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Large Protected Areas Safeguard Mammalian Functional Diversity in Human-Modified Landscapes

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Abstract: Habitat loss and fragmentation are pervasive processes driving the disappearance of populations and species in the Neotropical region. Since species loss may translate into functional loss, assessing changes in the composition of assemblages' functional traits might improve our understanding of the ecological roles played by species and ecosystem functioning. Here, we investigate how landscape structure and composition impact the functional diversity of terrestrial mammals in 18 forest patches composing eight protected areas in Southern Brazil. We used functional diversity (FD) based on dietary, physical, and behavioral traits and species vulnerability to extinction. We determined which landscape variables (patch size, proportions of forest and sugarcane, and patch isolation) most influenced mammal FD values by using a both-direction stepwise model selection from a linear global model. Finally, we evaluated the role of trophic guilds in explaining the variation in the FD values using a Principal Component Analysis. Between 2012 and 2017, using camera traps, we recorded 26 native medium- and large-sized mammals throughout the protected areas, of which 6 are regionally threatened, and 5 domestic/exotic species. Richness among the forest patches varied from 4 to 24 species (9.05 ± 5.83), while the FD values varied from 1.29 to 6.59 (2.62 ± 1.51). FD variation was best explained by patch size, which exhibited a strong positive correlation (adjusted $R^2 = 0.55$, slope = 0.67, $p < 0.001$). Insectivores and frugivores presented the highest correlation with patch size, explaining most of the variation in the FD values. Our findings strengthen the paramount role of large protected areas in maintaining mammal diversity and their ecological functions in human-modified landscapes.

Keywords: habitat loss; camera traps; fragmentation; human disturbance

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1. Introduction

Driven by human activities, the ongoing sixth mass extinction [1] threatens about one million species worldwide [2]. However, South America was impacted by the early loss of large mammals in the Pleistocene, possibly caused by overhunting [3,4]. This contemporary pulse of extinctions will have a profound ecological impact on ecosystem functioning since species sensitive to habitat loss and large-sized ones are more prone to disappear with environmental changes [5,6]. In this sense, the consequences of losing functionally unique

species may be more substantial than the extinction of those with redundant traits [7,8]. These losses can be associated with and explained by the widespread phenomenon of defaunation, which comprises the loss of species and their functions mediated by habitat loss, fragmentation, and overhunting, affecting, directly and indirectly, the provision of ecosystem services [9].

The Neotropical realm is extensively impacted by anthropogenic activities, especially agricultural land uses [10], which in recent decades replaced a great portion of the natural ecosystems, such as in the Atlantic Forest and the Cerrado, two biodiversity hotspots in Brazil [11]. Currently, most of the landscapes of these biomes are characterized by patches of native vegetation of varying sizes, but overall small and isolated, immersed in anthropogenic matrices composed of agriculture, urban areas, and roads [12,13]. These altered landscapes pose a substantial risk to biodiversity, potentially leading to the decline and extinction of species and populations due to the depletion of critical resources [14–16] and a reduction in genetic variation caused by a combination of increased genetic drift, inbreeding, and reduced gene flow [17–19]. Moreover, these modified environments favor generalist taxa that are more competitive in human-modified habitats than specialists (e.g., [20]). The biotic and abiotic changes in these landscapes lead to functionally impoverished assemblages [21–24], which in turn can disrupt the regime of ecological functions performed by organisms [25–27].

Despite the substantial loss of biodiversity in fragmented landscapes, smaller patches provide refuge for several species, including both habitat generalists and specialists [24,28–30], some of which can exploit agricultural matrices to obtain food and use it as habitat [20,31,32]. Therefore, these remnants of native vegetation still retain several ecological functions [27] and deserve attention for species conservation and to be integrated into landscape management strategies.

Protected areas are known to safeguard biodiversity worldwide and are at the core of local and global conservation efforts, with particular importance in human-modified landscapes [27]. Nonetheless, our understanding of how anthropogenic stressors influence the functional roles performed by species within protected areas is limited [33,34], including mammals, a group widely affected by anthropogenic stressors [17,35,36].

Mammals play a crucial role in ecosystem functioning by performing several ecological functions that exert control over both animal and plant species, contributing substantially to biodiversity maintenance [37,38]. Therefore, reductions in mammalian diversity and abundance in fragmented landscapes, mainly of keystone species and ecosystem engineers, can directly and indirectly impact population persistence [39–41], ecological functions performed [42,43], and ecosystem services provided [35,38,44–46].

Traditional measures such as observed richness and species diversity are widely employed to assess the diversity of animal assemblages [47–49]. However, these measures consider all species as ecologically equivalent, not accounting for the functional uniqueness of each species. Functional diversity measures can combine into a single framework of morphological, ecological, and behavioral traits that differentiate species, facilitating the quantification of attributes within an assemblage [50–53]. This analytical approach, as the measure proposed by Petchey and Gaston [54,55], has proven reliable and had successful applications in previous studies with mammals [23,24,56–58], allowing for a broader exploration of the impacts of habitat loss and fragmentation on biodiversity.

In this study, we assessed how landscape structure and composition affect the functional diversity of medium- and large-sized mammals in forest patches distributed in eight protected areas in Southern Brazil. We expect that small and more isolated patches will exhibit functionally impoverished mammal assemblages.

