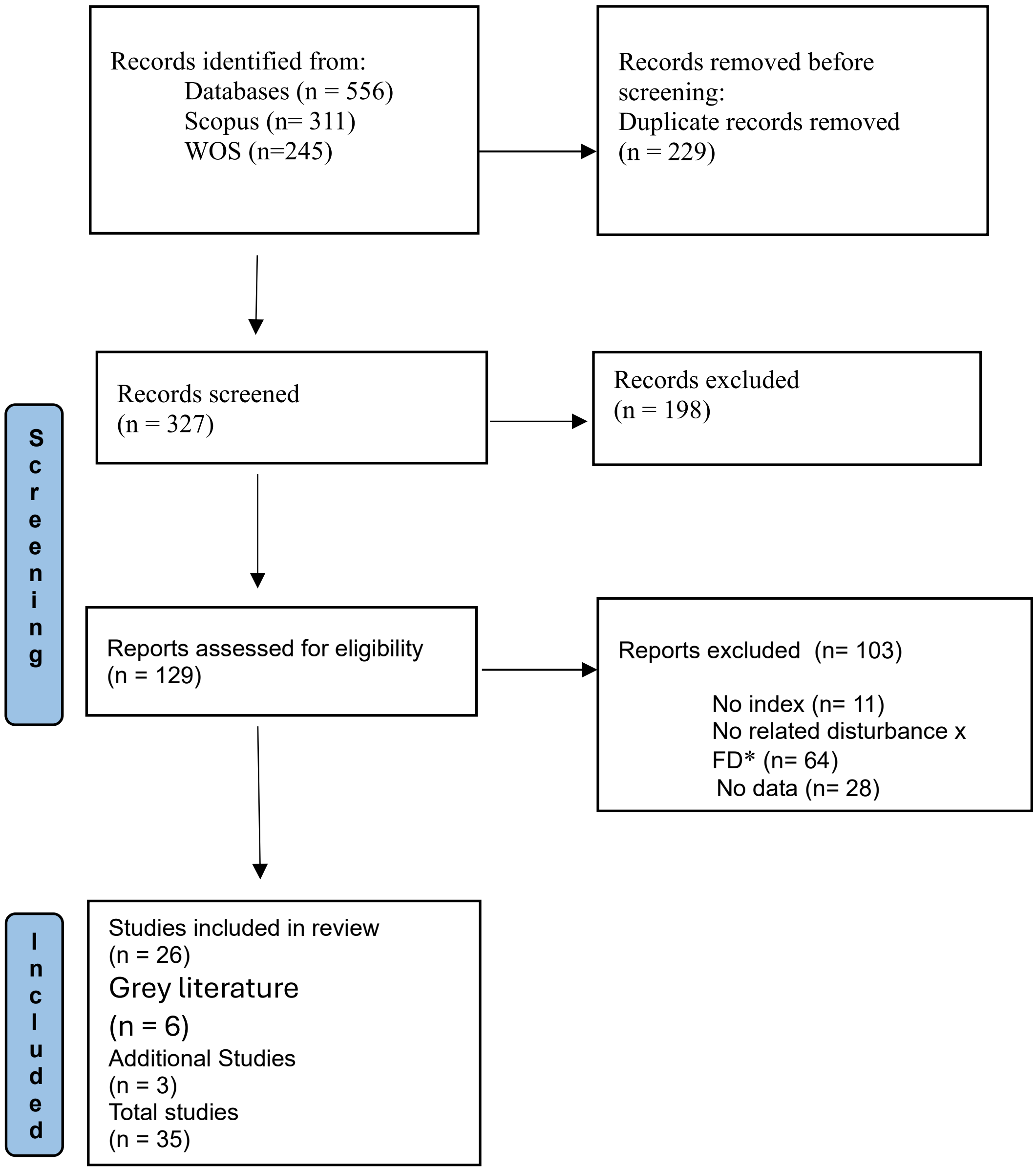
Supporting Information

Appendices (Supporting Tables and Figures) for "A meta-analysis of the effects of anthropogenic disturbances on tropical mammal functional diversity"



Appendix S1: Sequence of information in the different phases of a systematic review using the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes) (Page et al. 2021).

*FD: Functional diversity

Appendix S2: List of studies included in the meta-analysis.

year	author	Title	Journal	Repository	Index type	Group	disturbance	Country of study	sample size
2011	Ahumada etal	Community structure and diversity of tropical forest mammals: Data from a global camera trap network	Philosophical Transactions of the Royal Society B: Biological Sciences	Scopus	FDis*	All mammals	Habitat loss fragmentation	Multiple	7
2012	Lima	Estrutura da comunidade de mamíferos de médio e grande porte em uma paisagem fragmentada com matriz de eucalipto, Capão Bonito e Buri, SP.	USP-dissertação	Google Scholar	FD	Medium and large	Agriculture	Brazil	11
2012	Lima	Estrutura da comunidade de mamíferos de médio e grande porte em uma paisagem fragmentada com matriz de eucalipto, Capão Bonito e Buri, SP.	USP-dissertação	Google Scholar	FD	Medium and large	Agriculture	Brazil	10
2012	Lima	Estrutura da comunidade de mamíferos de médio e grande porte em uma paisagem fragmentada com matriz de eucalipto, Capão Bonito e Buri, SP.	USP-dissertação	Google Scholar	FD	Medium and large	Agriculture	Brazil	11
2014	Maués	Efeito do plantio de dendê (Elaeis guineensis Jacquin 1763) sobre a diversidade funcional de mamíferos terrestres.	Museu Paraense Emílio Goeldi-dissertação	Google Scholar	FD	Medium and large	Agriculture	Brazil	13
2015	Magioli	Thresholds in the relationship between functional diversity and patch size for mammals in the Brazilian Atlantic Forest	Animal Conservation	web of science	FD	Medium and large	Habitat loss fragmentation	Brazil	53
2016	Magioli etal	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes	European Journal of Wildlife Research	web of science	FD	All mammals	Habitat isolation	Brazil	8
2016	Magioli etal	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes	European Journal of Wildlife Research	web of science	FD	All mammals	Habitat loss fragmentation	Brazil	8
2016	Magioli etal	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes	European Journal of	web of science	FD	All mammals	Habitat loss fragmentation	Brazil	8

			Wildlife Research						
2016	Magioli etal	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes	European Journal of Wildlife Research	web of science	FD	All mammals	Habitat isolation	Brazil	8
2016	Magioli etal	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes	European Journal of Wildlife Research	web of science	FD	All mammals	Agriculture	Brazil	8
2016	Magioli etal	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes	European Journal of Wildlife Research	web of science	FD	All mammals	Agriculture	Brazil	8
2016	Garcia-Morales etal	Deforestation Impacts on Bat Functional Diversity in Tropical Landscapes	PLoS ONE	references	FD	Bat	Habitat loss fragmentation	Mexico	36
2016	Garcia-Morales etal	Deforestation Impacts on Bat Functional Diversity in Tropical Landscapes	PLoS ONE	references	FD	Bat	Habitat loss fragmentation	Mexico	36
2016	Garcia-Morales etal	Deforestation Impacts on Bat Functional Diversity in Tropical Landscapes	PLoS ONE	references	FD	Bat	Habitat loss fragmentation	Mexico	36
2016	Garcia-Morales etal	Deforestation Impacts on Bat Functional Diversity in Tropical Landscapes	PLoS ONE	references	FEve	Bat	Habitat loss fragmentation	Mexico	36
2016	Garcia-Morales etal	Deforestation Impacts on Bat Functional Diversity in Tropical Landscapes	PLoS ONE	references	FEve	Bat	Habitat loss fragmentation	Mexico	36
2016	Garcia-Morales etal	Deforestation Impacts on Bat Functional Diversity in Tropical Landscapes	PLoS ONE	references	FEve	Bat	Habitat loss fragmentation	Mexico	36
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FD	All mammals	Habitat loss fragmentation	Mexico	39
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FEve	All mammals	Habitat isolation	Brazil	39

2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FEve	All mammals	Habitat loss fragmentation	Brazil	39
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FDiv	All mammals	Habitat loss fragmentation	Brazil	39
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FDiv	All mammals	Habitat loss fragmentation	Brazil	39
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FDiv	All mammals	Habitat loss fragmentation	Brazil	39
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FD	All mammals	Habitat loss fragmentation	Brazil	33
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FEve	All mammals	Habitat loss fragmentation	Brazil	33
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FEve	All mammals	Urbanization	Brazil	33
2016	Campos	O efeito da fragmentação na diversidade específica e funcional de primatas no Brasil	Dissrtação-Unesp	Google Scholar	FDiv	All mammals	Habitat loss fragmentation	Brazil	33
2016	Velez Garcia	Diversidade taxonômica e funcional de pequenos mamíferos em paisagens antrópicas da Mata Atlântica do Sul da Bahia, Brasil	UESC-Tese	references	FRic	Small mammals	Habitat loss fragmentation	Brazil	11
2016	Velez Garcia	Diversidade taxonômica e funcional de pequenos mamíferos em paisagens antrópicas da Mata Atlântica do Sul da Bahia, Brasil	UESC-Tese	references	FEve	Small mammals	Habitat loss fragmentation	Brazil	11
2016	Velez Garcia	Diversidade taxonômica e funcional de pequenos mamíferos em paisagens antrópicas da Mata Atlântica do Sul da Bahia, Brasil	UESC-Tese	references	FDiv	Small mammals	Habitat loss fragmentation	Brazil	11
2017	Arévalo-Sandi etal	Diversity of terrestrial mammal seed dispersers along a lowland Amazon forest regrowth gradient	PLoS ONE	Scopus	FDis	Medium and large	Habitat loss fragmentation	Brazil	30
2017	Arévalo-Sandi etal	Diversity of terrestrial mammal seed dispersers along a lowland Amazon forest regrowth gradient	PLoS ONE	Scopus	FDis	Medium and large	Hunting	Brazil	30
2017	Arévalo-Sandi etal	Diversity of terrestrial mammal seed dispersers along a lowland Amazon forest regrowth gradient	PLoS ONE	Scopus	FDis	Medium and large	Habitat loss fragmentation	Brazil	30
2017	Arévalo-Sandi etal	Diversity of terrestrial mammal seed dispersers along a lowland Amazon forest regrowth gradient	PLoS ONE	Scopus	FDis	Medium and large	Habitat loss fragmentation	Brazil	15
2017	Derhe etal	Recovery of mammal diversity in tropical forests: a functional approach to measuring restoration	Restoration Ecology	web of science	FEve	All mammals	Agriculture	Australia	11

2017	Derhe etal	Recovery of mammal diversity in tropical forests: a functional approach to measuring restoration	Restoration Ecology	web of science	FDis	All mammals	Agriculture	Australia	11
2017	Derhe etal	Recovery of mammal diversity in tropical forests: a functional approach to measuring restoration	Restoration Ecology	web of science	FRic	All mammals	Agriculture	Australia	11
2017	Derhe etal	Recovery of mammal diversity in tropical forests: a functional approach to measuring restoration	Restoration Ecology	web of science	FDiv	All mammals	Agriculture	Australia	11
2017	Zimbres etal	Terrestrial mammal responses to Habitat structure and quality of remnant riparian forests in an Amazonian cattle-ranching landscape	Biological Conservation	Scopus	FD	Medium and large	Habitat loss fragmentation	Brazil	43
2017	Zimbres etal	Terrestrial mammal responses to habitat structure and quality of remnant riparian forests in an Amazonian cattle-ranching landscape	Biological Conservation	Scopus	FD	Medium and large	Habitat loss fragmentation	Brazil	43
2018	Bovendorp etal	Defaunation and fragmentation erode small mammal diversity dimensions in tropical forests	Ecography	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	283
2018	Bovendorp etal	Defaunation and fragmentation erode small mammal diversity dimensions in tropical forests	Ecography	Scopus	Rao's	Small mammals	Defaunation	Brazil	283
2018	Bovendorp etal	Defaunation and fragmentation erode small mammal diversity dimensions in tropical forests	Ecography	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	283
2018	Farneda etal	Functional recovery of Amazonian bat assemblages following secondary forest succession	Biological Conservation	references	Rao's	Small mammals	Habitat loss fragmentation	Brazil	13
2018	Farneda etal	Functional recovery of Amazonian bat assemblages following secondary forest succession	Biological Conservation	references	Rao's	Bat	Habitat loss fragmentation	Brazil	13
2018	Farneda etal	Functional recovery of Amazonian bat assemblages following secondary forest succession	Biological Conservation	references	Rao's	Bat	Habitat loss fragmentation	Brazil	12
2018	Farneda etal	Functional recovery of Amazonian bat assemblages following secondary forest succession	Biological Conservation	references	Rao's	Bat	Habitat loss fragmentation	Brazil	13
2018	Farneda etal	Functional recovery of Amazonian bat assemblages following secondary forest succession	Biological Conservation	references	Rao's	Bat	Habitat loss fragmentation	Brazil	13
2018	Farneda etal	Functional recovery of Amazonian bat assemblages following secondary forest succession	Biological Conservation	references	Rao's	Bat	Habitat loss fragmentation	Brazil	12
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FRic	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FEve	Medium and large	Agriculture	Brazil	7

2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FDiv	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FRic	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FEve	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FDiv	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FRic	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FEve	Medium and large	Agriculture	Brazil	7
2018	Begotti etal	Landscape context of plantation forests in the conservation of tropical mammals	Journal for Nature Conservation	web of science	FDiv	Medium and large	Agriculture	Brazil	7
2018	Pereira etal	Loss of multiple dimensions of bat diversity under land-use intensification in the Brazilian Cerrado	Hystrix-Italian Journal of Mammalogy	web of science/ref	FDis	Bat	Multiple	Brazil	18
2018	Pereira etal	Loss of multiple dimensions of bat diversity under land-use intensification in the Brazilian Cerrado	Hystrix-Italian Journal of Mammalogy	web of science/ref	FDis	Bat	Agriculture	Brazil	18
2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat loss fragmentation	Brazil	9
2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat loss fragmentation	Brazil	9
2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat loss fragmentation	Brazil	9

2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat loss fragmentation	Brazil	9
2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat loss fragmentation	Brazil	9
2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat isolation	Brazil	9
2018	Oliveira	Patch attributes affect the functional diversity of forest medium-and large-sized mammals	Dissertação-Instituto Federal Goiano	Google Scholar	FD	Medium and large	Habitat loss fragmentation	Brazil	9
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FRic	All mammals	Hunting	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FRic	All mammals	Habitat loss fragmentation	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FEve	All mammals	Hunting	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FEve	All mammals	Habitat loss fragmentation	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FDiv	All mammals	Habitat loss fragmentation	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FDiv	All mammals	Hunting	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FDis	All mammals	Habitat loss fragmentation	Multiple	201
2019	Treichl	Efeito da perda de hábitat e pressão de caça sobre a diversidade funcional de primatas na América	TCC-Unesp	Google Scholar	FDis	All mammals	Hunting	Multiple	201
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Hunting	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Habitat loss fragmentation	Cameroon	223

