

Research Article

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Biogeographic and fragmentation-related research biases on antbirds and non-flying small mammals in Brazil

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Abstract

Major biogeographic and taxonomic biases are recurrent in biological surveys, including fragmentation studies. Detecting biases and subsequent gaps is crucial to steer future research and suitable conservation policies. We evaluated biogeographic and fragmentation-related biases on antbirds and non-flying small mammals in Brazil, two oversampled and vulnerable taxonomic groups, by surveying papers in the Scielo and the Web of Science. We found 566 articles published from 1945 to 2018, including 55 and 43 fragmentation studies for antbirds and small mammals, respectively. Considering the species richness for each group across the Brazilian biomes, the number of publications for small mammals tended to disproportionately increase while increasing richness. The Atlantic Forest, the most degraded and densely populated biome, contained the highest number of publications. However, the Amazon included a disproportionately high number of papers considering its low population density. Conversely, non-forest biomes such as the Caatinga, Pampa and Pantanal were mostly overlooked. Our results show that research effort for small mammals and antbirds in Brazil is biogeographically biased. We call future research to consider more studies across non-forest biomes and vast unexplored areas within forest biomes to overcome major knowledge gaps on diversity, distribution and ecology of antbirds and small mammals in Brazil.

Introduction

Sampling biases are persistent and pervasive issues in biodiversity and ecological research that result in knowledge shortfalls across regions, taxa and species traits, with profound consequences for biodiversity conservation and management strategies (Clark & May 2002, Mokany & Ferrier 2011, Nemésio *et al.* 2013, Ribeiro *et al.* 2016). For example, birds and mammals are disproportionately more sampled in biodiversity research across the world (e.g., Shine & Bonnet 2000, Trimble & Van Aarde 2010, Troudet *et al.* 2017). Likewise, biogeographic biases result in areas, countries or ecosystems neglected or undersampled, which is particularly apparent in developing and in large countries wherein research institutions are unevenly distributed (e.g., Deikumah *et al.* 2014, Moerman & Estabrook 2006, Oliveira *et al.* 2016). Reviewing published literature through electronic databases allows us to identify knowledge gaps, suggesting future research effort towards neglected regions and taxa, which deserve further attention.

Research related to habitat loss and fragmentation is both biogeographic and taxonomically biased across world's tropical forests (Deikumah *et al.* 2014). Given that habitat loss and fragmentation are among the most important threats to biodiversity (Fahrig 2003, Hanski 2015, Kruess & Tschardt 1994, Wintle *et al.* 2019), detecting unevenness in studies of these processes across regions and among taxa is of paramount importance to provide decision-making for conservation policies (Deikumah *et al.* 2014). Although habitat loss and fragmentation usually occur simultaneously, habitat loss is directly associated with habitat quantity (i.e., reduction in the suitable habitat area in the landscape over time), whereas fragmentation *per se* is mostly related to differences in landscape spatial configuration (i.e., subdivision of the natural habitat in fragments) (Didham *et al.* 2012, Fahrig, 2003, 2017, Hanski 2015). However, fragmentation *per se* can generate positive effects under particular landscape-level contexts (Fahrig 2017), although the relative importance of negative versus positive effects caused by fragmentation regardless of habitat loss remains in an intense debate (see Fahrig 2017, Fahrig *et al.* 2019, Fletcher *et al.* 2018 for opposite views). Here, we embrace fragmentation in a broad sense, thus including both habitat loss and fragmentation *per se*. We also focus on fragmentation-related research biases without considering effects on biodiversity.

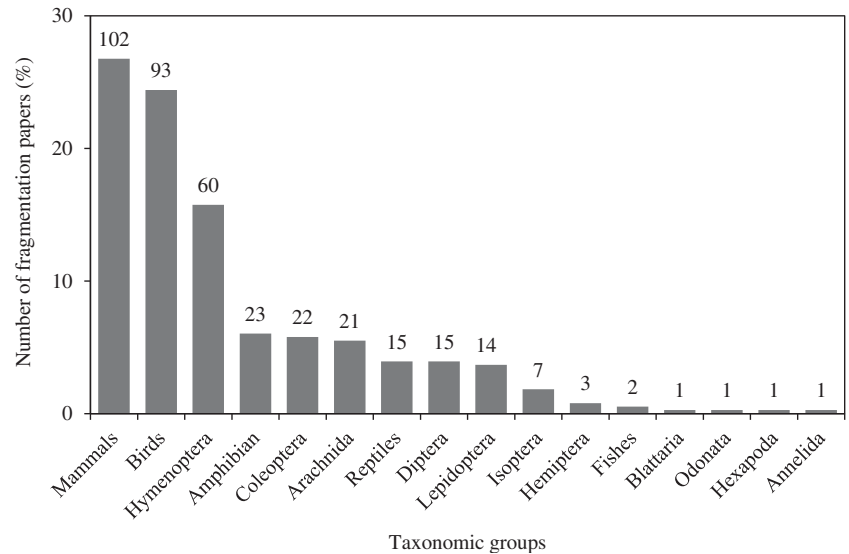


Figure 1. Percentage of fragmentation papers found in the Web of Science and the Scielo database for different taxonomic groups in Brazil. Numbers on each bar show the total number of fragmentation papers for each taxonomic group.