2. Materials and Methods

The study was conducted across 18 forest patches distributed within eight protected areas in an ecotonal zone between Cerrado and Atlantic Forest biomes in the north, northeast, and south-central regions of the São Paulo state, Brazil (Figure 1), biomes that have

experienced substantial levels of fragmentation over time [14]. The patches encompass a wide range of sizes, from 96 to 10,285 hectares, within the protected areas of sustainable use and strict protection (Table 1). The surrounding landscape is dominated by sugarcane (*Saccharum* spp.), pine (*Pinus* spp.), eucalyptus (*Eucalyptus* spp.), orange (*Citrus* spp.), and coffee (*Coffea* spp.) plantations, in addition to pastures, roads, and urban areas [59–61]. The climate varies between tropical, subtropical humid, and highland subtropical, with average temperatures between 20.1 °C and 23.9 °C and average precipitation ranging from 1333 to 1588 mm [62]. In São Paulo state, 25% of the remaining native vegetation is maintained as protected areas that harbor 255 species of mammals, representing ~33% of the species found in Brazilian territory [63].

Table 1. Area identification and classification, climate, patch size, number of fragments and sampling points, and effort per area of the 18 forest patches distributed in the eight protected areas in the north, northeast, and south-central regions of São Paulo state, Brazil. Aw: tropical; Cwa: humid subtropical; Cwb: subtropical highland.

Protected Area	Classification	Climate	Patch Size (ha)	Fragments	Sampling Points	Sampling Effort (Traps-Day)
Jataí Ecological Station (JES)	Strict protection	Aw	10,285	1	44	2902
Santa Bárbara Ecological Station (SBES)	Strict protection	Cwa	2585	1	19	1309
			1612	2	8	530
Santa Rita do Passa Quatro Experimental Station (SRES)	Sustainable use	Cwa	9	1	1	78
			19	2	2	156
			51	3	2	156
Bebedouro State Forest (BSF)	Strict protection	Aw	99	1	2	82
Furnas do Bom Jesus State Park (FBJSP)	Strict protection	Cwb	2069	1	25	2021
Porto Ferreira State Park (PFSP)	Strict protection	Cwa	611	1	9	608
Vassununga State Park (VSP)	Strict protection	Cwa	231	1	2	118
			329	2	5	357
			130	3	2	124
			1217	4	13	764
			169	5	3	175
Augusto Ruschi Biological Reserve (ARBR)	Strict protection	Aw	115	1	1	38
			56	2	1	34
			189	3	2	115
			124	4	3	75

Our study focused on medium- and large-sized mammals (≥1 kg [64]). We followed the list of the Brazilian Society of Mammalogy for species nomenclature [65], classified mammal species according to their trophic guild following Magioli et al. [27], and defined threat categories at the regional [66], national [67], and international levels [68]. The mammals were identified using the specialized literature [69,70].

We collected data from October 2012 to August 2017 using non-baited camera traps placed at each intersection of a 1 km^2 grid to guarantee spatial independence (Figure 1). The selection of these points followed a systematic distribution method, guided by Google Earth satellite imagery. The number of points varied according to the patch size to ensure the comprehensive coverage of the entire area (Table 1), but the difficulty to access and lack of security limited camera deployment in some parts, totaling 145 camera-trapping stations installed. The camera traps were affixed to tree trunks 30–40 cm above the ground and programmed for continuous operation (24 h/day), capturing three photographs at each triggering event with a 10 s interval between events. Each camera trap remained active for an average of 60 days, subjected to routine inspections every 15 to 20 days. The total sampling effort was 9642 trap-days. We considered records taken at 60 min intervals

between the photos of the same species at the same sampling station as independent records. We calculated a relative abundance index (RAI) defined by the number of independent photographs recorded per sampling effort [71].