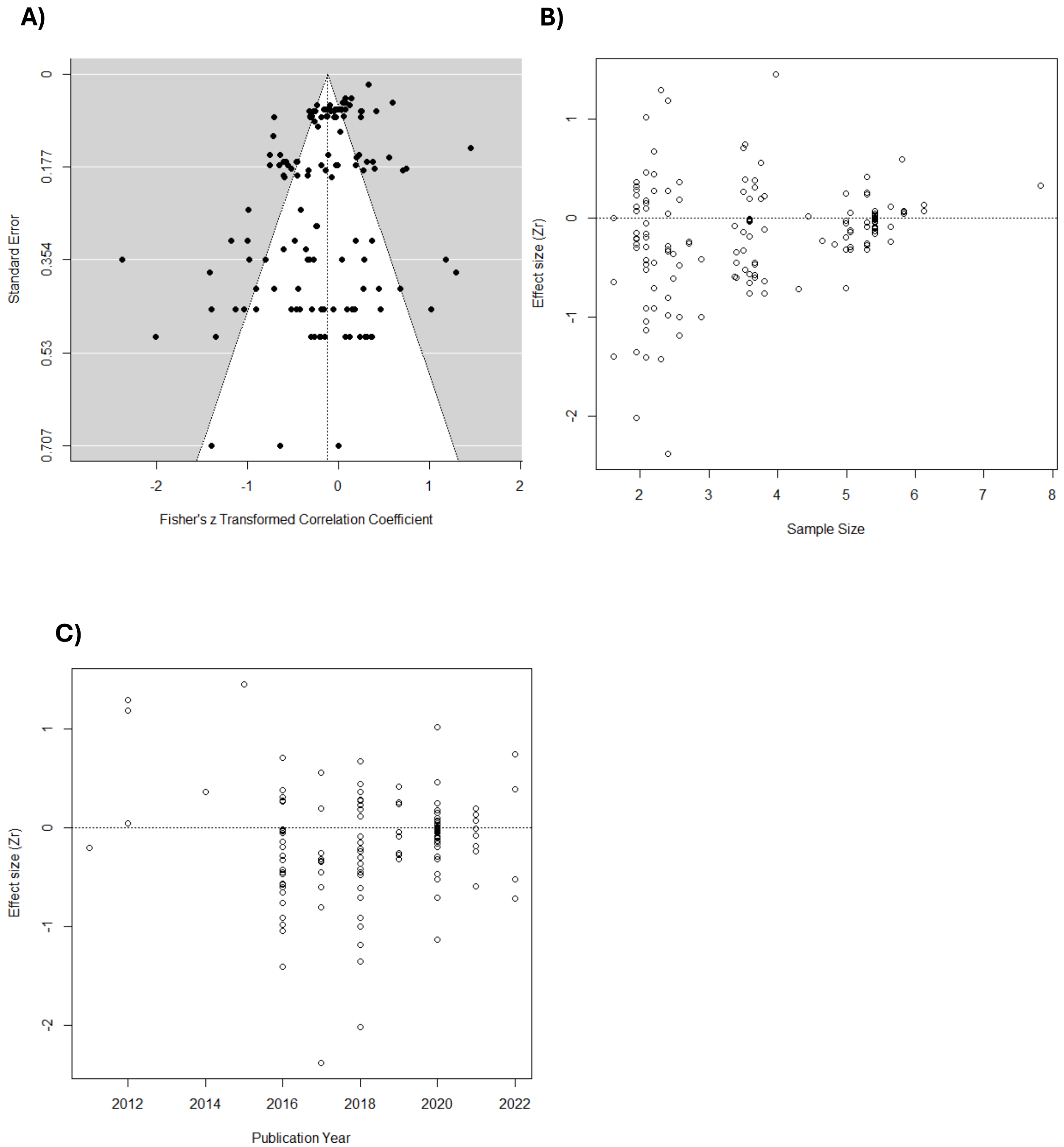
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Hunting	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Urbanization	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Hunting	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Urbanization	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Multiple	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	223

2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FSpe	Medium and large	Habitat loss fragmentation	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FSpe	Medium and large	Multiple	Cameroon	223
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Habitat loss fragmentation	Cameroon	148
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FDis	Medium and large	Habitat loss fragmentation	Cameroon	148
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	148
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FOri	Medium and large	Habitat loss fragmentation	Cameroon	148
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FSpe	Medium and large	Habitat loss fragmentation	Cameroon	148
2020	Lameris etal	Drivers affecting mammal community structure and functional diversity under varied conservation efforts in a tropical rainforest in Cameroon	Animal Conservation	web of science	FSpe	Medium and large	Habitat loss fragmentation	Cameroon	148
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8

2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	Meza-Joya etal	Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia	Mastozoología Neotropical	Scopus	FDis	Medium and large	Habitat loss fragmentation	Colombia	8
2020	de la Sancha etal	Disentangling drivers of small mammal diversity in a highly fragmented forest system	Biotropica	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	340
2020	de la Sancha etal	Disentangling drivers of small mammal diversity in a highly fragmented forest system	Biotropica	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	340
2020	de la Sancha etal	Disentangling drivers of small mammal diversity in a highly fragmented forest system	Biotropica	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	340
2020	Gorczynski Beaudrot	Functional diversity and redundancy of tropical forest mammals over time	Biotropica	Scopus	FDis	Medium and large	Habitat loss fragmentation	Costa Rica	8
2020	Gorczynski Beaudrot	Functional diversity and redundancy of tropical forest mammals over time	Biotropica	Scopus	FDis	Medium and large	Habitat loss fragmentation	Costa Rica	8
2021	Palmeirim etal	Forest area predicts all dimensions of small mammal and lizard diversity in Amazonian insular forest fragments	Landscape Ecology	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	29
2021	Palmeirim etal	Forest area predicts all dimensions of small mammal and lizard diversity in Amazonian insular forest fragments	Landscape Ecology	Scopus	Rao's	Small mammals	Habitat loss fragmentation	Brazil	29
2021	Gorczynski etal	Tropical mammal functional diversity increases with productivity but decreases with anthropogenic disturbance	Proceedings. Biological sciences	Scopus	FRic	Medium and large	local extinction	Multiple	15

2021	Bogoni etal	Spatial and land-use determinants of bat species richness, functional diversity, and site uniqueness throughout the largest Tropical country, Brazil	Mammal Review	Scopus	FRic	Bat	Urbanization	Brazil	456
2021	de Mattos etal	Habitat Specificity Modulates the Response of Small Mammals to Habitat Fragmentation, Loss, and Quality in a Neotropical Savanna	Frontiers in Ecology and Evolution	web of science	Rao's	Small mammals	Habitat loss fragmentation	Brazil	36
2021	de Mattos etal	Habitat Specificity Modulates the Response of Small Mammals to Habitat Fragmentation, Loss, and Quality in a Neotropical Savanna	Frontiers in Ecology and Evolution	web of science	Rao's	Small mammals	Habitat isolation	Brazil	36
2021	de Mattos etal	Habitat Specificity Modulates the Response of Small Mammals to Habitat Fragmentation, Loss, and Quality in a Neotropical Savanna	Frontiers in Ecology and Evolution	web of science	Rao's	Small mammals	Habitat loss fragmentation	Brazil	36
2022	Bogoni etal	Spatial and land-use determinants of bat species richness, functional diversity, and site uniqueness throughout the largest Tropical country, Brazil	Mammal Review	Scopus	Rao's	Bat	Agriculture	Brazil	456
2022	Cantera etal	Low level of anthropization linked to harsh vertebrate biodiversity declines in Amazonia	Nature Communications	Scopus	FRic	All mammals	Logging	Brazil	74
2022	Colombo etal	Functional diversity and trait filtering of insectivorous bats on forest islands created by an Amazonian mega dam	Functional Ecology	Scopus	FRic	Bat	Large dam	Brazil	34
2022	Colombo etal	Functional diversity and trait filtering of insectivorous bats on forest islands created by an Amazonian mega dam	Functional Ecology	Scopus	FEve	Bat	Large dam	Brazil	34
2022	Colombo etal	Functional diversity and trait filtering of insectivorous bats on forest islands created by an Amazonian mega dam	Functional Ecology	Scopus	FDis	Bat	Large dam	Brazil	34

*FDis: Functional dispersion; FD: Functional diversity; FDiv: Functional Divergence; FEve: Functional Evenness; FRic: Functional Richness; Rao’s: Rao's Quadratic Entropy



Appendix S3: Funnel plot showing that there was no apparent publication bias in the meta-analysis. A) In this graph, the publication bias is indicated by gaps in this funnel distribution, especially at effect sizes around zero, which indicates that small effect sizes are systematically underrepresented [for more details see Hillebrand & Gurevitch (2016)]. B) Effect size-sample size relationship plot showing the non-existent influence of the sample size on the measured effect sizes. C) Effect size-year relationship plot showing the non-existent influence of time on the measured effect sizes. This graph shows the temporal trend in effect size across years [for more details see Nakagawa et al. (2017)].

Appendix S4: Egger's regression tests considering the effect of anthropic disturbance on functional diversity. CI = confidence interval of 95%, k = number of cases.

	K	Intercept	Lower CI	Upper CI	P value
Overall model (Egger's test)	124	-0.027	-0.259	0.204	0.817

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CAPÍTULO II:

FUNCTIONAL DEFAUNATION OF THE ATLANTIC FOREST: THE FUNCTIONAL DIVERSITY OF MEDIUM AND LARGE MAMMALS AND THEIR RELATIONSHIP WITH HABIT LOSS AND FRAGMENTATION

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Functional defaunation of the Atlantic Forest: The functional diversity of medium and large mammals and their relationship with habitat loss and fragmentation

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Abstract

Mammals play critical roles in ecosystem functioning, including seed dispersal, regulation of prey populations, and regulation of disease. However, they are seriously threatened by habitat loss and fragmentation, especially in the Atlantic Forest. A biome with high endemism and biodiversity, where several species are seriously threatened or even locally extinct. This rapid loss of species, whether on a local, global, or functional level, is known as defaunation and significantly affects the areas experiencing this phenomenon. This study assesses the degree of functional defaunation in the Atlantic Forest by compiling data on medium and large mammals in forest fragments. Using functional diversity indices, we analyzed the relationship between functional richness (FRic), functional uniformity (FEve) and functional divergence (FDiv) with fragment size, defaunation level and whether these fragments were located in protected areas. Using Generalized Linear Models, our results indicate a positive relationship between fragment size and functional richness, with larger fragments exhibiting greater functional richness and lower defaunation rates. Protected areas play an important role in conserving functional diversity, especially for endangered species and large mammals. However, challenges remain in integrating smaller fragments into conservation strategies and understanding the long-term consequences of defaunation. This study highlights the complexity of ecological interactions and the need for integrated conservation approaches to maintain biodiversity and ecosystem services in the Atlantic Forest.

Keywords: Biodiversity, Mammal conservation, Species extinction, Functional Ecology, Protect areas

Introduction

Mammals contribute to critical functional processes of an ecosystem, such as the regulation of plant communities through predation on seeds, and seedlings (Janzen, 1970), they are important seed dispersers that maintain forest carbon stocks (Bello et al., 2015; Peres et al., 2016). They are relevant reservoirs of zoonoses (Widmer, 2009) and help regulate prey populations (Tabarelli & Peres, 2002). These animals are highly threatened, mainly due to the loss and fragmentation of habitats, which leads to a drastic decrease in the size of populations and causes their isolation, becoming restricted to islands immersed in a landscape modified by humans (Canale et al., 2012; Galetti et al., 2017).

The Atlantic Forest is considered one of the world's conservation hotspots, being one of the largest tropical forests in the Americas. However, it is currently highly fragmented, with only 28% of its original area remaining (Rezende et al., 2018). The biome has very diverse environmental conditions and still harbors many plant and animal species, most of which are endemic (Myers et al., 2000; Ribeiro et al., 2009). Due to the advanced fragmentation process, the remaining vegetation forms islands, mostly areas smaller than 50 ha, surrounded by cities, large areas of crops and pastures, isolating the forest fragments between different matrices

(Ribeiro et al., 2009; Lima & Mariano-Neto, 2014). The type and shape of the matrix can affect biodiversity, acting as a filter that can facilitate displacement or act as a barrier, affecting resource availability and even the environmental conditions of the place (Driscoll et al., 2013).

Considering the current deforetation of the Atlantic Forest, the loss of species has already been observed in several regions, mainly with a reduction in top predators, causing an important change in the trophic structure of these communities (Galetti et al., 2009; Bogoni et al., 2019; Bovendorp et al., 2019; Magioli et al., 2019). The rapid loss of animal species in terms of richness and decrease in abundance is known as defaunation. This process is occurring across the planet, leading to a change in community structure, which in turn leads to changes in ecosystem functioning (Dirzo et al., 2014). Anthropogenic activities, such as hunting, loss and fragmentation of habitats, mainly caused by changes in land use, are one of the main factors leading to this loss of species (Bogoni et al., 2023). These activities reduce the number of available resources, limit the dispersion of individuals, and change their interactions (Young et al., 2016).

If the composition of the community is changing, it is also expected that the frequency of the ecological processes that species perform will change (Pires & Galetti, 2023). Some drivers, such as habitat loss and fragmentation, that drives the defaunation of a region are already known. Still, the way they act on the functioning of the ecosystem involves more complex mechanisms and interactions, and there is still much to be studied in this regard (Young et al., 2016). For example, habitat fragmentation due to land-use change may benefit certain functional groups to the detriment of others, leading to community simplification (Bogoni et al., 2019). Generalist species tend to benefit because they can meet their needs in anthropogenically modified environments and thus become more dominant (Pires & Galetti, 2023). For example, an increase in the density of granivorous rodents can lead to a decrease in plant recruitment (Bovendorp et al., 2019), and the loss of large herbivores can reduce the dispersal of large seeds, which would affect the reproductive dynamics of large tree species in the long term (Galetti et al., 2021).

Global concern about the human impact on biological diversity has prompted a series of studies on the factors and consequences of changes in biodiversity, with a particular focus on taxonomic diversity. However, this metric has several limitations (Hillebrand et al., 2018). Functional diversity indices can measure the relationship between organisms in a community and the ecosystem to which they belong. Functional diversity provides a link between organisms and the communities in which they live, making it possible to predict the functioning of ecosystems by associating species with certain specific functions performed in the environment (Petchey & Gaston, 2006). The functional traits studied, provides data that helps to understand the ecosystem services provided by a given group, the processes that influence the structure of the community, and the functionality of that ecosystem (Mason et al., 2005). Therefore, functional diversity can be used as an important tool to help understand how defaunation affects the functioning of these ecosystems.

Quantification of the effects of changes in animal diversity on ecosystem function, i.e. functional defaunation, is still limited (Bogoni et al., 2023). High levels of defaunation can lead to the extinction of mammalian communities at regional scales, and its main drivers and consequences on functional diversity remain poorly understood, especially at larger scales (Bogoni et al., 2019). Therefore, it is as important to know which species are being lost, as it is to understand which ecological functions are at risk and/or are also being lost, to understand the functional consequences of this change that communities are undergoing so that strategic conservation actions can be applied.

Here, we compile published secondary data from studies of medium to large mammals throughout the Atlantic Forest with the following objectives (i) determine the degree of functional defaunation for this biome. (ii) Evaluate which fragment size has managed to maintain the functional diversity of medium and large mammals in the Atlantic Forest and (iii) evaluate whether there is a relationship between protected areas and the functional diversity of medium and large mammals. We hypothesize that more defaunated areas will have less functional diversity, with high levels of functional defaunation in the Atlantic Forest. We expect that areas exhibiting greater functional diversity overlap with protected areas.