In this study, we aim to address biogeographic and fragmentation-related biases and knowledge gaps in antbirds (family Thamnophilidae) and non-flying small mammals (hereafter, small mammals, i.e., rodent species of the families Caviidae, Cricetidae, Echimyidae and marsupials of the family Didelphidae, with a body mass < 1.5 kg: Bovendorp *et al.* 2017, Lopes & Mendes-Oliveira 2015, Mendes-Oliveira *et al.* 2015, Mendonça *et al.* 2018, Paglia *et al.* 2012) across Brazilian biomes (i.e., Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal). Brazilian biomes are well-defined regional ecosystems characterised by a dominant vegetation and similar floristic characteristics, climatic conditions and geological structure, which have experienced the same historical processes of landscape formation (IBGE 1992, 2018a). Brazilian biomes have the following equivalence in the classification of Olson *et al.* (2001): Amazon and Atlantic Forest = Tropical and Subtropical Moist Broadleaf Forests; Caatinga = Deserts and Xeric Shrublands; Cerrado and Pampa = Tropical and Subtropical Grasslands, Savannas, and Shrublands; and Pantanal = Flooded Grasslands and Savannas.

Biogeographic research biases were determined considering both the species richness for each taxonomic group and human population density across biomes. We focused on antbirds and small mammals because of their overrepresentation in fragmentation research in Brazil and their vulnerability to anthropogenic impacts on landscape. Mammals and birds together contain >50% of fragmentation-related papers focused on fauna in Brazil and, specifically, small mammals and antbirds represent 46% and 59% for each group, respectively (Teixido *et al.* 2020; see also Figure 1). Antbirds and small mammals are also frequently used as biological indicators, acting as good predictors of responses to ecosystem changes (Avenant 2011, Pardini *et al.* 2010, Piratelli *et al.* 2008). Antbirds show the world's highest diversity in the Neotropical region (Lepage, 2018) and comprise species highly sensitive to fragmentation due to their limited dispersal capacity in non-forest areas (Sick 1997, Zimmer & Isler 2018). These bird species are mainly insectivorous, thus regulating insect populations and subsequently reducing herbivore-mediated plant damage (Sekercioglu 2006, Van Bael *et al.* 2003, Whelan *et al.* 2015). Small mammals are a diverse group widely distributed worldwide (Eisenberg & Redford 1999, Reis *et al.* 2011), including key components of the trophic webs within communities and playing a

relevant role as seed dispersers, contributing to forest regeneration and connectivity between forest remnants (Brewer & Rejmánek 1999, Galetti *et al.* 2015). Patch area, isolation and habitat quality have been reported in determining the abundance and composition of several small mammal species (Delciellos *et al.* 2016, Prugh *et al.* 2008, Santos-Filho *et al.* 2012).

We used Brazil as a model system for manifold reasons. First, Brazil is a megadiverse and huge country that contains heterogeneous ecosystems such as rainforests, savannas, grasslands and seasonally dry woodlands (Myers *et al.* 2000, Overbeck *et al.* 2015). This large diversity includes the Amazon, the world's largest rainforest, the Pantanal, one of the world's largest tropical wetlands, and two biodiversity hotspots, the Atlantic Forest and the Cerrado (Myers *et al.* 2000). However, these biomes have been traditionally managed and human-induced changes have extensively reduced the original vegetation (Lapola *et al.* 2014). Second, small mammals and antbirds are unevenly distributed across these biomes (Paglia *et al.* 2012, Piacentini *et al.* 2019), which allows us to evaluate biogeographic research effort based on species richness for each biome. Lastly, Brazilian biodiversity is undersampled and research is unevenly distributed among biomes, concentrated near large cities (Oliveira *et al.* 2016, Ribeiro *et al.* 2016, Teixeira *et al.* 2020). Our study can provide compelling evidence to steer future research effort and to guide decision-making for conservation policies on antbirds and small mammals.