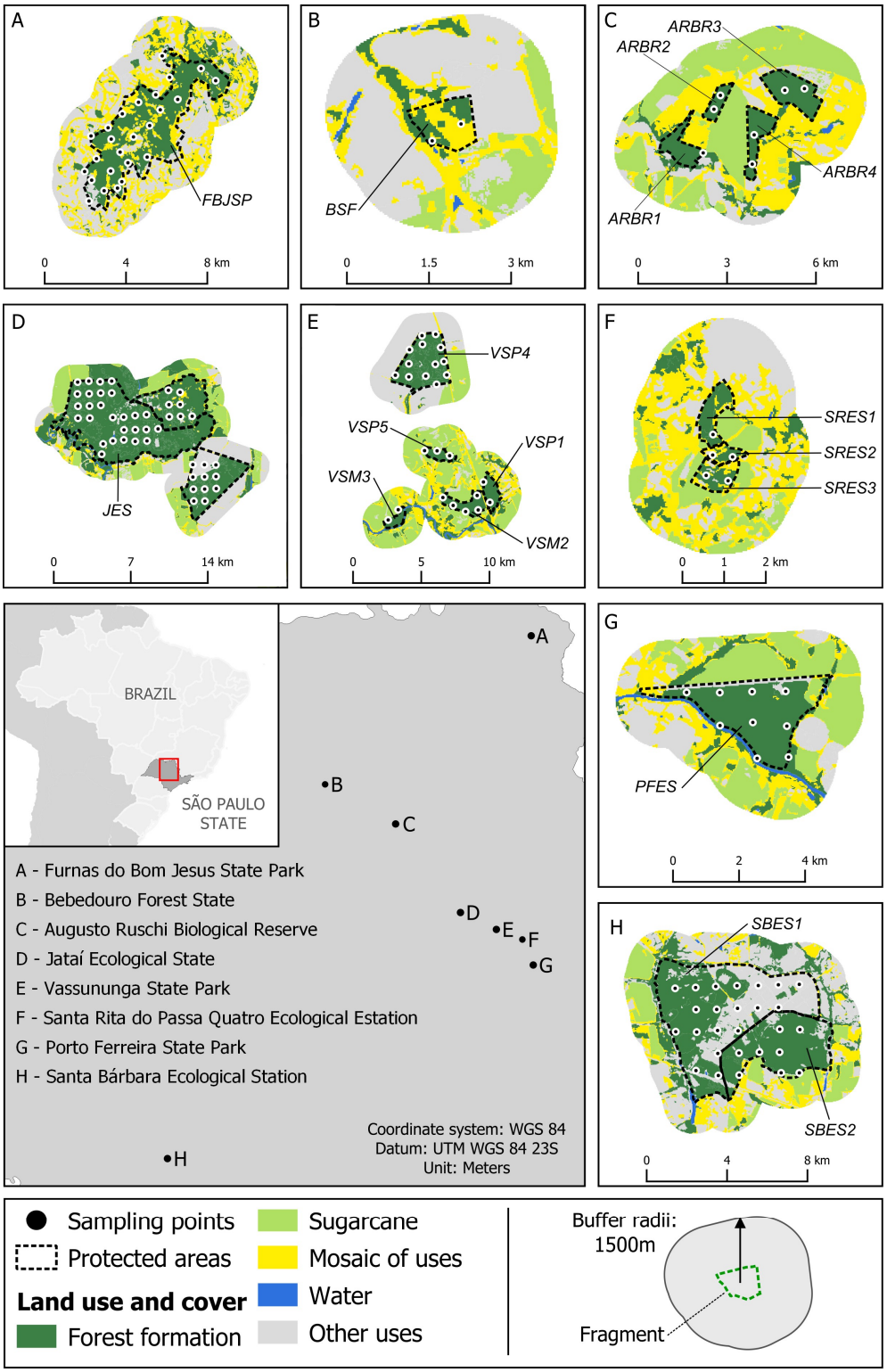


Figure 1. Forest patches within the protected areas in the north, northeast, and south-central regions of São Paulo state, Brazil, where the medium- and large-sized mammals were sampled, depicting the main land uses and the location of the camera traps.

To evaluate how landscape composition and structure impact the functional diversity of mammals, we calculated variables in 1.5 km radius circular buffer zones from the centroid of the sampled patches using the landscapemetrics package [72]. Variables were obtained from the land use and land cover maps of MapBiomas, collection 8 [73], with a spatial resolution of 30 m for the corresponding sampling years. Using histograms, we evaluated land use classes with enough variation among the sampling sites, which include the percentages of forest, sugarcane, and the mosaic of uses. We also calculated the isolation among the patches based on the Euclidean distance from the patch edge to the nearest native vegetation patch edge. Then, we used Person's correlation test to exclude variables with correlation values above r = |0.7|, of which, we excluded the mosaic of uses class that was negatively correlated with forest cover (−0.81). Therefore, we included in the analysis as variables the size of the forest patches (patch size, in ha), percentages of forest and sugarcane in 1.5 km buffers, and patch isolation (in meters).

For each mammal assemblage, we calculated the functional diversity index (FD) proposed by Petchey and Gaston [54,55], implemented through the picante package [74]. The calculation consists of constructing a trait matrix encompassing all medium- and large-sized mammals recorded in each forest patch and transforming it into a distance matrix. Then, the matrix is grouped using the UPGMA method and the Gower distance [75], which accommodates both categorical and continuous variables, producing a functional dendrogram. The sum of the total length of the dendrogram branches determines FD values. The functional traits selected for analysis include locomotion form, body mass, litter size, feeding habits (diet and foraging substrates), social behavior, activity periods, and vulnerability to extinction (Table 2). Data on traits were compiled from the literature [22,24,67,76,77].

Table 2. Functional traits used to calculate the functional diversity (FD) of the medium- and large-sized mammals in the 18 forest patches of the protected areas in the north, northeast, and south-central regions of the São Paulo state, Brazil.

Trait Type	Trait	Category	Data Type
Dietary	Diet	Leaves	Percentage
		Fruits	Percentage
		Vertebrates	Percentage
		Invertebrates	Percentage
	Foraging substrate	Water	Binary
		Trees	Binary
		Vegetation	Binary
		Soil	Binary
Physical	Locomotion form	Terrestrial	Binary
		Semifossorial	Binary
		Semiaquatic	Binary
		Arboreal	Binary
	Body mass	Kg	Continuous
	Litter size	Average number of puppies	Continuous
Behavioral	Period of activity	Diurnal	Binary
		Nocturnal	Binary
		Crepuscular	Binary
	Social behavior	Social	Binary
Threat categories	IUCN Brazil São Paulo	Data Deficient	Categorical
		Least Concern	Categorical
		Near Threatened	Categorical
		Vulnerable	Categorical
		Endangered	Categorical

To evaluate the impact of landscape variables on FD, first, we tested data distribution using the Shapiro–Wilk test. Then, we performed a both-direction stepwise regression implemented by the step function from package stats in R 3.4.1 using a linear global model with all explanatory variables [FD ~ log1p(patch size) + forest + sugarcane + log1p(isolation)], and including the log-transformed sampling effort at each sampling area as weight in the model to account for the difference in sampling effort per area (Table 1). We selected the model with the lowest Akaike Information Criterion (AIC) value as the best model.