Materials and methods

<u>Study Area</u>

The Atlantic Forest is one of the most biodiverse biomes of South America. Spanning over 17 States, the Atlantic Forest biome covers *ca.* 12% of the Brazilian territory, where *ca.* 70% of the Brazilian population lives, consolidating the largest urban center across South America (Ribeiro et al., 2009). Due to chronic human-impacts over five centuries of devastation — which led to dramatic declines in natural habitat cover — the Atlantic Forest is considered one of the most threatened tropical ecosystems worldwide (Myers et al., 2000). Despite that, this tropical biome still embracing a myriad of species, with a large number of endemic species. For instance, only considering tetrapods, the Atlantic Forest biome has a richness of 512 species of amphibians (260 endemics), more than 300 species of reptiles (95 endemics), 861 bird species (213 endemics), and 321 mammal species (89 endemics) (Lima et al., 2017; Hasui et al., 2018; Vancine et al., 2018; Rodrigues et al., 2019). Therefore, due the combination of high human-induced threats and high rates of diversity, the Atlantic Forest biome is considered a hotspot of biodiversity (Myers et al., 2000).

Data Collection

A bibliographic search will be carried out in the Scielo, Web of Science and Google Scholar databases, searching for scientific articles, theses, and dissertations with a survey of medium and large mammal species in the Atlantic Forest, using the keywords in Portuguese and English: Mammal(s), Research(s), Inventory(s) and Atlantic Forest. The 'AND' operator is used to make different combinations with these words. We also used data on medium and large mammals contained in Lima et al. (2017); Bogoni et al. (2019); Rios et al. (2022). For inclusion in our dataset, the study should achieve the following criteria: (i) present all species of medium and large mammals detected in each forest fragment; (ii) if were a protected area and (iii) fragment size. From these studies, a list of species was compiled for each forest remnant. We used this information to calculate functional diversity indices and defaunation index. For this study, we collected data for species of medium and large mammals weighing more than 1 kg (Chiarello, 2000).

To enhance the comprehensiveness of our database, we categorize the species following the threat categories delineated by the IUCN (critically endangered, endangered, near threatened, vulnerable, and data deficient; www.iucnredlist.org).

Data Analysis

Functional diversity

According to the characteristics of the individuals found in each forest fragment, the functional diversity was calculated. Based on the proposal of Villéger et al. (2008), a multidimensional approximation is used that allows the separation of functional diversity into three components: functional richness (FRic), functional evenness (FEve), and functional divergence (FDiv). Functional diversity indices are also adequate when calculated from presence-absence data (Villéger et al., 2008).

For definition functional richness (FRic) represents the amount of functional space occupied by a community and can be understood as the number of traits or categories of a trait represented by the community, this index better represents changes in the functional space occupied by the community (Mouchet et al., 2010). Functional equitability (FEve) corresponds to regularity relative positioning of each species in functional space that allows efficient use of all available resources (Villéger et al., 2008; Mouchet et al., 2010). The functional divergence index (FDiv) represents the distribution or grouping of species within the functional space. A high FDiv may indicate a high degree of niche differentiation for the species (Villéger et al., 2008; Mouchet et al., 2010).

For our purposes, functional space could be defined as the range of species vulnerability to extinction in human-modified landscapes. Thus, in larger and functionally richer fragments, species vulnerability would be more variable. In larger fragments where functional uniformity is high, the number and degree of vulnerable species would be equivalent to non-vulnerable species. In functionally divergent forest fragments, the degree of vulnerability between species would be more contrasting.

The selection of functional traits to be used is based on the life history characteristics of the registered species obtained from specific literature. Functional traits that reflect the niche of a given species also represent the resources it requires, reflecting its relationship to the functionality of the ecosystem, so the use of life history data such as foraging habits is indicated (Flynn et al., 2009). We selected species characteristics, including those based on resource use such as morphological data, and we collected body mass.

For dietary data, we collected foraging substrate: water, trees, ground vegetation, ground (soil) and stable carbon and nitrogen isotope ratios. Specifically, stable carbon isotopes allow us to assess changes in species resource use based on differences in isotopic values between C3 (forest) and C4 plants (non-forest, C4 crops, pasture). Nitrogen, on the other hand, provides insights into species trophic organization. The way species obtain resources from the environment can be influenced by the way organisms move, so we select a behavioral characteristic and classify species as terrestrial, fossorial, aquatic, or arboreal, and social behaviour (yes or no). Finally, following Magioli (2015), species are classified according to their environmental sensitivity. This classification is based on the species' tolerance to habitat modification, resource availability, and human pressure, which limits the occurrence of sensitive species. This trait is considered an important differentiator, especially when examining assemblages in forest remnants with different structural characteristics and landscape configurations. Physical and behavioural data were extracted from Paglia et al. (2012), and dietary data from Magioli et al. (2019).

Defaunation Index

The defaunation index (DI) will be calculated as described by Giacomini and Galetti (2013) for medium and large mammals. The defaunation index was calculated for each mammal community evaluated in the study. This index ranges from zero (completely intact) to 1.0 (completely defaunated) and is measured against a reference community that is still intact. For this reference community, the occurrence of mammals is used based on polygons of known geographic range obtained from the IUCN (2023). We and used the presence/absence of each fragment found in studies to estimate the actual composition. We then calculated the defaunation index (DI), for medium- and large-sized mammals as follows:

$$DI = 1 - \underline{\sum_{j}^{N} BWES_{j}}$$

$$\sum_i^N BWES_i$$

where N represents the total number of species in the community; j is the total number of species in the actual community composition; i is the total number of species in the potential community composition; BWES is the average body mass for each species of medium and large mammal, since the decline of large species is regarded as one of the primary outcomes of defaunation (Dirzo et al., 2014). To make the scale clearer the result of the division of sums was subtracted from 1.

We use generalized linear models (GLMs) to compare models between the functional diversity indexes in each fragment (response variable) to the size of the fragments, defaunation index and if they were in protected areas (explanatory variables). We then ranked the models using the Akaike Information Criterion (AIC; Burnham et al., 2011), selecting the best model that presented the $\Delta AICc < 2$ and a high weight value. All analyses were performed using the R 4.3.2 (R Core Team, 2023), using the FD and MuMIn packages (Laliberté et al.,2014; Bartoń, 2023).

Results

We collected data from 137 studies according to our selection criteria, totaling 287 forest fragments, of which 146 (50.87%) are in legally protected areas (Fig 1). A total of 70 species of medium and large mammals were recorded and 13 records that only reached the genus level (for more details see Table S1).

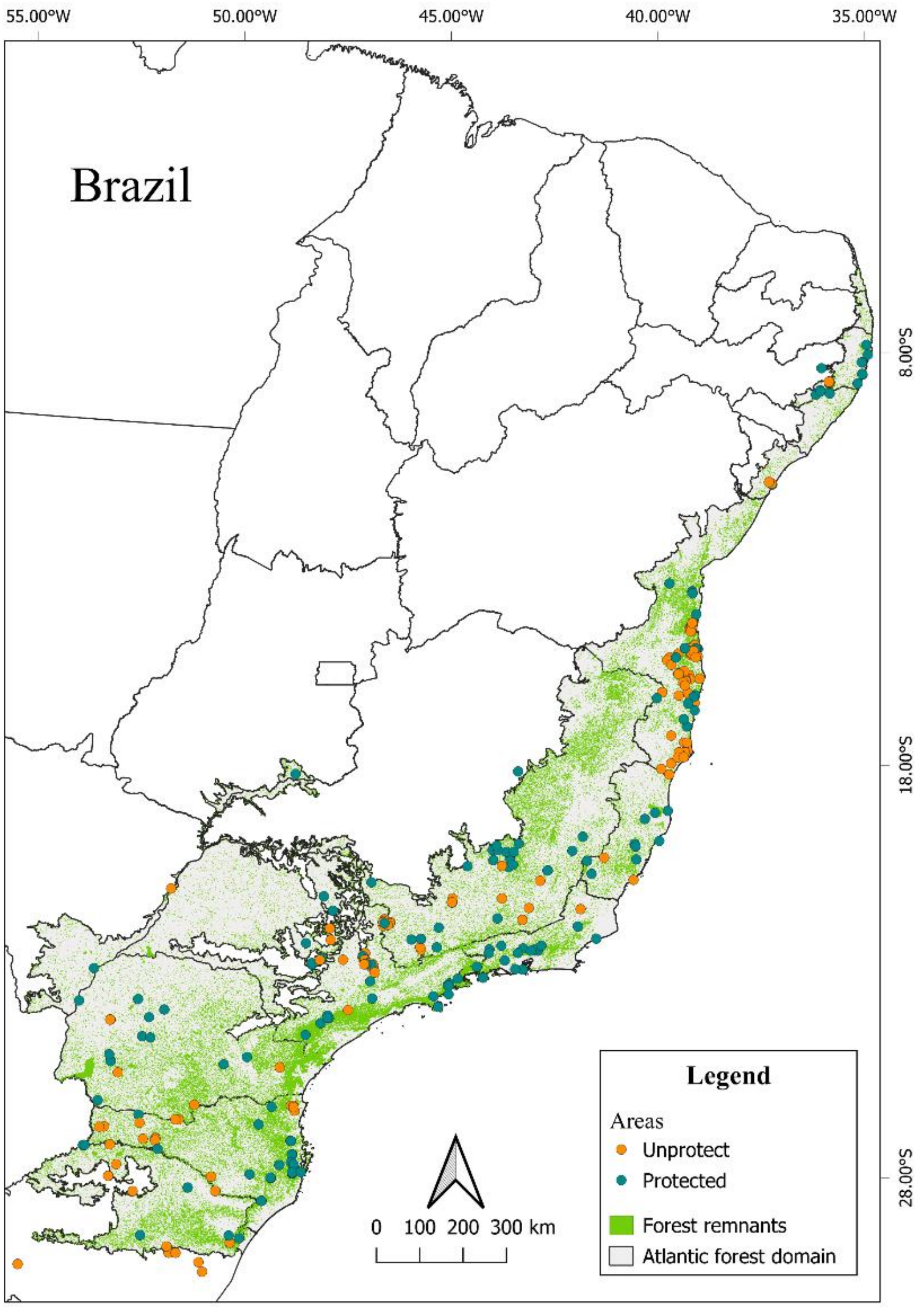


Fig. 1 Location of forest fragments where surveys for medium and large mammals were conducted according to our criteria in the Brazilian Atlantic Forest. The colored circles indicate whether the fragments belonged to protected areas or not.

The fragment exhibiting the greatest species richness was found to contain 33 species, while 13 fragments were found to contain only a single species (11.59 ± 8.15, mean ±

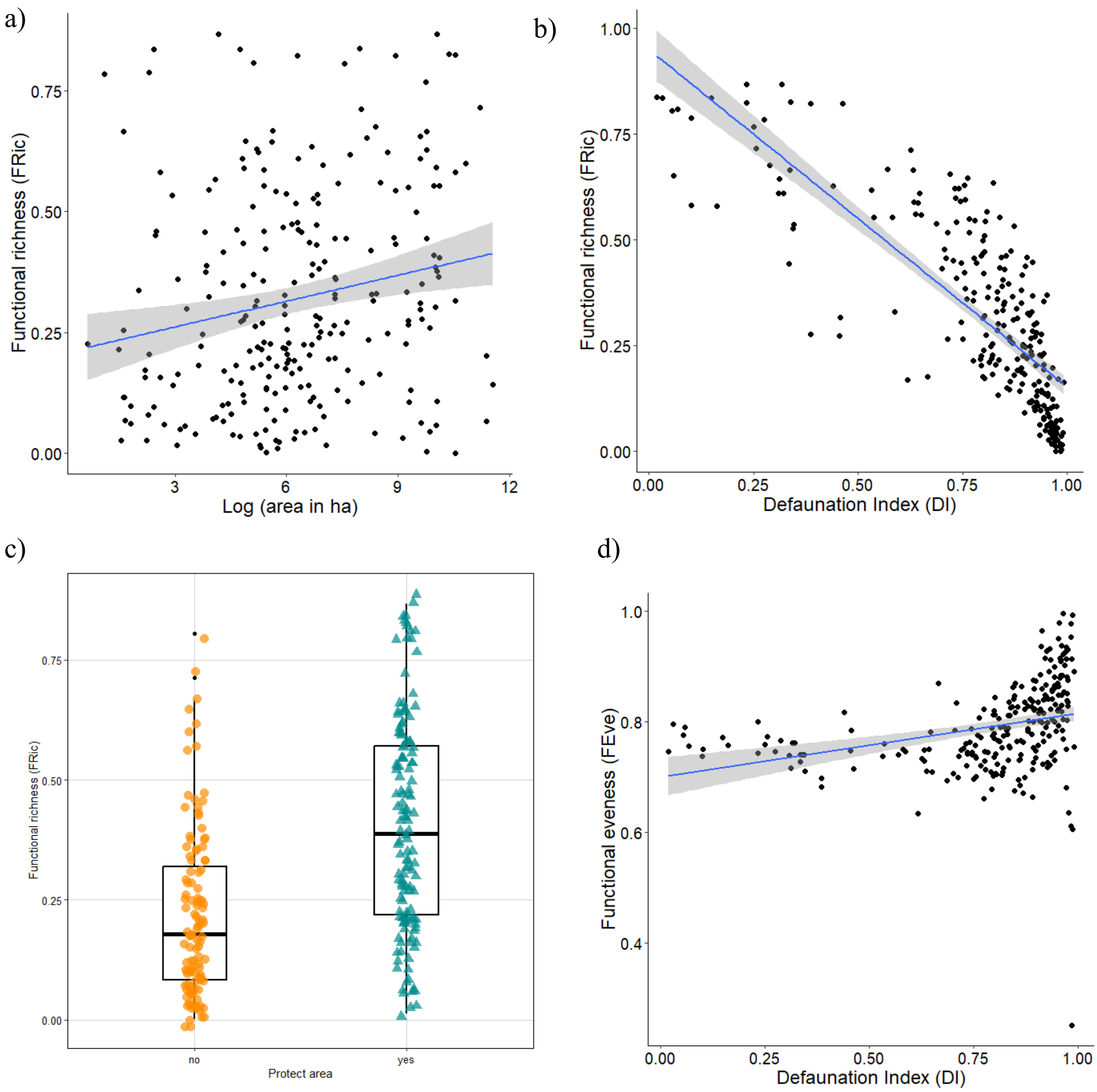
SD), the largest fragment recorded was 104,000 ha while the smallest was 1 ha (5,318.0 ± 15,058.7, mean ± SD).