Lastly, we performed a Principal Component Analysis (PCA) aiming to identify which variables associated with the FD values accounted for the most substantial variance in trophic guilds when considering the first two axes of the PCA. To do this, for each sampled patch, we used the FD values, the patch size, and the number of species in the five trophic guilds considered (carnivores, insectivores, frugivores, omnivores, and herbivores) (Tables A1–A3). All the analyses were performed in R 4.3.1 [78], and graphical implementation was done using the ggplot2 package [79].

3. Results

We recorded 26 native species of medium- and large-sized mammals from nine orders and 20 families, and 5 domestic/exotic species (Table A1). Six species are threatened in São Paulo state [66], four in Brazil [67], and two worldwide [68]; three species are considered Data Deficient in the different lists (*Cabassous tatouay*, *Conepatus semistriatus*, and *Dasyprocta azarae*) (Table A1). The most recorded species were the white-eared opossum (*Didelphis albiventris*) (RAI = 0.044), Azara's agouti (*D. azarae*) (RAI = 0.043), and nine-banded armadillo (*Dasypus novemcinctus*) (RAI = 0.038), respectively (Table A2). Omnivores were the most recorded (N = 10, 38.46%), followed by insectivores (N = 5, 19.23%), herbivores (N = 5, 19.23%), carnivores (N = 4, 15.38%), and frugivores (N = 2, 7.70%) (Table A3). The average wildlife species richness was 9.05 ± 5.83 SD among the forest patches, varying from 4 species in the patches of BFS, ARBR, and SRES, to 24 species in FBJSP. FD ranged from 1.29 in a patch of ARBR to 6.59 in FBJSP, with an average of 2.62 ± 1.47 SD. On average, the FD values were higher in strictly protected areas (2.80 ± 1.58 SD) compared to those of sustainable use (1.73 ± 0.68 SD), but the difference was not significant (Wilcoxon test, W = 35, $p = 0.15$).

The stepwise selection indicated that the model with patch size best explained the variation in the FD values (AIC = 36.2; Table 3), showing a strong positive and significant relationship (adjusted $R^2 = 0.55$, slope = 0.67, $p < 0.001$) (Figure 2a). Concerning trophic guilds, the first two axes explained 71% and 10% of the total variance in the FD values (Figure 2b), respectively. Our findings revealed a higher correlation of insectivore and frugivore mammals with large patches, while omnivores, herbivores, and carnivores emerged as the most prominent contributors to the higher FD values observed.

Table 3. Both-direction stepwise model selection concerning the relationship between the functional diversity (FD) of the medium- and large-sized mammals and landscape variables in the 18 forest patches within the protected areas in the north, northeast, and south-central regions of São Paulo state, Brazil. SSQ = sum of squares; RSS = residual sum of squares; AIC = Akaike Information Criterion.

Model	SSQ	RSS	AIC
Start: FD ~ log1p (patch size) + log1p (isolation) + forest + sugarcane			
− log1p (isolation)	0.00	106.60	40.02
− Forest	0.74	107.33	40.14
− Sugarcane	0.91	107.50	40.17
No change		106.59	42.02
− log1p (patch size)	36.52	143.11	45.32

Table 3. *Cont.*

Model	SSQ	RSS	AIC
Step 1: FD ~ log1p (patch size) + forest + sugarcane			
− Forest	0.74	107.33	38.14
− Sugarcane	0.93	107.52	38.17
No change		106.60	40.02
− log1p (patch size)	39.45	146.04	43.68
Step 2: FD ~ log1p (patch size) + sugarcane			
− Sugarcane	0.47	107.80	36.22
No change		107.33	38.14
− log1p (patch size)	77.40	184.74	45.91
Step 3 FD ~ log1p (patch size)			
No change		107.80	36.22
− log1p (patch size)	146.32	254.12	49.65

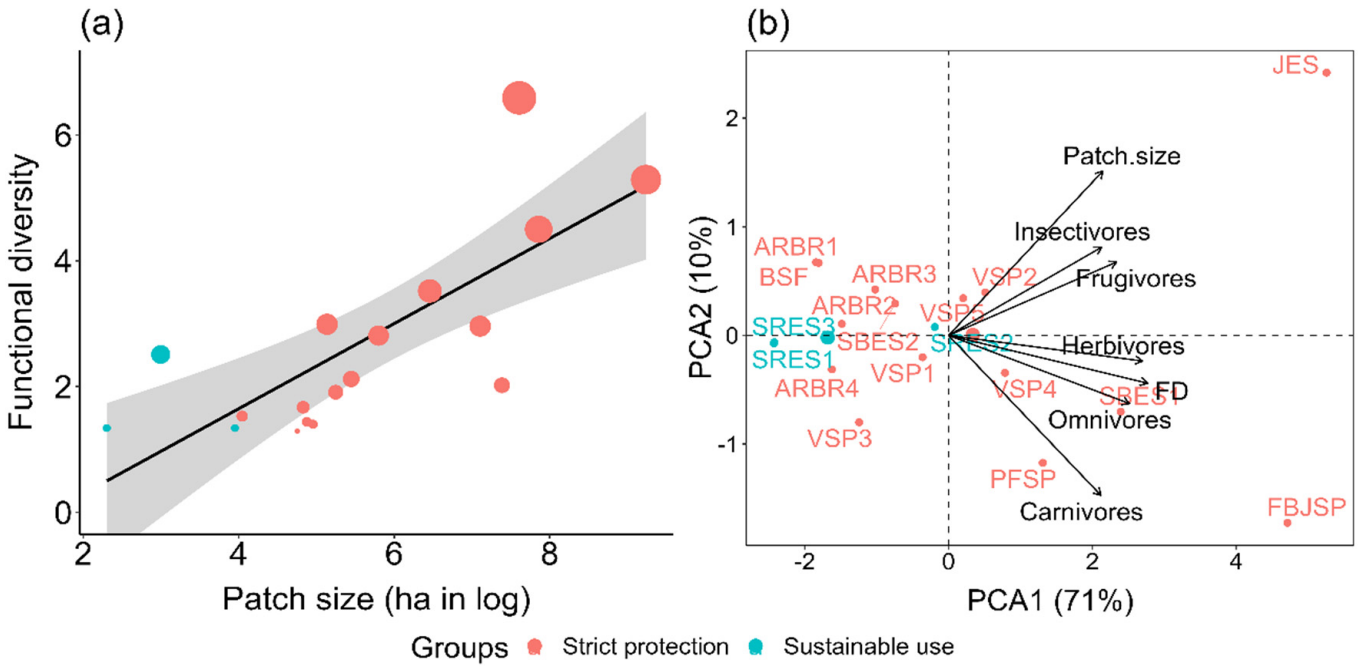


Figure 2. (**a**) Relationship between the functional diversity (FD) of the medium- and large-sized mammals and the patch size of the 18 forest patches within the protected areas in the north, northeast, and south-central regions of São Paulo state, Brazil. The dot size indicates the FD value of each assemblage. (**b**) The dispersion of the sampled forest patches and mammal trophic guilds with patch size and FD values. JES: Jataí Ecological Station; FBJSP: Furnas do Bom Jesus State Park; SBES: Santa Barbara Ecological Station; VSP: Vassununga State Park; ARBR: Augusto Ruschi Biological Reserve; PFES: Porto Ferreira State Park; BSF: Bebedouro State Forest; SRES: Santa Rita do Passa Quatro Ecological Station.

4. Discussion

We showed that patch size explained most of the variation in the functional diversity of the medium- and large-sized mammal assemblages, particularly related to insectivore and frugivore species, which might require large habitat patches to ensure their persistence within human-modified landscapes. Although this is an expected relationship, we highlight that no other landscape variable explained the variation in the functional diversity, strengthening the ubiquitous role of large forest patches and the invariable importance of protected areas.

As expected, the functional diversity increased with patch size. This relationship might be related to an increasing diversity of the structural attributes of the vegetation,

which in turn is expected to provide more resources (e.g., food and shelter) and support a higher number of species [80–82], a consistent pattern in the Neotropics [21,27,83–85]. Even small forest patches are important for the persistence of mammals in human-modified landscapes [24,28,86], which can serve as stepping stones to move between more favorable areas through fragmented landscapes [87,88]. In addition, some species can use the matrix (especially agriculture) to search for food resources and as habitat [20,31,32,89], favoring their presence in small and/or isolated patches.

While these factors may promote the occurrence of species in small forest patches, including generalists and specialists, it is important to recognize that the long-term viability of mammal populations depends on patch size and quality [90], and disturbance regime exerted by anthropogenic stressors, such as hunting [91]. Although most of our sampling sites are located within strictly protected areas, and patch size was the main predictor of functional diversity, several forest patches with different sizes presented low FD values. Isolation had no significant effect on mammal functional diversity in our study, but this predictor is known to negatively affect mammalian diversity [24,83,87,92]. Furthermore, the loss of native vegetation surrounding large patches, which might result in connectivity loss, is a major driver of population declines worldwide [93,94]. Therefore, despite the ecological value of small forest patches [41], their connectivity with large ones through surrounding native habitats is paramount to sustaining biodiversity and, consequently, the vital ecological functions they perform [95,96].

Species more sensitive to habitat loss, including forest-dependent and large-sized ones, tend to be the first to disappear [97,98], such as the jaguar (*Panthera onca*), which is virtually extinct from our study landscapes. Although the large forest patches have the higher species richness, of the 13 patches smaller than 1000 ha, only 2 did not present any sensitive species, while at least one threatened species was recorded in 14 out of the 18 sampled patches. The giant anteater (*Myrmecophaga tridactyla*) and the ocelot (*Leopardus pardalis*) are among the regionally threatened species that have been recorded in most patches, and although considered sensitive to habitat loss [99,100], they demonstrate the importance of small patches on connecting habitats for more demanding species. On the other hand, the abundant records of habitat and diet generalists such as the white-eared opossum (*D. albiventris*) and the nine-banded armadillo (*D. novemcinctus*), even in the largest patches, suggest a high degree of habitat disturbance, particularly where carnivore diversity and abundance is reduced [101–103].