To calculate functional diversity, those fragments with richness lower than 3 were excluded, thus totaling 249 fragments analyzed. We find values between 0.001- 0.867 for FRic, 0.251 – 0.995 for FEve and 0.587 – 0.916 for FDiv. Of the 287 fragments, 89.55% (257) are more than 50% defaunated, and 70.73% (203) are 80% or more defaunated, only 1 fragment recorded the largest apex predator (*Panthera onca*), the largest arboreal seed disperser (*Brachyteles spp*.), the largest seed predator (*Tayassu pecari*) and the largest herbivore (*Tapirus terrestris*) together. Individually they appear in 4.88% (14), 5.57% (116), 7.32% (21) and 11.5% (33). The analysis showed that the largest fragments had greater FRic and a lower defaunation rate, and FRic was also greater in protected areas. For FEve and FDiv, only the defaunation index presented significant values (Fig 2a, b, c, d, e, Table 1).

Table 1: Model estimates for generalized linear models (GLM) assessing the response of functional diversity. The fixed variables considered included fragment size (Log), defaunation index and protected area. Significant models are highlighted in bold (ΔAIC <2).

Functional Diversity	Model	Int.	ΔAIC	Weight
Fric	**Size+DI+PA**	**2.188821**	**0**	**0.5620401**
	DI+PA	**1.695283**	**0.572717**	**0.009708713**
	Size+DI	1.111735	8.117099	0.006162762
	DI	0.532854	9.026096	6.78678E-12
	Size+PA	5.411976	50.27972	1.21938E-12
	PA	4.54226	53.71299	8.0035E-19
	Size	4.260916	82.18611	6.97555E-20
Feve	**DI**	**1.42221**	**0**	**0.504267**
	DI+PA	**1.406174**	**1.561244**	**0.231015**
	Size+DI	1.426743	2.038304	0.181990
	Size+DI+PA	1.410596	3.618105	0.082604
	PA	1.242577	17.55512	0.000078
	Size+PA	1.23246	19.41071	0.000031

	Size	1.252155	23.13212	0.000005
	DI	**1.444181**	**0**	**0.3054105**
	Size+DI	**1.465432**	**0.386395**	**0.2517558**
	DI+PA	**1.426938**	**0.452771**	**0.2435376**
Fdiv	**Size+DI+PA**	**1.448156**	**0.862764**	**0.198398**
	PA	1.341454	12.50554	0.000587951
	Size+PA	1.350776	14.07831	0.000267805
	Size	1.364976	20.2247	1.23921E-05



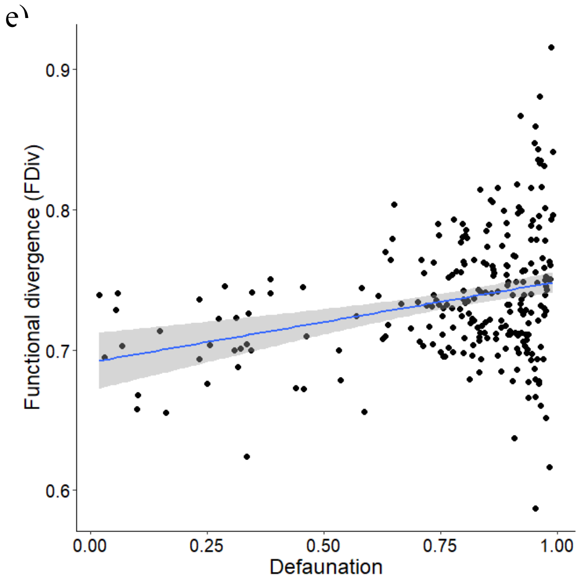


Fig. 2 Relationships between functional diversity and the respective predictor variables. A) Functional richness and forest size (log). B) Functional richness and Defaunation index. C) Functional richness and protected areas. D) Functional eveness and Defaunation index. E) Functional divergende and Defaunation index. The 95% confidence intervals are shown in gray.

Discussion

The high degree of fragmentation of the Atlantic Forest, as well as the consequences of this loss and conversion of habitats, is a topic that receives considerable attention in ecology, with numerous studies. However, studies that address functional diversity on a larger scale are more recent (Magioli et al., 2015; Bogoni et al., 2019; Rios et al., 2022). The results of this study align with those previously reported by Magioli (2015) and Bogoni (2018). These findings indicate that the current situation has not improved. Species continue to be lost in a targeted manner, and the ecological functions they perform are being diminished.

The present study demonstrates a positive relation between functional diversity and fragment size, exclusively in terms of functional richness. This finding supports the proposed hypothesis. If we consider that the availability of resources influences species occurrence and that larger and more complex areas will have more resources, this result is to be expected. A study conducted in the Atlantic Forest for Magioli (2015) revealed critical values for maintaining the functional diversity of medium and large mammals. The findings indicated that areas below 60 hectares are unable to support high functional diversity, as they present a low quality and a high degree of degradation. Conversely, areas above 2050 hectares support higher levels of functional diversity, indicating a greater number of functions maintained in larger forest fragments when compared to small and intermediate patches (Magioli et al., 2015). In this study, only 24% of the fragments were more than 2,050 ha, while 24% were less than 60 ha. Nevertheless, it is noteworthy that small and especially intermediate-sized fragments (which constituted the majority in this study) can facilitate connectivity between larger fragments, thus increasing overall connectivity (Magioli et al., 2015).

Habitat loss and fragmentation have been identified as an important driver of defaunation (Galetti et al., 2021), the impact of defaunation in the Atlantic Forest reveals a series of environmental concerns that go beyond the direct loss of species. Our results indicate that defaunation is an important predictor of functional diversity loss in the Atlantic Forest, affecting multiple dimensions of functional diversity, these changes result in a change in functional space, presenting a higher concentration of non-vulnerable species. The interconnectedness between different elements of ecosystems shows how the extinction or reduction of animal populations can trigger cascading effects, affecting essential ecological processes such as the spread of diseases, fire dynamics and biogeochemical cycles (Dirzo et al. 2014). This leads to the loss of important functions, mainly those performed by top predators, large herbivores and seed dispersers, which are no longer present in most fragments, as we pointed out in our results (Peres & Palacios, 2007).

The heterogeneity of defaunation highlights the need to consider different groups of animals when planning conservation strategies. Our data show that 51% of the species found in the fragments are listed in some IUCN threat category (CR, EN, NT, VU, DD;

www.iucnredlist.org), and most fragments of the Atlantic Forest are under high levels of defaunation. The concentration of threats in specific functional groups points to the importance of approaches that consider their ecological needs and vulnerabilities (Bogoni et al., 2019).

For instance, the top-down control exerted by herbivores illustrates the significance of these animals in structuring plant communities. The substantial reduction in the population of large herbivores could result in notable alterations in plant composition and dynamics, which could in turn affect biodiversity and ecosystem services such as carbon storage and water retention (Bello et al., 2015; Jia et al., 2018). Moreover, the discussion of seed dispersal demonstrates how defaunation can affect forest regeneration and plant diversity (Galetti et al. 2021). The absence of large seed dispersers not only reduces the efficiency of plant species propagation but can also affect soil nutrient cycling and the dynamics of associated microbial communities (Eldridge et al., 2016; Villar et al., 2021). It is therefore important to consider the impact of this phenomenon on the wider ecosystem. It is also noteworthy that dispersion accumulators are effective dispersion agents, yet their dispersion function is significantly impaired in fragments below 1,000 ha (Mauro Galetti et al., 2006), which represented only 31.7% of the fragments analyzed in this study.

Furthermore, this study provides evidence that protected areas are an effective means of conserving functional diversity in medium and large mammals, thereby reinforcing the proposed hypothesis. In addition, the hypothesis of ecosystem decay indicates that smaller habitats have lower species richness and abundance, which in turn compromises ecosystem functions (Chase et al., 2020). These areas preserve the largest fragments and functional diversity found in the biome. In many regions of the planet, protected areas conserve a significant portion of the original biological diversity, which not only implies the preservation of different species but also the maintenance of vital functions for the ecosystem and essential environmental services that they provide (Magioli et al., 2021). It is, however, important to note that a large part of these areas is under intense human pressure or located above 1,200 meters, which corresponds to the smallest portion of the area in this biome (Bogoni et al., 2019), reducing the effectiveness of these areas. This reinforces the notion that conservation strategies must also consider non-protected areas.

It is evident that small patches of unprotected habitat, situated on private land, serve as invaluable tools for enhancing structural and functional connectivity in fragmented landscapes (Lindenmayer, 2019; Magioli et al., 2021). Although they are less biodiverse than pristine areas, these small remnants play a crucial role in slowing the loss of species. They serve as steppingstones for fauna to move between large remnants and those under legal protection and prevent the local extinction of many species. They are vital for long-term conservation efforts (Kremen & Merenlender, 2018; Wintle et al., 2019; Fahrig, 2020). While most species are documented in large, protected areas, some threatened species are still observed in small, isolated habitats, underscoring the necessity to incorporate them into conservation strategies. It is commonly accepted that protected areas serve as refuges for most mammals (Magioli et al., 2021). Conversely, unprotected areas, particularly those situated within agricultural landscapes, may initially appear attractive, but over time, they can have a detrimental impact on the reproductive potential of populations, and your functions (Flynn et al., 2009; Marcelo Magioli et al., 2016).

In conclusion, the significance of large forest areas is further evidenced by the expansion of the functional diversity of mammals, as has also been previously demonstrated in species richness studies in the Atlantic Forest (Magioli et al., 2015). Despite an increase in functional diversity as patch size increased, mammals that were most vulnerable to habitat loss and/or large and medium-sized species were largely absent from most small remnants. All threatened and large species were practically restricted to large forest remnants, especially those under legal protection. This highlights the ubiquitous role of protected areas in maintaining the functional diversity of mammals and the need to link them to smaller remnants, while promoting functional connectivity between them, beyond gene flow.

The implementation of conservation strategies, including species reintroduction, the expansion of suitable habitats, and the reduction of human impacts is essential for the long-term survival of medium and large mammals. The maintenance of extensive, continuous forest areas is crucial for the continued existence of large mammal populations in fragmented landscapes. Nevertheless, despite the advances in understanding the impacts of defaunation, there are still many uncertainties about the long-term consequences. The lack of comprehensive data and long-term studies makes it difficult to fully assess the effects of the loss of species and their functions in the Atlantic Forest. Therefore, more research and monitoring efforts are needed to better understand these processes and guide effective conservation actions. In conclusion, the discussion on defaunation in the Atlantic Forest demonstrates the complexity of ecological interactions and the need to adopt an integrated, long-term approach to safeguard biodiversity and ecosystem services in this vital ecosystem.

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Supporting Information

Table S1: Secundary data used to create the database of medium-and- large sized mammal assemblages at the Atlantic forrest domain, Brazil.

Author	Publication_ year	Title
Alves_et.al	2019	Medium and large-sized mammals in an Atlantic Forest fragment of Brazil: Recording of threatened species
Araujo_et.al	2020	Sharing the nature: Mammals and neighbor human population of a protected area in the Atlantic Forest, Brazil
Aximoff_et.al	2022	Mamíferos de médio e grande porte no parque estadual das várzeas do rio Ivinhema, Mato Grosso do Sul, Brasil
Batista_et.al	2021	Mammals in atlantic forest remnants of barbacena, minas gerais mamíferos em remanescentes florestais de mata atlântica, barbacena, minas gerais
Boas_et.al	2022	Survey of mediumand large-sized mammals in Atlantic Forest remnants of Conceição dos Ouros, Minas Gerais, Brazil
Bogoni_et.al	2016	Landscape features lead to shifts in communities of medium- to large-bodied mammals in subtropical Atlantic Forest
Brocado_et.al	2013	No changes in seedling recruitment when terrestrial mammals are excluded in a partially defaunated Atlantic rainforest
Cronembergeer_et.al	2023	Factors influencing terrestrial mammal dectection in an atlantic forest area, southeastern Brazil
Rosa_Souza	2017	Large and medium-sized mammals of Nova Baden State Park, Minas Gerais, Brazil
Oliveira_et.al	2012	Inventory of medium and large-sized mammals from Serra do Brigadeiro and Rio Preto State Parks, Minas Gerais, southeastern Brazil
Prado_et.al	2008	Mamíferos de médio e grande porte em um fragmento de mata atlântica, Minas Gerais, Brasil
Falcao_et.al	2012	Medium and large-sized mammals of RPPN Estação Veracel, southernmost Bahia, Brazil
Gatti_et.al	2017	Medium and large-bodied mammals of the private reserve of natural heritage recanto das antas, in espírito santo, Brazil
Graciano_et.al	2020	Medium and large mammals of caparaó national park, southeastern brazil; [Mamíferos de médio e grande porte no parque nacional do caparaó: composição riqueza e abundância]
Homem_et.al	2020	Mammal fauna in Eucalyptus plantations and forest remnants in três lagoas, mato grosso do sul state, brazil
Magioli_et.al	2014	Medium and large-sized mammals of an isolated Atlantic Forest remnant, southeast São Paulo State, Brazil
Magioli_et.al	2022	Mammals from a pampa and atlantic forest ecotone in south Brazil
Magioli_et.al	2021	The role of protected and unprotected forest remnants for mammal conservation in a megadiverse Neotropical hotspot
Martins_et.al	2016	Large and medium-sized mammals in the urban park Cinturão Verde, Cianorte, northwestern Paraná

Melo_Dias_et.al	2018	Large and medium-sized mammals on the campus of the Universidade Federal de Lavras, south of Minas Gerais state, Brazil; [Mamíferos de médio e grande porte no campus da Universidade Federal de Lavras, Sul do estado de Minas Gerais, Brasil]
Pontes_et.al	2016	Mass extinction and the disappearance of unknown mammal species: Scenario and perspectives of a biodiversity hotspot's hotspot
Monteiro_et.al	2020	Metropolitan mammals: Understanding the threats inside an urban protected area
Norris_et.al	2012	A survey of mid and large bodied mammals in Núcleo Caraguatatuba, Serra do Mar State park, Brazil; [Mastofauna de Médio e Grande Porte na Núcleo Caraguatatuba, Parque Estadual Serra do Mar, SP, Brasil]
Reale_et.al	2014	Medium and Large-sized Mammals in a Private Reserve of Natural Heritage in the Municipality of Jaú, São Paulo, Brazil
Rocha_et.al	2015	Medium- and large-sized mammals in Mata Atlântica State park, southeastern Goiás, Brazil
Sanchez_et.al	2019	Medium- and large-sized mammals in A PROTECTED area of atlantic forest in the northeast of Brazi
Tedesco_et.al	2018	Medium-sized mammals in peri-urban environments in southern Brazil
Verissimo_et.al	2022	Medium- and large-sized mammals from Estação Biológica Fiocruz Mata Atlântica, Rio de Janeiro, south-eastern Brazil
Abreu Júnior_et.al	2009	Mammalian fauna of medium and large sized in the RPPN of UNISC, RS, Brazil.
Alves_et.al	2012	Mamíferos de médio e grande porte e sua relação com o mosaico de habitats na cuesta de Botucatu, Estado de São Paulo, Brasil.
Albuquerque_et.al	2013	Mammals of a forest fragment in Cambuci municipality, state of Rio de Janeiro, Brazil
Bogoni_et.al	2013	The Influence of Landscape and Microhabitat on the Diversity of Large-and Medium-Sized Mammals in Atlantic Forest Remnants in a Matrix of Agroecosystem and Silviculture.
Bogoni_et.al	2016b	Contributions of the mammal community, habitat structure, and spatial distance to dung beetle community structure
Bovendorp_et.al	2007	Density and population size of mammals introduced on a land-bridge island in southeastern Brazil
Brocado_et.al	2012	Persistência de mamíferos de médio e grande porte em fragmentos de Floresta Ombrófila Mista no estado do Paraná, Brasil.
Carvalho_et.al	2014	Medium and large-sized mammals of the Reserva Ecológica de Guapiaçú, Cachoeiras de Macacu, RJ.
Carvalho_et.al	2013	Non-volant mammal assemblage of serra do Japi biological reserve, Jundiaí, São Paulo, southeastern Brazil.