The importance of patch size may be related to the species' energy needs, habitat productivity, and resource irregularity [104]. Fruit trees are not evenly distributed in forests [105], and tend to have lower diversity and availability in fragmented landscapes [106,107], with a limited availability for frugivores [108]. For the insectivores recorded (armadillos and anteaters), invertebrates (especially ants and termites) are their main food resource [109–112], which can be unpredictably distributed in the landscape or become scarce in certain seasons of the year [113,114]. In addition, the anteaters and armadillos are known for their low thermoregulation capacity and use forest areas as thermal shelters [112,115,116], so bearing in mind that the studied patches are mainly composed of forests, it is likely that larger patches with better opportunities for thermal regulation might favor insectivores presence.

Among the perceived threats to the mammalian fauna, the presence of five domestic/exotic species in the protected areas, particularly the domestic dog (*Canis lupus familiaris*) and domestic cat (*Felis silvestris catus*), is a worrying indicative of habitat disturbance. Some exotic species can perform ecological functions similar to native species that were extirpated [117–119], and even make assemblages with non-native species similar to pre-extinction ones [120]. Nevertheless, domestic/exotic species generally pose a significant risk to native species since they may act as predators and competitors for food resources and habitat, in addition to being vectors and susceptible to diseases [121–125]. Patch proximity to roads negatively impacts species through roadkills, especially large animals that often move between patches in fragmented landscapes [26]. Therefore, although small forest

patches may harbor some threatened species and habitat specialists, caution is needed when interpreting the extent to which these areas are capable of sustaining their populations in the long term without conservation efforts to improve their quality and connectivity.

5. Conclusions

Our results highlight the importance of maintaining large forest patches and emphasize the paramount role of protected areas in human-modified landscapes in maintaining mammalian functional diversity. Although forest fragmentation tends to reduce the functional diversity of mammals, we observed that small forest patches still support considerable mammalian diversity, including threatened species. Frugivores and insectivores were the most affected by habitat reduction, stressing the need to evaluate species-specific and group responses. Therefore, conservation strategies should not only target threatened species or large forest patches, but also species groups with similar functional characteristics. Protected areas alone cannot sustain high biodiversity levels in the long term, particularly the populations of sensitive species and large-sized ones. Thus, integrating small adjacent patches in strategies aiming to enhance connectivity might be an important strategy to improve species conservation, population viability, and the maintenance of ecological processes and ecosystem services in these landscapes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16135419/s1, Dataset S1: Number of records per species in each fragment sampled, functional traits per species, variable values used to calculate the functional diversity (FD) of the medium- and large-sized mammals, and variable values used to calculate the PCA.

Author Contributions: Conceptualization, L.F. and R.B.; methodology, L.F., M.M. and R.B.; software, L.F., J.A.G., R.T.C. and M.M.; validation, L.F. and M.M.; formal analysis, L.F., R.T.C. and M.M.; investigation, L.F., J.A.G. and R.T.C.; resources, L.F., J.A.G., R.T.C. and R.B.; data curation, L.F., J.A.G. and R.T.C.; writing—original draft preparation, L.F. and R.B.; writing—review and editing, L.F., R.T.C. and M.M.; visualization, L.F., R.T.C. and M.M.; supervision, L.F. and R.B.; project administration, L.F. and R.B.; funding acquisition, L.F. and R.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The original contributions presented in the study are included in the Supplementary Material, further inquiries can be directed to the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Medium- and large-sized mammals recorded in the 18 forest patches within the eight protected areas in São Paulo, Brazil, including the functional traits and trophic guilds [27] for native species, the number of patches in which each species was recorded, the number of records per species, and the threat categories at regional (SP [66]), national (BR [67]), and international levels [68]. DD: Data Deficient; EN: Endangered; LC: Least Concern; NT: Near Threatened; VU: Vulnerable. * Domestic/exotic species.