Cunha_et.al	2007	Mamíferos Terrestres e Aves da Terra Indígena Sapukai (Aldeia Guarani do Bracui), Angra dos reis, Rj, Brasil.
Delciellos_et.al	2012	Mammals of Serra da Bocaina National Park, state of Rio de Janeiro, southeastern Brazil
Dias_et.al	2012	Registro de mamíferos de médio e grande porte em dois fragmentos florestais no município de São Carlos, Estado de São Paulo.
Elias_et.al	2021	Mamíferos de médio e grande porte da estação ecológica barreiro rico, estado de São Paulo, sudeste do Brasil
Dotta_Verdade_et.al	2011	Medium to large-sized mammals in agricultural landscapes of south-eastern Brazil
Duprat_et.al	2011	Mastofauna não-voadora de médio e grande porte em um fragmento de Mata Atlântica no município de Rio Novo, MG
Espartosa_et.al	2011	Performance of camera trapping and track counts for surveying large mammals in rainforest remnants.
Flesher_et.al	2013	Protecting Wildlife in a Heavily Hunted Biodiversity Hotspot: A Case Study from the Atlantic Forest of Bahia, Brazil
Fornitano_et.al	2015	Medium to large-sized mammals of the Augusto Ruschi Biological Reserve, São Paulo State, Brazil.
Gatti_et.al	2014	Mamíferos de médio e grande porte da Reserva Biológica Augusto Ruschi, Espírito Santo
Gatti_et.al	2016	Diversity of medium-sized and large mammals from Atlantic Forest remnants in southern Minas Gerais state, Brazil
Hendges_et.al	2015	Mamíferos de médio e grande porte de remanescentes de Floresta Estacional Decidual no Parque Estadual Fritz Plaumann e em áreas adjacentes, Sul do Brasil
Junges_et.al	2012	Composição da mastofauna de médio e grande porte em um remanescente de floresta com araucária no sul do Brasil.
Juraszek_et.al	2014	Levantamento de mamíferos de médio e grande porte na RPPN Federal Corredor do Iguaçu na região centro-oeste do Paraná.
Kasper_et.al	2007	Composição e abundância relativa dos mamíferos de médio e grande porte no Parque Estadual do Turvo, Rio Grande do Sul, Brasil.
Lima_et.al	2014	Riqueza de espécies de mamíferos de médio e grande porte na Fundação Jardim Botânico de Poços de Caldas, Minas Gerais, Brasil.
Maciel_et.al	2015	Levantamento preliminar de mamíferos silvestres em uma área de Floresta Ombrófila Mista na região de Porto Vitória-PR.
Marques_et.al	2011	Mastofauna no Planalto das Araucárias, Rio Grande do Sul, Brasil.
Mendes_et.al	2015	Diversidade de mamíferos de médio e grande porte da reserva particular do patrimônio natural da Mata do Sossego e seu entorno, Minas Gerais.
Modesto_et.al	2008	Mamíferos do Parque Estadual do Desengano, Rio de Janeiro, Brasil.

Morcatty_et. al	2013	Habitat loss and mammalian extinction patterns: are the reserves in the Quadrilátero Ferrífero, southeastern Brazil, effective in conserving mammals?
Negrão_et.al	2006	Registros de mamíferos de maior porte na Reserva Florestal do Morro Grande, São Paulo.
Nunes_et.al	2013	Survey of large and medium-sized terrestrial mammals in the Serra do Brigadeiro State Park, Minas Gerais, Brazil.
Olveira_et.al	2013	Caracterização faunística de mamíferos de médio e grande porte de um fragmento florestal do noroeste do estado do Paraná, Brasil.
Passamani_ et.al	2005	Mamíferos não-voadores em áreas com predomínio de Mata Atlântica da Samarco Mineração SA, município de Anchieta, Espírito Santo.
Penido_et.al	2012	Checklist of large and medium-sized mammals of the Estação Ecológica Mata do Cedro, an Atlantic forest remnant of central Minas Gerais, Brazil.
Pereira_et.al	2013	Mamíferos de um Fragmento Florestal em Volta Redonda, Estado do Rio de Janeiro
Santos_et.al	2016	Medium-sized and large mammals from Quedas do Rio Bonito Ecological Park, Minas Gerais, Brazil.
Spezia_et.al	2013	Inventário rápido de mamíferos não voadores em um fragmento florestal do bioma Mata Atlântica.
Tortato_et.al	2014	Mastofauna terrestre da Reserva Biológica Estadual do Sassafrás, Doutor Pedrinho, Santa Catarina, Sul do Brasil.
Wolfart_et.al	2013	Mamíferos terrestres em um remanescente de Mata Atlântica, Paraná, Brasil.
Srbek_et.al	2016	Mamíferos de Médio e Grande Porte das Florestas de Tabuleiro do Norte do Espírito Santo: Grupos Funcionais e Principais Ameaças.
Paschoal_et. al	2012	Is the domestic dog becoming an abundant species in the Atlantic forest? A study case in southeastern Brazil.
Kionka_et.al	2013	Mastofauna não-voadora em fragmentos florestais nativos circundados por uma matriz agrícola e de pastagem em palmeira das missões, RS, Brasil.
Goulart_et.a l	2009	Habitat selection by large mammals in a southern Brazilian Atlantic Forest.
Srbek_et.al	2005	Is camera-trapping an efficient method for surveying mammals in Neotropical forests? A case study in south-eastern Brazil
Silva_et.al	2009	Mamíferos de médio e grande porte em fragmentos florestais no município de Lavras, MG
Soares_et.al	2013	Levantamento de mamíferos de maior porte em seringais e florestas do sul da Bahia (Brasil) utilizando armadilhas fotográficas.
Barros_et.al	2008	Levantamento e estimativas populacionais de mamíferos de médio e grande porte num fragmento de Mata Atlântica em área urbana no sudeste do Brasil.
Tonini_et.al	2010	Non-volant tetrapods from Reserva Biológica de Duas Bocas, State of Espírito Santo, Southeastern Brazil.
Neto_et.al	2009	. Mamíferos de um fragmento florestal particular periurbano de Juiz de Fora, Minas Gerais, Brasil.
Alves_et.al	2005	Camera traps used on the mastofaunal survey of Araras Biological Reserve, IEF-RJ.

Rocha_et.al	2015	Non-volant mammals from Núcleo Santa Virgínia, Serra do Mar State Park, São Paulo, Brazil.
Srbek_et.al	2013	Influence of camera-trap sampling design on mammal species capture rates and community structures in southeastern Brazil.
Modesto_et.al	2008b	Mammals Serra da Concórdia, state of Rio de Janeiro, Brazil.
Gheler_et.al	2002	Mamíferos não-voadores do campus “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, Brasil.
Silva_et.al	2008	The effect of a mega-fragmentation process on large mammal assemblages in the highly-threatened Pernambuco Endemism Centre, north-eastern Brazil.
Magioli_et.al	2016	Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes.
Ferreguetti_et.al	2017	Differences in the mammalian habitat use in a mosaic of vegetation types of an Atlantic rain-forest reserve, Brazil.
Eduardo_et.al	2009	Mammals of medium and large size in Santa Rita do Sapucaí, Minas Gerais, southeastern Brazil.
Antunes_et.al	2009	Mamíferos (Chordata: Mammalia) florestais de médio e grande porte registrados em Barreiro Rico, Anhembi, estado de São Paulo.
Brocado_et.al	2012	Mamíferos não voadores do Parque Estadual Carlos Botelho, continuum florestal do Paranapiacaba.
Castilho_et.al	2010	Comunidade de mamíferos de médio e grande porte em fragmentos de Mata Semidecidual da APA Municipal de Campinas, SP.
Dias_et.al	2006	Levantamento e conservação da mastofauna em um remanescente de floresta ombrófila mista, Paraná, Brasil.
Gaspar_et.al	2005	Comunidade de mamíferos não voadores de um fragmento de Floresta Atlântica semidecídua do município de Campinas, SP.
Siviero_et.al	2011	Pegadas de mamíferos em parcelas de areia em fragmentos de vegetação da bacia do ribeirão Ananhumas, Campinas, São Paulo.
Srbek_et.al	2008	Domestic dogs in Atlantic Forest preserves of south-eastern Brazil: a camera-trapping study on patterns of entrance and site occupancy rates.
D'Bastiani_et.al	2018	Inventory of medium and large mammals in the Biological Reserve of Araucarias, Parana, Brazil.
Lima_et.al	2016	Inventario preliminar de maiferos de medio e grande porte na porcao sul do parque nacional de Ilha Grande.
Pazio_et.al	2013	Inventariamento de mamiferos terrestres de médio e grande porte em áreas de recuperação do Parque Estadual Lago Azul, Paraná, Brasil.
Pianca_et.al	2004	A caca e seus efeitos sobre a ocorrencia de mamiferos de medio e grande porte em areas preservadas de Mata Atlantica na Serra de Paranapiacaba (SP).

Travassos_et.al	2018	Living and lost mammals of Rio de Janeiro's largest biological reserve: an updated species list of Tingua.
Cunha_et.al	2010	Negative effects of tourism in a Brazilian Atlantic Forest National Park.
Chagas_et.al	2009	Survey of the Populations of Callicebus coimbrai Kobayashi & Langguth, 1999 in Fragments of the Atlantic Forest in the south of the Brazilian state of Sergipe.
Vale_et.al	2015	Diversidade de Mamiferos do Parque Estadual Cachoeira da Fumaca, Alegre, Espirito Santo.
Albuquerque_et.al	2016	Densidade e preferencias de habitat de mamiferos em um fragmento de Mata Atlantica no nordeste do Brasil.
Pereira_et.al	2018	Checklist of medium-sized to large mammals of Campos Gerais National Park, parana, Brazil.
Xavier_et.al	2016	Mamiferos terrestres de medio e grande porte do Parque Nacional da Restinga de Jurubatiba: riqueza de especies e vulnerabilidade local.
Preuss_et.al	2016	Levantamento Rapido de mamiferos terrestres em um remanescente de mata atlantica do sul do Brasil.
Pereira_et.al	2017	Factors Affecting Mammalian Encounter Rates in Transect Surveys: A Case Study in Ilha Grande State Park, State of Rio de Janeiro, Brazil.
Koester_et.al	2007	Padrao de distribuicao e abundancia de aves e mamiferos de medio e grande porte em Ilhabela, SP, Brasil.
Dorneles_et.al	2017	Diversidade de mamiferos em fragmentos florestais urbanos na Bacia Hidrografica do Rio Cachoeira, Joinville, SC.
Melo_et.al	2012	Use of camera-traps in natural trails and shelters for the mammalian survey in the Atlantic Forest.
Pereira_et.al	2023	Composition of medium and large¬ sized mammals in two protected areas of the Atlantic forest in the central western mesoregion of Paraná state, Brazil
Alves_et.al	2021	Medium-sized and large mammals of the Floresta da Cicuta Area of Relevant Ecological Interest, a protected area in southeastern Brazil
Hübel_et.al	2021	Mamíferos de médio e grande porte na área de proteção ambiental municipal do rio vermelho em Santa Catarina, sul do Brasil
Roma_et.al	2020	Sensibilização ambiental por meio de dados da fauna local da Reserva Biológica Serra dos Toledos no bioma Mata Atlântica
Paolino_et.al	2021	Inventário de mamíferos e aves por meio de armadilhas fotográficas em duas unidades de conservação e corredor de biodiversidade da serra do mar
Bella_et.al	2022	Riqueza e diversidade funcional de mamíferos em fragmentos urbanos de floresta estacional semidecidual no sudeste do Brasil
Neves_et.al	2022	Levantamento de mamíferos terrestres de médio e grande porte ocorrentes na floresta nacional Mário Xavier- Seropédica - RJ
Ferreira_et.al	2022	Mamíferos de médio e grande porte do parque estadual do Ibitipoca, Lima Duarte – MG

Falquetto_et .al	2020	Riqueza, diversidade e abundância de mamíferos terrestres da fazenda Capijuma, área do corredor ecológico saíra apunhalada, em Conceição De Castelo, ES

Table S2. Medium- and large-sized mammals recorded in the forest fragments of the Atlantic Forest, number de fragments records and the threat category international levels (IUCN, 2023).

Taxon	Common name	Records	Threaten category
PRIMATES			
ATELIDAE			
Alouatta belzebul (Linnaeus, 1766)	Red-handed Howler Monkey	5	VU
Alouatta caraya (Humboldt, 1812)	Black-and-gold Howler Monkey	7	NT
Alouatta guariba (Humboldt, 1812)	Brown Howler Monkey	44	VU
Alouatta sp		1	
Brachyteles arachnoides (É. Geoffroy, 1806)	Southern Muriqui	10	CR
Brachyteles hypoxanthus (Kuhl, 1820)	Northern Muriqui	6	CR
CEBIDAE			
Sapajus apella (Linnaeus, 1758)	Black-capped Capuchin	6	LC
Sapajus cay (Illiger, 1815)	Azara's Capuchin	3	VU
Sapajus flavius (Schreber, 1774)	Blonde Capuchin	3	EN
Sapajus libidinosus (Spix, 1823)	Bearded Capuchin	1	NT
Sapajus nigritus (Goldfuss, 1809)	Black-horned Capuchin	63	NT
Sapajus robustus (Kuhl, 1820)	Crested Capuchin	15	EN
Sapajus sp.		1	
Sapajus xanthosternos (Wied-Neuwied, 1826)	Buff-headed Capuchin	18	CR
PITHECIIDAE			
Callicebus coimbrai (Kobayashi & Langguth, 1999)	Coimbra-Filho's Titi Monkey	2	EN
Callicebus melanochir (Wied-Neuwied, 1820)	Black-handed Titi	17	VU
Callicebus nigrifrons (Spix, 1823)	Black-fronted Titi Monkey	35	NT
Callicebus personatus (É. Geoffroy, 1812)	Atlantic Titi	7	VU
Callicebus sp.		5	
DIDELPHIMORPHIA			
DIDELPHIDAE			
Didelphis aurita (Wied-Neuwied, 1826)	Black-eared opossum	111	LC
Didelphis albiventris (Lund, 1840)	White-eared Opossum	75	LC
Didelphis sp.		29	
PILOSA			
MYRMECOPHAGIDAE			
Tamandua tetradactyla (Linnaeus, 1758)	Southern tamandua	121	LC
Myrmecophaga tridactyla Linnaeus, 1758	Giant anteater	16	Vu
BRADYPODIDAE			
Bradypus torquatus Illiger, 1811	Maned sloth	13	VU
Bradypus variegates Schinz, 1825	Brown-throated sloth	29	LC
CINGULATA			
CHLAMYPHORIDAE			
Cabassous tatouay (Desmarest, 1804)	Greater naked-tailed armadillo	79	LC
Euphractus sexcinctus (Linnaeus, 1758)	Six-banded armadillo	92	LC