Species	Functional Traits							Trophic Guild	Number of Patches	Number of Records	Threat Categories		
	Dietary		Physical			Behavioral							
	Diet	Foraging Substrate	Locomotion Form	Body Mass (Kg)	Litter Size	Period of Activity	Social Behavior				IUCN	BR	SP
Artiodactyla													
Bovidae													
Bos taurus *	-	-	-	-	-	-	-	-	1	19	-	-	-
Cervidae													
Subulo gouazoubira	Leaves and fruits	Vegetation and soil	Terrestrial	21	1	Diurnal	No	Herbivore	11	228	LC	LC	LC
Suidae													
Sus scrofa *	-	-	-	-	-	-	-	-	1	22	-	-	-
Tayassuidae													
Dicotyles tajacu	Leaves, invertebrates, and fruits	Vegetation and soil	Terrestrial	26	3	Diurnal and nocturnal	Yes	Frugivore/Herbivore	8	107	LC	LC	NT
Cingulata													
Chlamyphoridae													
Euphractus sexcinctus	Leaves, vertebrates, invertebrates, and fruits	Vegetation and soil	Semifossorial	5	2	Diurnal	No	Omnivore	3	8	LC	LC	LC
Dasypodidae													
Cabassous tatouay	Invertebrates	Soil	Semifossorial	5	1	Nocturnal	No	Insectivore	3	50	LC	DD	DD
Dasypus novemcinctus	Leaves, vertebrates, invertebrates, and fruits	Vegetation and soil	Semifossorial	4	4	Nocturnal and crepuscular	No	Insectivore	14	367	LC	LC	LC
Didelphimorphia													
Didelphidae													
Didelphis albiventris	Vertebrates, invertebrates, and fruits	Trees and soil	Terrestrial	2	9	Nocturnal and crepuscular	No	Omnivore	17	426	LC	LC	LC
Rodentia													
Dasyproctidae													
Dasyprocta azarae	Leaves, invertebrates, and fruits	Vegetation and soil	Terrestrial	3	2	Diurnal and crepuscular	No	Frugivore/Herbivore	15	424	DD	LC	NT
Caviidae													
Hydrochoerus hydrochaeris	Leaves	Vegetation and soil	Terrestrial	50	5	Nocturnal and crepuscular	Yes	Herbivore	2	3	LC	LC	LC
Cuniculidae													
Cuniculus paca	Leaves and fruits	Vegetation and soil	Terrestrial	9	1	Nocturnal	No	Frugivore/Herbivore	4	196	LC	NT	LC
Erethizontidae													
Coendou spinosus	Leaves and fruits	Trees	Arboreal	4	1	Nocturnal and crepuscular	No	Herbivore	1	3	LC	LC	DD
Carnivora													
Canidae													
Canis lupus familiaris *	-	-	-	-	-	-	-	-	8	98	-	-	-
Cerdocyon thous	Vertebrates, invertebrates, and fruits	Vegetation and soil	Terrestrial	7	5	Nocturnal and crepuscular	No	Omnivore	3	77	LC	LC	LC

Table A1. *Cont.*

Species	Functional Traits							Trophic Guild	Number of Patches	Number of Records	Threat Categories		
	Dietary		Physical			Behavioral							
	Diet	Foraging Substrate	Locomotion Form	Body Mass (Kg)	Litter Size	Period of Activity	Social Behavior				IUCN	BR	SP
Chrysocyon brachyurus	Leaves, vertebrates, invertebrates, and fruits	Vegetation and soil	Terrestrial	22	2	Nocturnal and crepuscular	No	Omnivore	4	23	NT	VU	VU
Felidae													
Felis silvestris catus *	-	-	-	-	-	-	-	-	4	6	-	-	-
Leopardus pardalis	Vertebrates and invertebrates	Soil	Terrestrial	10	3	Nocturnal	No	Carnivore	7	75	LC	LC	VU
Puma concolor	Vertebrates and invertebrates	Soil	Terrestrial	46	4	Nocturnal	No	Carnivore	9	38	LC	VU	VU
Herpailurus yagouaroundi	Vertebrates and invertebrates	Vegetation and soil	Terrestrial	5	2	Diurnal and nocturnal	No	Carnivore	6	30	LC	VU	LC
Mephitidae													
Conepatus semistriatus	Vertebrates, invertebrates, and fruits	Vegetation and soil	Terrestrial	2	5	Nocturnal and crepuscular	No	Omnivore	4	29	LC	LC	DD
Mustelidae													
Eira barbara	Vertebrates, invertebrates, and fruits	Vegetation and soil	Terrestrial	7	3	Diurnal	No	Omnivore	8	114	LC	LC	LC
Lontra longicaudis	Vertebrates	Water	Semiaquatic	6	3	Diurnal and nocturnal	No	Carnivore	1	6	NT	NT	NT
Procyonidae													
Nasua nasua	Vertebrates, invertebrates, and fruits	Trees and soil	Terrestrial	5	5	Diurnal	Yes	Omnivore	8	47	LC	LC	LC
Procyon cancrivorus	Vertebrates, invertebrates, and fruits	Vegetation and soil	Terrestrial	5	3	Nocturnal	No	Omnivore	2	28	LC	LC	LC
Lagomorpha													
Leporidae													
Lepus europaeus *	-	-	-	-	-	-	-	-	1	5	-	-	-
Sylvilagus brasiliensis	Leaves	Vegetation and soil	Terrestrial	1	5	Nocturnal and crepuscular	No	Herbivore	7	84	EN	NT	NT
Perissodactyla													
Tapiridae													
Tapirus terrestris	Leaves and fruits	Vegetation and soil	Terrestrial	260	1	Nocturnal	No	Frugivore/Herbivore	1	1	VU	VU	VU
Pilosa													
Myrmecophagidae													
Myrmecophaga tridactyla	Invertebrates	Soil	Terrestrial	31	1	Diurnal and nocturnal	No	Insectivore	8	264	VU	VU	VU
Tamandua tetradactyla	Invertebrates	Trees and soil	Terrestrial	5	1	Nocturnal	No	Insectivore	12	51	LC	LC	LC
Primates													
Callitrichidae													
Callithrix penicillata	Invertebrates and fruits	Trees	Arboreal	0.5	2	Diurnal	Yes	Omnivore	1	6	LC	LC	LC
Cebidae													
Sapajus nigritus	Leaves, invertebrates, and fruits	Trees	Arboreal	4	1	Diurnal	Yes	Omnivore	4	27	NT	NT	NT
Total										2862	3	5	5

Table A2. Number of records, species richness, and relative abundance (RAI) per area for the medium- and large-sized mammals recorded in the 18 forest patches within the eight protected areas in São Paulo, Brazil. * Domestic/exotic species.