Cabassous unicinctus (Linnaeus, 1758)	Southern Naked-Tailed Armadillo	13	LC
Cabassous sp		8	
Priodontes maximus (Kerr, 1792)	Giant Armadillo	5	VU
DASYPODIDAE			
Dasypus novemcinctus (Linnaeus, 1758)	Nine-banded armadillo	204	LC
Dasypus septemcinctus (Linnaeus, 1758)	Brazilian Lesser Long-nosed Armadillo	38	LC
Dasypus sp.		7	
RODENTIA			
CAVIIDAE			
Hydrochoerus hydrochaeris (Linnaeus, 1766)	Capybara	72	LC
CUNICULIDAE			
Cuniculus paca (Linnaeus, 1766)	Lowland paca	144	LC
DASYPROCTIDAE			
Dasyprocta azarae Lichtenstein, 1823	Azara's agouti	63	DD
Dasyprocta leporina (Linnaeus, 1758)	Red-rumped agouti	60	DD
Dasyprocta fuliginosa (Wagler, 1832)	Black Agouti	1	LC
Dasyprocta iacki (Feijó and Langguth, 2013)		8	DD
Dasyprocta sp.		12	
ERETHIZONTIDAE			
Chaetomys subspinosus (Olfers, 1818)	Bristle-spined porcupine	9	VU
Coendou insidious (Lichtenstein, 1818)	Bahian hairy dwarf porcupine	14	LC
Coendou prehensilis (Linnaeus, 1758)	Brazilian porcupine	16	LC
Coendou sp.		9	
Coendou spinosus (F. Cuvier, 1823)	Paraguayan hairy dwarf porcupine	50	LC
MYOCASTORIDAE			
Myocastor coypus (Molina, 1782)	Coypu	25	LC
ARTIODACTYLA			
BOVIDAE			
Bos taurus (Linnaeus, 1758)[a]	Cattle	16	
CERVIDAE			
Blastocerus dichotomus (Illiger, 1815)	Marsh Deer	1	VU
Mazama americana (Erxleben, 1777)	Red Brocket	46	DD
Mazama bororo (Duarte, 1996)	Small Red Brocket	2	VU
Subulo gouazoubira (Fischer, 1814)	Gray Brocket	44	LC
Mazama nana (Hensel, 1872)	Brazilian Dwarf Brocket	15	VU
Mazama sp.		33	
Ozotoceros bezoarticus (Linnaeus, 1758)	Pampas Deer	2	NT
TAYASSUIDAE			
Tayassu pecari (Link, 1795)	White-lipped Peccary	21	LC
Dicotyles tajacu (Linnaeus, 1758)	Collared peccary	93	VU
SUIDAE			
Sus scrofa domesticus (Erxleben, 1777)[a]	Pig	11	LC

CARNIVORA			
CANIDAE			
Canis lupus familiaris (Linnaeus, 1758)[a]	Domestic dog	114	
Cerdocyon thous (Linnaeus, 1766)	Crab-eating fox	199	LC
Chrysocyon brachyurus (Illiger, 1815)	Maned Wolf	43	NT
Lycalopex gymnocercus (G. Fischer, 1814)	Pampas Fox	8	LC
Lycalopex vetulus (Lund, 1842)	Hoary Fox	4	NT
Speothos venaticus (Lund, 1842)	Bush Dog	3	NT
FELIDAE			
Felis catus (Linnaeus, 1758)[a]	Domestic cat	11	
Leopardus wiedii (Schinz, 1821)	Margay	85	NT
Herpailurus yagouaroundi (É. Geoffroy Saint-Hilaire, 1803)	Jaguarundi	79	LC
Leopardus braccatus (Cope, 1889)	Pampas cat	1	NE
Leopardus guttulus (Hensel, 1872)	Southern Tiger Cat	66	VU
Leopardus pardalis (Linnaeus, 1758)	Ocelot	112	LC
Leopardus sp		51	
Leopardus tigrinus (Schreber, 1775)	Northern Tiger Cat	33	VU
Panthera onca (Linnaeus, 1758)	Jaguar	14	NT
Puma concolor (Linnaeus, 1771)	Puma	106	LC
MEPHITIDAE			
Conepatus chinga (Molina, 1782)	Molina's Hog-nosed Skunk	7	LC
Conepatus semistriatus (Boddaert, 1785)	Striped Hog-nosed Skunk	20	LC
Conepatus sp		4	
MUSTELIDAE			
Eira barbara (Linnaeus, 1758)	Tayra	151	LC
Galictis cuja (Molina, 1782)	Lesser Grison	56	LC
Galictis sp		7	
Galictis vittata (Schreber, 1776)	Greater Grison	3	LC
Lontra longicaudis (Olfers, 1818)	Neotropical Otter	62	NT
PROCYONIDAE			
Nasua nasua (Linnaeus, 1766)	South America coati	185	LC
Procyon cancrivorus (G. Cuvier, 1798)	Crab-eating raccoon	162	LC
Potos flavus (Schreber, 1774)	Kinkajou	11	LC
LAGOMORPHA			
LEPORIDAE			
Lepus capensis (Linnaeus, 1758)	Cape Hare	3	LC
*Lepus europaeus *Pallas, 1778)*	European Hare	36	LC
Lepus sp.		2	
PERISSODACTYLA			
TAPIRIIDAE			
Tapirus terrestris (Linnaeus, 1758)	South american tapir	33	VU
EQUIDAE			
Equus ferus caballus (Boddaert, 1785)[a]	Domestic horse	12	

CAPÍTULO III:

FUNCTIONAL DIVERSITY OF MEDIUM AND LARGE MAMMALS IN AREAS OF COCOA AGROFORESTRY IN SOUTHERN BAHIA

Manuscrito formatado nas normas da revista Functional Ecology

Functional diversity of medium and large mammals in areas of cocoa agroforestry in southern Bahia

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Abstract

Sustainable food production is an important challenge against high rates of habitat changes and climate urgency. Modern agriculture (i.e., agribusiness) is considered a major threat to biodiversity, whereas Agroforestry systems are known for their more permeable matrix compared to traditional systems, helping the maintainance of local biodiversity and its ecosystem functions. Cocoa (*Theobroma cacao*) in southern Bahia Brazil is cultivated in an agroforestry system, planted under the canopy of native trees, locally known as 'cabrucas', being more biodiversity-friendly than other monocultures and intensive croplands. We evaluated the contribution of cabruca systems in maintaining the functional diversity of medium- to large-bodied mammals at both local and landscape levels in the Atlantic Forest of Southern Bahia, Brazil. We expected that sites with less canopy opening, greater forest cover, and less fragmentation will exhibit higher functional richness and divergence, and lower functional evenness, once it has been demonstrated that areas with greater mammal richness and more complete assemblages exhibit a greater diversity of ecological functions than those that have been modified by humans. We installed camera-traps in 15 cocoa agroforests with varying levels of forest cover at the landscape scale. The results showed that forest cover had a positive correlation with Functional Richness (FRic), while more defaunated areas had a negative correlation. Our study found that FRic was not related to canopy openness and cocoa tree density. We also found that agroforests play a significant role in maintaining functional diversity at the landscape scale. Areas with greater forest coverage in their surroundings showed greater functional richness. These areas can serve as refuges and maintain species that perform important ecological functions.

Keywords: Agroforestry systems, cabruca, defaunation, ecological functions

Introduction

Agriculture has been identified as one of the main threats to biodiversity, leading to the reduction and fragmentation of forests, particularly in tropical region (Gibbs et al., 2010; Newbold et al., 2020). The interactions between biological and socioeconomic factors caused by the development of agricultural areas modify the structure of vegetation, nutrient cycling, and plant biomass, thus altering the composition of the wildlife assemblages through the loss of both species and the functions they perform (Bisseleua et al., 2009). Consequently, new technologies and more sustainable farming practices have become a way to mitigate biodiversity loss. Agroforestry systems, that is, croplands associated with native forests, known to be a more permeable matrix for biodiversity (Schroth et al., 2004), a farming practice widely employed that attempts to reconcile agricultural development and biodiversity maintenance (Deheuvels et al., 2014). In southern Bahia, Brazil, for example, cocoa (*Theobroma cacao*) is one of the main economic activities for the production of chocolate, and is mostly cultivated on a traditional agroforestry system, in which cocoa is planted under the shade of native trees, locally known as 'cabruca' (Fonseca et al., 2023; Sambuichi et al., 2012).

The cocoa agroforests of southern Bahia are located in the northern portion of the Atlantic Forest domain, a highly threatened biome, with most fragments smaller than 50 ha, which has historically suffered from a wide range of anthropogenic pressures, including urbanization and agriculture (Lima et al., 2014; Ribeiro et al., 2009). Although this region was heavily modified by human activities since the Brazilian colonization (Faria et al. 2021), it harbors extensive forested areas safeguarding a rich biodiversity (Faria et al., 2007; Magioli et al., 2021; Morante-Filho et al., 2015a). Cacao agroforests plays an important role for the maintenance of the Atlantic Forest and its biodiversity in this region, preserving many ecological characteristics of natural forests (Cabral et al., 2021; Felicitas et al., 2018).

However, the contribution of these agroforrests to biodiversity conservation is directly related to their management, structure, and composition, as well as the quantity and quality of the remaining native forest habitats in the landscape (Cassano et al., 2009; Schroth & Harvey, 2007). In recent years, there has been a substantial increase in the intensification of management in these areas, with an increase in the use of inputs (i.e., agrochemicals) and reduction of shade trees aimed at enhancing cocoa productivity, which could lead to major impact on local biodiversity (Ambele et al., 2023). In anthropogenically modified landscapes, the type and form of the matrix can function as a filter that facilitates movement or serves as a barrier, influencing resource availability and even the environmental conditions of the place (Driscoll et al., 2013). Species with low habitat requirements may benefit, while sensitive ones might experience population declines orlocal extinctions, resulting in the loss of ecological functions performed (Flynn et al., 2009; Magioli et al., 2015; Tabarelli et al., 2010).

Although the diversity of mammals in cacao agroforests has been documented in some studies (Cassano et al., 2014; Ferreira et al., 2020), highlighting the presence of important herbivores, seed dispersers, and predators, none evaluated the species functional characteristics. Considering the historic of habitat loss and fragmentation in the Atlantic Forest of Bahia (Faria et al. 2021), important functional traits might have been lost due to mammalian loss, for example, large species (> 7 kg) with very limited occurrence in the region, virtually restricted to large, protected areas (Magioli et al., 2021). This loss of large vertebrates and their functions on local, regional, and global scale is a phenomenon known as defaunation, which has been particularly reported in tropical ecosystems, leading to changes in ecosystem functioning (Bogoni et al., 2019; Dirzo et al., 2014; Pires & Galetti, 2023). Therefore, studies relating mammalian diversity and ecological functions are needed to evaluate the contribution of cocoa agroforests to ecosystem functioning, and the impact of defaunation.

In this context, measures of functional diversity can overcome the limitations of traditional diversity indices in establishing a relationship between biodiversity and ecological functions. Studies employing these measures have grown substantially in the last decade (e.g., Bogoni et al., 2019; Bovendorp et al., 2019; da Silva et al., 2020; Magioli et al., 2015, 2016) as they offer insights and predictions of ecosystem functioning by relating species diversity to specific functions performed (Petchey & Gaston, 2006).

Therefore, understanding how cocoa agroforests shape the functional diversity of mammals is paramount in developing realistic management strategies to ensure the maintenance of important ecological functions they perform. The present study aims to evaluate the local and landscape-level influence of cocoa agroforests in southern Bahia, Brazil, on the functional diversity of medium and large-sized mammals, in addition to the modulating effect of defaunation of mammal assemblages. To do this, we employed a multidimensional approach that allowed us to uncover the functional structure of communities based on three functional components: Functional Richness (FRic), Functional Evenness (FEve), and Functional Divergence (FDiv).

FRic represents the amount of the functional space occupied by an assemblage and can be understood as the number of features or categories of a characteristic presented by the assemblage. FEve measures the uniformity of species abundance distribution in the functional space, reflecting the degree of functional similarity between the species that make up a community weighted by abundance. FEve values decrease when there are empty areas in the functional space and others that are highly occupied (Mouchet et al., 2010; Pla et al., 2012). We used capture rates weighted by the sampling effort as a proxy for mammal relative abundance (e.g., see Magioli et al., 2021), which was calculated by summing the independent records of each species and weighting it by the sampling effort obtained for each area.

The FDiv index represents the distribution or clustering of species within a functional space, which is based on species frequency and can be used to understand how taxa differentiate within each attribute (Villéger et al., 2008). A high FDiv value may indicate a high degree of niche differentiation for species, resulting in low competition for resources.

We hypothesized that: 1) areas with high forest cover have higher mammalian richness and more complete assemblages, presenting a wider set of ecological functions than human-modified areas (Estrada-Villegas et al., 2010; Magioli et al. 2021). Thus, areas with less canopy opening (i.e., with greater shading, used here as a proxy for management), higher forest cover and less fragmented, will present higher functional richness and divergence, and lower functional evenness. Conversely, defaunated areas will present the reverse patterns, even in areas with high forest cover because the loss of sensitive species leads to a simplification of the assemblages, which becomes dominated by generalist and opportunistic ones (Dotta & Verdade, 2011; Lindenmayer & Fischer, 2007, Magioli et al. 2021).

Materials and methods

Study Area

This study was conducted in a cocoa-producing region of Southern Bahia, Brazil (Figure 1), which is inserted in one of the five endemism centers of the Atlantic Forest, and safeguards some of the largest forest remnants in northeastern Brazil (Thomas et al., 1998). The study region comprises the municipalities of Ilhéus, Una, and Belmonte, characterized by various land uses, but mainly composed of a mosaic of cocoa cultivation, eucalyptus plantations, pastures, and different amounts of native forest (Fonseca et al., 2023). Our study is part of the project "Economia das Cabrucas" led by the Applied Ecology and Conservation Laboratory (LEAC) of the State University of Santa Cruz (UESC), which objective is to understand the dynamics of biodiversity assemblages in cocoa agroforests, considering species diversity, ecosystem services, and productivity. In total, we selected 15 areas contemplated in the project "Economia das Cabrucas", primarily small private rural properties, with varying levels of native forest cover and different land uses in their surroundings (Figure 1; Table 1).

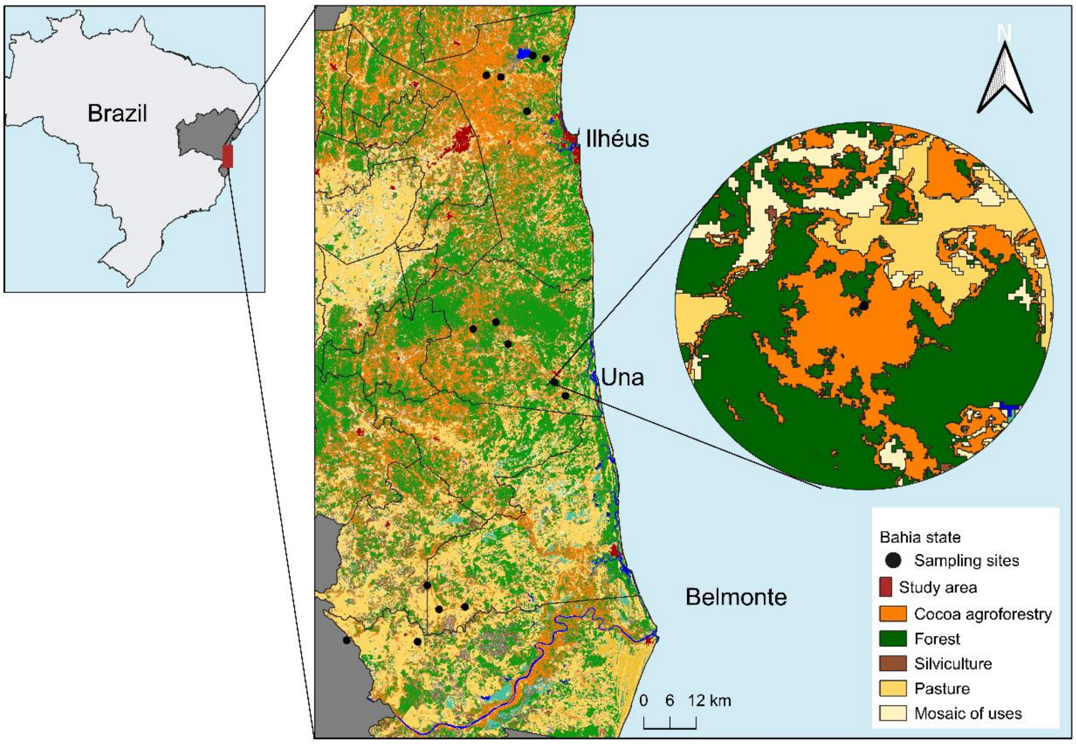

Figure 1: Location of sampling sites (agroforestry) in southern Bahia, Brazil, depicting the main land uses.

Data Collection

Mammal sampling

To sample medium and large-sized mammals (> 1 kg; Chiarello, 2000), we used camera traps (Bushnell Trophy Cam HD, model 119876). We deployed between 8 and 10 camera traps per site, based on property size, without baits, and with at least 100 m among stations. Cameras operate continuously for an average of 70 days (minimum of 64 and maximum of 77 days) in each area, divided into two campaigns between 2021 and 2022, and installed on trees at a height of 30-40 cm above the ground. The variation in the number of sampling days was due to logistical adaptations related to the COVID-19 pandemic, as well as some cameras were malfunctioning or stolen. The average sampling effort was 578 trap-days per area, for a total of 8,670 trap-days. We considered as independent records of each species, those taken at least with one-hour interval in the same sampling stations. We consulted specialized literature to identify the medium and large-sized mammal species (Emmons & Feer, 1997; Oliveira & Cassaro, 2006). Species nomenclature followed Abreu et al. (2023), and we assigned threat categories per species (i.e., Vulnerable, Endangered, and Critically Endangered) following regional (Bahia, 2017), national (BRASIL, 2022), and international levels (IUCN, 2023). We considered exotic species those that occurred outside their natural range, as defined in Falk-Petersen et al. (2006).

Local-scale variables

To obtain variables at the local scale, we used a database available from the “Economia das Cabrucas" project. In each area, a 100 × 25m (0.25 ha) plot was constructed to obtain information of shading), which was estimated as the percentage of shade at 1.5 m above the ground using a densitometer and canopy photographs. With the densitometer, shading was measured 20 times, and the foliage was counted, while five canopy photographs were obtained, and with the help of GLMA application, we obtained the percentage of shade.

To assess the impact of defaunation on the mammalian assemblage, we calculated the defaunation index as proposed by Giacomini and Galetti (2013). For that, we used a survey conducted on forest remnants in southern Bahia (Magioli et al., 2021), to obtain a baseline of potential assemblage composition, we chose to use only presence/absence data from camera trap sampling (Supplementary Material: Table A1) and used the presence/absence data collected in this study to estimate the actual composition. We then calculated the defaunation index (DI), for medium- and large-sized mammals for each community (i.e., sampling location) as follows:

$$DI = 1 - \frac{\sum_j^N BWES_j}{\sum_i^N BWES_i}$$

where N represents the total number of species in the community; j is the total number of species in the actual community composition; i is the total number of species in the potential community composition; BWES is the average body mass for each species of medium and large mammal, since the decline of large species is regarded as one of the primary outcomes of defaunation (Dirzo et al., 2014). To make the scale clearer the result of the division of sums was subtracted from 1. Thereby, DI ranged from 0 (non-defaunated sites) to 1 (which indicates a completely defaunated site).

Landscape-scale variables

For landscape characterization, we used the maps from the MapBiomas project, collection 7 of 2020, and MapBiomas cocoa of July 2023, with a resolution of 30m, derived from Landsat satellite and available for download on the website http://mapbiomas.org. In first map, the separation between forest and cocoa agroforestry is not yet available, and in MapBiomas cocoa, silviculture is combined with forest, and other land use classes are not differentiated. Therefore, we overlaid these two maps, making it possible to quantify the amount of forest and cocoa agroforestry in the landscape, as well as other land uses.

We opted for metrics that describe the composition and configuration of the landscape and are correlated with the species assemblage characteristics (Lindenmayer & Fischer, 2007). We quantified the percentage of native forest cover, and the number of fragments (total number of fragments not connected within each area). These metrics were calculated by creating 1,500 m buffers around the sampling sites. We believe that this radius size is sufficient to explain the relative contribution of landscape structures to the distribution of mammals found in this study (Supplementary Material: Table A2), considering that the average home range does not exceed this radius. Larger radius scales were not tested to avoid confusion with spatial autocorrelation, as larger radii increase the overlap between sampling regions (Lyra-Jorge et al., 2009). Landscape variables were calculated using R software v.4.3.2 (R Development Core Team, 2023) and QGIS v.3.32, using the Landscape Ecology plugin.

Data Analysis

Species Richness

The species richness of medium- and large-sized mammals was estimated using first-order Jackknife and Bootstrap with 1000 randomizations using the 'vegan' package (Oksanen et al., 2022).

Functional Diversity

We used the approach proposed by Villéger et al. (2008), implemented through the "FD" package (Laliberté & Legendre, 2010), to calculate the functional diversity of the medium and large-sized mammal assemblages.

Functional traits were selected based on the life history characteristics of the species compiled from the literature. Functional traits that reflect a species niche also portray the resources it requires, reflecting its relationship with ecosystem functioning. Therefore, the use of life history data, such as foraging habits, is recommended (Flynn et al., 2009). We selected species characteristics, including those based on resource use such as physical data, body mass, dietary data, and stable carbon and nitrogen isotope ratios. Specifically, stable carbon isotopes allow us to assess changes in species resource use based on differences in isotopic values between C3 (forest) and C4 plants (non-forest, C4 crops, pasture). Nitrogen, on the other hand, provides insights of species trophic organization. The way species obtain resources from the environment can be influenced by the way organisms move, so we select a behavioural characteristic and classify species as terrestrial, arboreal, or fossorial (Flynn et al., 2009). The classification of species can be seen in the Supplementary (Supplementary Material: Table A3). Physical and behavioral data were extracted from Paglia et al. (2012), and dietary data from Magioli et al. (2019).

We used the Akaike information criterion corrected for small samples (AICc) (Burnham et al., 2011) to compare generalized linear models between the functional diversity indexes in each area (response variable) and the local and landscape metrics (explanatory variables).

Table 1: Sampling sites selected for our study and their geographic location, forest cover and sampling effort (camera-day). The proportion of forest cover was made from buffers around the points with a radius of 1.5 km.

Sample Sites	Lat	Long	Municipality	% Forest Cover	Sampling effort
Almada	-14.66	-39.19	Ilhéus	17.2	455
I8	-14.73	-39.13	Ilhéus	56.7	495
I4	-14.65	-39.22	Ilhéus	14.9	594
I9	-14.61	-39.12	Ilhéus	60.9	352
I10	-14.62	-39.09	Ilhéus	71.4	576
U11	-15.19	-39.25	Una	59.9	555
U7	-15.18	-39.20	Una	71.2	600
U2	-15.31	-39.07	Una	48.2	675
U4	-15.23	-39.17	Una	48.0	462
U1	-15.34	-39.05	Una	38.8	646
B9	-15.86	-39.52	Belmonte	45.9	730
B10	-15.78	-39.27	Belmonte	10.7	693
B1	-15.79	-39.32	Belmonte	6.2	476
B8	-15.86	-39.37	Belmonte	6.9	710
B2	-15.74	-39.35	Belmonte	20.7	650

Results

We recorded a total of 13 species of medium- and large-sized terrestrial mammals and six species of domestic animals (Table 2). The richness of wild mammals per area varied from four to 10 (7 ± 2, mean ± SD) (Supplementary Material: Table A3). *Cerdocyon thous*, *Cuniculus paca*, and *Tamandua tetradactyla* were recorded in 12 areas. *Cerdocyon thous* and C. *paca* also had the highest number of independent records (149 and 114 respectively), while *Cabassous tatouay* was recorded only once. The species richness recorded was similar to that estimated by first-order Jackknife (13.93 ± 0.93) and Bootstrap (13.39 ± 0.51) estimators, suggesting that a sufficient sample size was achieved for the study area.

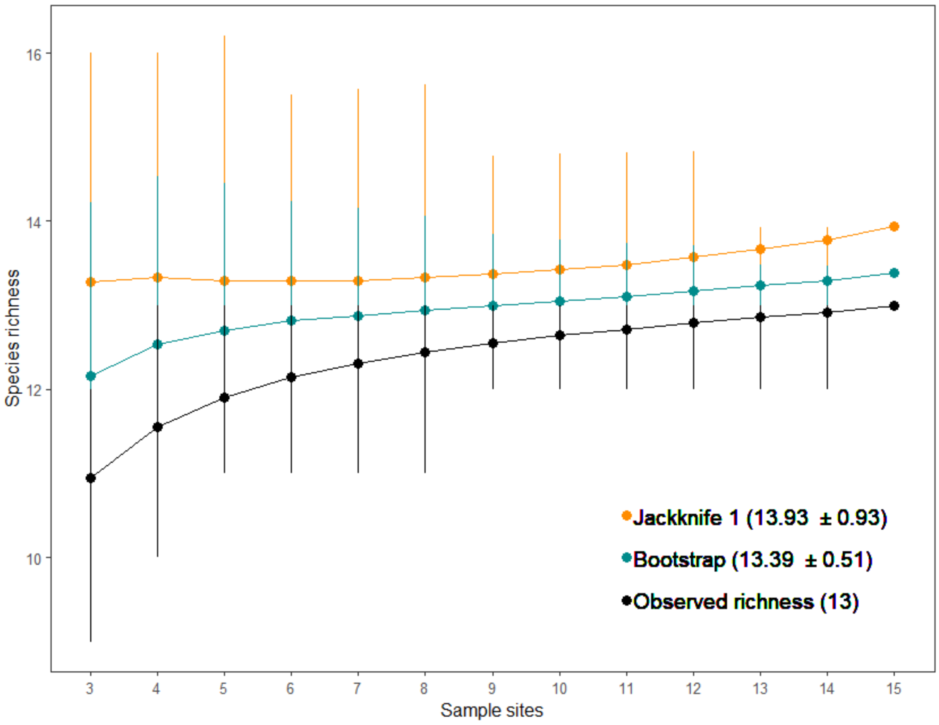

Figure 2: Observed species richness of medium and large mammals and richness estimated from Jacknife 1 and bootstrap estimators, with 1000 randomizations, in 15 cocoa agroforests in southern Bahia.

Table 2. Medium- and large-sized mammals recorded in the 15 cocoa agroforests of Southern Bahia, Brazil, including species trophic guild (Paglia et al., 2012), threat category at regional (Bahia, 2017), national (ICMBio, 2022) and international levels (IUCN, 2023), and the relative abundance record.

Taxon	Common name	Guild	Threaten category			Relative abundance
			Bahia	Brazil	World	
DIDELPHIMORPHIA						
DIDELPHIDAE						
Didelphis aurita (Wied-Neuwied, 1826)	Black-eared opossum	Fr/Om			LC	0.127
PILOSA						
MYRMECOPHAGIDAE						

Tamandua tetradactyla (Linnaeus, 1758)	Southern tamandua	In			LC	0.043
CINGULATA						
CHLAMYPHORIDAE						
Cabassous tatouay (Desmarest, 1804)	Greater naked-tailed armadillo	In			LC	0.001
Euphractus sexcinctus (Linnaeus, 1758)	Six-banded armadillo	In/Om			LC	0.015
DASYPODIDAE						
Dasypus novemcinctus (Linnaeus, 1758)	Nine-banded armadillo	In/Om			LC	0.102
RODENTIA						
CUNICULIDAE						
Cuniculus paca (Linnaeus, 1766)	Lowland paca	Fr/Hb			LC	0.193
ARTIODACTYLA						
BOVIDAE						
Bos taurus (Linnaeus, 1758)[a]	Cattle	Hb				0.635
CERVIDAE						
Passalites nemorivagus (Cuvier, 1817)[b]	Amazonian Brown Brocket	Hb/Fr			LC	0.030
TAYASSUIDAE						
Dicotyles tajacu (Linnaeus, 1758)	Collared peccary	Fr/Hb			LC	0.062
SUIDAE						
Sus scrofa domesticus (Erxleben, 1777)[a]	Pig	Om				0.021
CARNIVORA						
CANIDAE						
Canis lupus familiaris (Linnaeus, 1758)[a]	Domestic dog	Ca/Om				0.716
Cerdocyon thous (Linnaeus, 1766)	Crab-eating fox	Om			LC	0.248
FELIDAE						
Felis catus (Linnaeus, 1758)[a]	Domestic cat	Ca				0.017
Leopardus wiedii (Schinz, 1821)	Margay	Ca	EN	VU	NT	0.024
MUSTELIDAE						
Eira barbara (Linnaeus, 1758)	Tayra	Fr/Om			LC	0.057
PROCYONIDAE						
Nasua nasua (Linnaeus, 1766)	South America coati	Fr/Om			LC	0.079
Procyon cancrivorus (G. Cuvier, 1798)	Crab-eating raccoon	Fr/Om			LC	0.065
PERISSODACTYLA						
EQUIDAE						
Equus ferus caballus (Boddaert, 1785)[a]	Domestic horse	Hb				0.057
Equus africanus asinus (Linnaeus, 1758)[a]	donkey	Hb				0.032

The relationships between local and landscape metrics and the different functional diversity dimensions were specific to Functional Richness (FRic). On a local scale, more defaunated areas showed a negative relationship with functional richness (FRic), whereas on landscape scale, forest cover around the study sites exhibited a positive and significant relationship (Table 3, Fig. 1a and b), but canopy openness (shading) and number of fragments were not related to FRic. Functional Evenness (FEve) and Functional Divergence (FDiv) showed no significant relationships with any of the variables.