Species	Number of Records																	
	BFS	FBJSP	JES	PFSP	ARBR				SBES		SRES			VSP				
					1	2	3	4	1	2	1	2	3	1	2	3	4	5
Artiodactyla																		
Bovidae																		
Bos taurus *	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0
Cervidae																		
Subulo gouazoubira	0	66	53	12	0	0	0	0	40	24	2	1	1	0	17	0	11	1
Suidae																		
Sus scrofa *	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tayassuidae																		
Dicotyles tajacu	0	0	40	11	0	0	0	0	11	2	0	0	0	0	6	4	15	18
Cingulata																		
Chlamyphoridae																		
Euphractus sexcinctus	0	4	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Dasypodidae																		
Cabassous tatouay	0	35	14	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Dasypus novemcinctus	27	202	45	16	3	5	39	0	8	2	1	14	1	2	2	0	0	0
Didelphimorphia																		
Didelphidae																		
Didelphis albiventris	0	200	53	19	11	4	17	8	2	2	18	20	24	7	9	9	17	6
Rodentia																		
Dasyproctidae																		
Dasyprocta azarae	13	2	201	18	3	9	16	2	8	0	0	5	0	20	36	31	37	23
Caviidae																		
Hydrochoerus hydrochaeris	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Cuniculidae																		
Cuniculus paca	0	160	7	0	0	0	0	0	0	0	0	26	0	3	0	0	0	0
Erethizontidae																		
Coendou spinosus	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carnivora																		
Canidae																		
Canis lupus familiaris *	4	51	1	0	0	0	1	0	0	17	4	10	0	0	0	0	0	0
Cerdocyon thous	0	72	0	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Chrysocyon brachyurus	0	5	8	9	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Table A2. *Cont.*

Species	Number of Records																	
	BFS	FBJSP	JES	PFSP	ARBR				SBES		SRES			VSP				
					1	2	3	4	1	2	1	2	3	1	2	3	4	5
Felidae																		
Felis silvestris catus *	2	1	0	0	0	0	0	0	1	9	1	0	0	0	0	0	0	0
Leopardus pardalis	0	43	19	1	0	0	0	0	0	0	0	0	0	1	7	1	3	0
Puma concolor	0	9	6	8	0	1	1	2	9	0	0	0	0	0	0	1	1	0
Herpailurus yagouaroundi	0	19	0	4	0	0	0	0	4	1	0	1	0	1	0	0	0	0
Mephitidae																		
Conepatus semistriatus	0	2	24	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0
Mustelidae																		
Eira barbara	0	87	14	2	0	0	0	0	3	1	0	0	0	0	2	0	3	2
Lontra longicaudis	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Procyonidae																		
Nasua nasua	1	15	5	0	0	0	0	0	5	0	2	7	8	0	0	0	0	4
Procyon cancrivorus	0	27	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Lagomorpha																		
Leporidae																		
Lepus europaeus *	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sylvilagus brasiliensis	0	1	44	20	0	0	0	0	3	0	0	0	0	0	6	0	9	1
Perissodactyla																		
Tapiridae																		
Tapirus terrestris	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pilosa																		
Myrmecophagidae																		
Myrmecophaga tridactyla	0	155	37	0	0	2	0	0	24	10	0	0	0	0	3	0	30	3
Tamandua tetradactyla	1	14	19	6	1	0	2	1	0	0	0	1	0	1	2	0	1	2
Primates																		
Callitrichidae																		
Callithrix penicillata	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cebidae																		
Sapajus nigritus	0	22	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1
Total records	42	1157	593	129	18	21	76	15	126	42	23	75	34	35	90	46	129	61
Richness (native species)	4	24	19	13	4	5	6	5	17	7	4	8	4	7	10	5	11	10
FD	1.40	6.59	5.29	3.52	1.29	1.53	1.91	1.67	4.50	2.02	1.34	2.51	1.34	2.12	2.81	1.44	2.96	2.99
RAI	0.004	0.120	0.061	0.013	0.002	0.002	0.008	0.001	0.013	0.004	0.002	0.008	0.003	0.004	0.009	0.005	0.013	0.006

Table A3. Number of species related to each functional trait of the medium- and large-sized mammals recorded in the 18 forest patches within the eight protected areas in São Paulo, Brazil. DD: Data Deficient; EN: Endangered; LC: Least Concern; NT: Near Threatened; VU: Vulnerable.

Trait Type	Trait	Category		Number of Species
Dietary	Diet	Leaves		12
		Fruits		17
		Vertebrates		13
		Invertebrates		19
	Foraging substrate	Water		1
		Trees		6
		Vegetation		15
		Soil		22
Physical	Locomotion form	Terrestrial		19
		Semifossorial		3
		Semiaquatic		1
		Arboreal		3
Behavioral	Period of activity	Diurnal		11
		Nocturnal		19
		Crepuscular		9
	Social behavior	Social		5
		Non-social		22
		IUCN	Brazil	São Paulo
Threat categories	Data Deficient	1	1	3
	Least Concern	19	16	13
	Near Threatened	3	4	5
	Vulnerable	2	5	5
	Endangered	1	0	0
Trophic guild	Carnivores			4
	Frugivores			4
	Herbivores			8
	Insectivores			4
	Omnivores			10

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