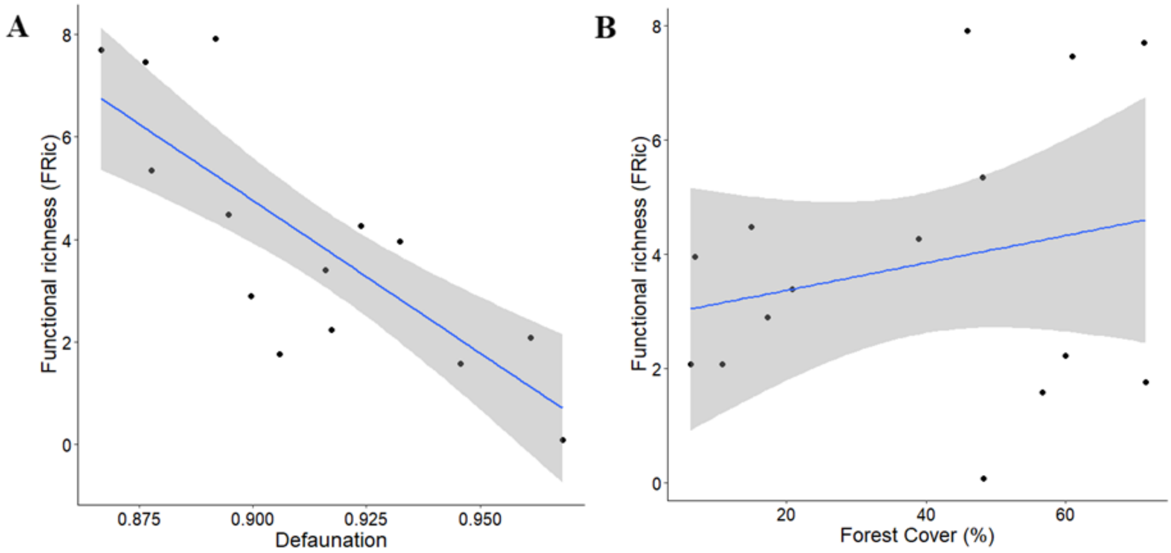

Fig. 1: Relationships between functional diversity – Functional richness and the respective predictor variables. A) Defaunation index. B) Forest cover (%) within a radius of 1500 meters. The 95% confidence intervals are shown in gray.

Table 3. Model estimates (Estimate), unconditional standard errors (SE), and the p-value given for the t-statistic of the fixed effects across all generalized linear models (GLM) evaluating the functional richness response. The fixed variables considered included forest cover, shaded cocoa cover, number of patches, and defaunation index (in a 1500 m radius).

	Estimate	*SE*	*t value*	*Pr(>|t|)*
(Intercept)	-8.068	2.220	-3.634	0.0045**
Forest cover	0.005	0.002	2.358	0.0401*
Shaded cocoa amount	-0.005	0.003	-1.743	0.1118
Number of patches	0.0004	0.0004	1.120	0.2887
Defaunation index	9.295	2.541	3.659	0.0044**

Discussion

Our study is the first to measure the functional diversity of mammals in cocoa agroforests. Specifically, our results revealed that in more defaunated agroforests, functional richness was lower, indicating not only the loss of species but also the functions they perform. Furthermore, we found a relationship between functional richness and forest cover of mammals, highlighting the importance of forest remnants around agroforests in retaining mammals that inhabit forests in anthropogenic landscapes (Ferreira et al., 2020). These results partially support our hypothesis, indicating that additional factors could better explain the contribution of local agroforest management to the maintenance of mammal functional diversity and that forest cover is a good predictor of functional diversity of medium and large mammals on cabrucas.

From the local-scale perspective, the evaluated agroforests were largely defaunated. The species richness found in this study represented approximately 40% of the species found in forest fragments. However, it lacks species such as *Panthera onca*, *Puma concolor, Tapirus terrestris*, and *Tayassu pecari*, which are large top predators, seed dispersers and predators, respectively. Half of all records are of species considered low habitat requirement and/or resource generalists, favoring their success in highly fragmented and agricultural landscapes (Dotta & Verdade, 2011; Magioli et al., 2019). However, we also recorded species that exhibited habitat and feeding specializations, such as *Leopardus wiedii*, and *Cabassous tatouay.*

One of the various phenomena related to the reduction of mammal populations is the "downsizing effect," in which individuals within a set become, on average, smaller (Pérez-Méndez et al., 2016). This loss can have significant ecological consequences, as these large animals play essential roles in ecosystems as dispersers of large seeds, top predators, or keystone species, influencing the dynamics of their habitats and leading to cascading effects on the overall structure and function of the ecosystem through the ecological interactions they engage in (Dirzo et al., 2014; Galetti et al., 2021).

In this context, animal-plant interactions are fundamental for the maintenance of tropical forests, specifically the dispersal of large seeds by mammals (Camargo-Sanabria et al., 2015). Given the above and knowing that a significant portion of the forested areas in this study's region is cocoa agroforests, responsible for the region's largest carbon stocks (Rocha Santos et al., 2021; Schroth et al., 2015b), the loss of these dispersers can affect not only the maintenance of this process but also the long-term maintenance of the forest itself. However, small, functionally similar species may counterbalance these losses through compensatory services (Boiten et al., 2023).

From the landscape perspective, areas with higher forest cover in their surroundings showed higher functional richness. However, with a wide range of values, despite maintaining a set of species with important ecological functions, highly fragmented and agricultural landscapes may not be able to sustain mammal populations in the long term (Galetti et al., 2009). In a review conducted in 2009, it was observed that agricultural intensification tends to reduce functional diversity values for mammal assemblages (Flynn et al., 2009), while another study conducted in sugarcane plantation areas indicated that the connectivity of forest fragments around sampling points was important in maintaining the functional diversity of mammals (Magioli et al., 2016).

Cocoa agroforests provide habitat and increase connectivity between forest fragments compared to homogeneous landscapes dominated by monocultures or pastures (Bhagwat et al., 2008; Cassano et al., 2009; Schroth et al., 2011) and appear to play a relevant role in maintaining functional diversity at the landscape scale, as we found higher FRic values in areas with greater forest cover. Similar results were found in studies of birds conducted in the same region; in particular, it was noted that a high level of forest cover in the landscape is necessary to maintain the functional diversity of birds (Rocha et al., 2019). Although forest specialist birds showed a sharp decrease in species richness in landscapes with less than 50% forest cover, there was a concomitant increase in the richness of generalist birds (Morante-Filho et al., 2015b). This pattern was also observed in cocoa agroforests in Indonesia, which showed that the richness of both species and functional groups of birds increased with proximity to the forest, demonstrating the importance of including landscape context in studies on cocoa agroforests (Clough et al., 2009).

The same pattern was not observed for medium and large mammals in a study carried out in south of Bahia, where the main impacts on agroforestry mosaics were driven by the intensification of local management and not by the surrounding forest cover (Cassano et al., 2014). It is worth highlighting, however, that Cassano and collaborators (2014) did not evaluate functional diversity and mammal diversity is likely related to a gradual loss of forest specialists, followed by an increase in habitat generalists, indicating that communities can maintain a local level of species richness and lose function, indicating its homogenization. Traditional measures of diversity have shown less predictive power at the landscape scale in tropical environments (Flynn et al., 2009; Lindenmayer et al., 2015; Magioli et al., 2016).

Land use changes can alter forest cover patterns, both by replacing natural vegetation with other types of uses, such as agriculture, and by drastic changes in vegetation structure and functionality, potentially altering their ecosystem services (Findell et al., 2017; Sales et al., 2020). It is important to emphasize that the intensification of land use and the planting of cocoa in the intensive system, known as full-sun cacao, that is, without shade trees, have been considered to increase productivity (Cassano et al., 2016), and the associated decline in biodiversity has recently been reported (Cassano et al., 2014; Clough et al., 2009; Ferreira et al., 2020; Gove et al., 2008; Harvey et al., 2006), as well as agroforests, they can be important refuges for mammal species and the functions they perform.

This study is the first to measure the functional diversity of medium and large mammals in cocoa agroforests. Considering that functional traits can improve the understanding of agricultural impacts on biodiversity, we provide valuable information on the contribution of this agrosystem to mammal conservation. Even though these areas are highly defaunated, they can serve as refuges and still support species that perform important ecological functions, highlighting the role that animals still present in agroforests can play in maintaining these ecosystems, as well as the need for forest areas in the surrounding area to maintain the existing communities. It is therefore important to consider that special conservation efforts need to be made for certain animal species that persist in defaunated areas and that these systems do not replace intact forests but can contribute to the conservation of species at the landscape scale.

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Supporting Information

Appendices (Supporting Tables and Figures) for “Functional diversity of medium and large mammals in areas of cocoa agroforestry in southern Bahia.”

Table A1: Medium- and large-sized mammals species expected to occur in the Atlantic Forest of Bahia, Brazil, following Magioli et al., 2021 and your respective mean body size following Mammals of Brazil guide (Reis et al., 2006).

Taxon	**Mean body mass**
Didelphis albiventris	1.625
Didelphis aurita	1.235

Tamandua tetradactyla	5.2
Cabassous tatouay	5.35
Euphractus sexcinctus	5.4
Dasypus novemcinctus	3.65
Dasypus septemcinctus	1.47
Tapirus terrestris	200
Mazama sp.	20.83
Dicotyles tajacu	25
Tayassu pecari	32.5
Cerdocyon thous	6.5
Herpailurus yagouaroundi	6.75
Leopardus guttulus	2.37
Leopardus pardalis	12.25
Leopardus wiedii	3.25
Leopardus sp.	7.75
Panthera onca	102
Puma concolor	74.5
Conepatus semistriatus	1.6
Eira barbara	7
Galictis cuja	1.75
Lontra longicaudis	10
Nasua nasua	5.725
Procyon cancrivorus	4.9
Sylvilagus brasiliensis	0.85
Hydrochoerus hydrochaeris	50.5
Cuniculus paca	9.3
Dasyprocta leporina	2.5
Chaetomys subspinosus	1.3
Coendou insidious	2

Table A2: Average home range of mammal species recorded in cocoa agroforests in the southern state of Bahia, Brazil, according to Reis et.al. (2006).

Taxon	**Mean home hange km²**
Cerdocyon thous	4.5
Cuniculus paca	0.04
Cabassous tatouay	4.1
Dasypus novemcinctus	0.21
Didelphis aurita	0.027
Eira barbara	9.8

Euphractus sexcinctus	9.5
Leopardus wiedii	28.5
Passalites nemorivagus	1.1
Nasua nasua	6.3
Pecari tajacu	7.5
Procyon cancrivorus	6.9
Tamandua tetradactyla	3.8
Mean	6.33

Table A3: Mammal species classification and ecological traits used for the functional diversity analysis of the assemblages recorded at cacao agroforestry in southern Bahia State, Brazil, according to Reis et.al., (2006) and Magioli et.al., (2019).

Taxon	**Mean body mass**	**body/tail**	**d13C**	**d15N**
Cerdocyon thous	6.5	2.166667	-16.766	9.034894
Cuniculus paca	9.3	62.95455	-24.55	7.45
Cabassous tatouay	5.35	2.553073	-21.35	9.8
Dasypus novemcinctus	3.65	1.308108	-22.8	8
Didelphis aurita	1.235	0.952864	-23.4429	8.64871
Eira barbara	7	1.458824	-28.5	5.5
Euphractus sexcinctus	5.4	2.222222	-17.6867	7.793333
Leopardus wiedii	3.3	1.425532	-19.85	8.8
Mazama sp	20.83	9.292854	-26.85	6.3
Nasua nasua	5.725	1.082474	-20.0046	7.575385
Pecari tajacu	25	85.71429	-25.8	5.8
Procyon cancrivorus	4.9	2.413793	-16.4773	9.992727
Tamandua tetradactyla	5.2	0.837838	-18.7683	5.168333

CONCLUSÃO GERAL

Os resultados aqui obtidos elucidam as principais tendências e lacunas a respeito da diversidade funcional de mamíferos, destacando a importância crucial dessa dimensão da diversidade para uma compreensão completa de como as crescentes ameaças influenciam tanto na existência desses animais quanto na manutenção dos processos ecossistêmicos dos quais participam. Nossos resultados destacam que perturbações antropogênicas, como perda de habitat e fragmentação, têm impactos significativos na diversidade funcional dos mamíferos, afetando não apenas a riqueza de espécies, mas também processos ecológicos fundamentais, como a dispersão de sementes e a regulação de populações de presas. No primeiro capítulo, realizamos uma análise abrangente sobre a diversidade funcional de mamíferos em ambientes tropicais, apresentando as principais tendências e lacunas, apontando que as perturbações antrópicas têm um impacto negativo significativo, especialmente em índices como riqueza funcional (FRic) e dispersão funcional (FDis). O isolamento do habitat foi identificado como um dos estressores mais prejudiciais. Esses resultados ressaltam não apenas a importância de proteger áreas naturais intactas, mas também a necessidade de adotar práticas sustentáveis em paisagens humanizadas para mitigar os efeitos negativos sobre a diversidade funcional.

No segundo capítulo, avaliamos a Mata Atlântica, um bioma altamente biodiverso e ameaçado, procurando entender o impacto da fragmentação (através do tamanho dos fragmentos), da perda direcionada de espécies, defaunação e a presença de áreas protegidas na diversidade funcional de mamíferos de médio e grande porte. Fragmentos maiores e áreas protegidas desempenham um papel crucial na conservação da diversidade funcional, especialmente para espécies ameaçadas e de grande porte. No entanto, ainda existem desafios significativos em integrar fragmentos menores e entender as consequências de longo prazo da defaunação, exigindo abordagens de conservação mais integradas e estratégias adaptativas. Demonstramos que uma boa parte dos remanescentes florestais está altamente defaunada, e que existe uma relação significativa entre esses fragmentos e a redução da riqueza funcional, indicando que não só estamos perdendo espécies, mas também suas funções. Vale destacar que estudos semelhantes a esse já haviam sido feitos e foram encontrados resultados semelhantes, ou seja, mesmo com ações para mitigar a perda de biodiversidade, a tendência de perda continua se mantendo nos últimos anos.

Quando abordamos uma escala mais regional e avaliamos o impacto da agricultura, mais especificamente os sistemas agroflorestais de cacau no sul da Bahia, as cabrucas, encontramos resultados importantes para a conservação da diversidade funcional de mamíferos de médio e grande porte em paisagens transformadas pelo homem. Esses sistemas mostram uma relação positiva entre a cobertura florestal e a riqueza funcional, destacando sua capacidade de oferecer refúgios e manter processos ecológicos importantes, e como possibilidade de conexão entre fragmentos florestais. Mesmo em áreas altamente defaunadas, as cabrucas ainda abrigam boa parte dos mamíferos esperados para a área, auxiliando na manutenção dessas populações, bem como dos serviços ecossistêmicos desempenhados por elas. É importante, no entanto, salientar que este foi o primeiro estudo a medir a diversidade funcional em agroflorestas de cacau, sendo necessários mais estudos para entender como se dá esse padrão, principalmente a longo prazo e em um número maior de áreas.

Portanto, é necessária uma abordagem integrada na conservação da biodiversidade em suas diversas facetas. Isso inclui a proteção de áreas naturais, a adoção de práticas sustentáveis em paisagens humanizadas e a promoção de sistemas agroflorestais e outras iniciativas que promovam a conectividade ecológica e a resiliência dos ecossistemas frente às crescentes pressões antropogênicas.