Methods

Data source

We surveyed papers on 30 November 2018 in the Web of Science (hereafter, WOS; www.webofknowledge.com) and the Scielo database (www.scielo.br) to analyse biogeographic bias and subsequent gaps on small mammal and antbird research across Brazilian biomes (Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal). All papers provided by our survey were considered (most recent paper from January 2019). The WOS is an online tool that provides access to a large database comprising more than 9,000 journals about diverse knowledge areas. The Scielo is a free-access database that includes the most relevant Brazilian journals published in English or Portuguese. For the small mammal

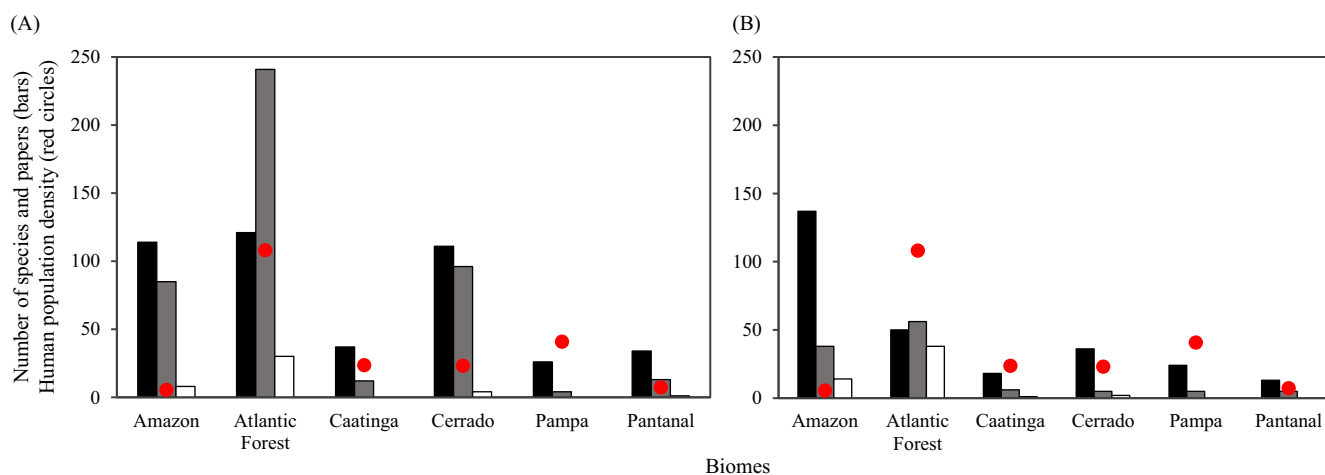


Figure 2. Species richness (black bars), number of general papers (grey bars), number of fragmentation papers (white bars) published from 1945 to 2018 and human population density (inhabitants/km²; red circles) across Brazilian biomes for (A) small mammals and (B) antbirds.

and antbird research, we searched for ‘small mammals’ and ‘antbirds’ or ‘Thamnophilidae’, respectively, and ‘Brazil’, included in the title, abstract and key words of papers. We also searched for each of the biomes and included a specific survey using the key words in Portuguese to include any paper missing exclusively published in this language. Since several small mammal species are largely used for laboratory experiments with medical purposes, we filtered our selection criteria by selecting the following topics: ‘Biodiversity and conservation’, ‘Biology’, ‘Ecology’, ‘Environmental sciences’, ‘Evolutionary biology’, ‘Forestry’, ‘Parasitology’ and ‘Zoology’. Species richness was recorded in Bovendorp *et al.* (2017), Mendes-Oliveira *et al.* (2015), Mendonça *et al.* (2018) and Paglia *et al.* (2012) for small mammals, and Piacentini *et al.* (2019) for antbirds. We also restricted our data to native species included in those references, respectively. After literature survey, we exclusively selected papers following our criteria (i.e., studies with small mammal or antbird species native to Brazil) based on the title and abstract. Besides the papers found in the databases, we completed the number of publications for small mammals using three recently published reviews (Bovendorp *et al.* 2017 for Atlantic Forest, Mendes-Oliveira *et al.* 2015 for Amazon, and Mendonça *et al.* 2018 for Cerrado).

Subsequently, we selected the fragmentation papers for each taxonomic group based on landscape ecology metrics (i.e., connectivity, deforestation, edge effect, fragment number, fragment size, habitat quality, habitat loss, land use change and matrix quality). We excluded those papers conducted on naturally fragmented landscapes (e.g., natural forest patch interspersed in a non-forest ecosystem). The results of our criteria that included any of the taxonomic groups are hereafter called ‘general papers’ (i.e., papers intended to examine biogeographic biases), whereas those studies exclusively related to fragmentation are denominated as ‘fragmentation papers’. Therefore, general papers include fragmentation-related studies.

Data analysis

To determine biogeographic research bias (i.e., across biomes), we obtained geographic coordinates showed in the papers for each taxonomic group. When coordinates were missing, they were procured from the studied sites by point plotting using the Google

Earth satellite imagery. Subsequently, we sorted out the geographic coordinates between general and fragmentation papers for each taxon. We used the ArcGis 10.5 software (ESRI, Redlands, California, USA) to assess the density of studies for each biome by elaborating density raster layers by kernel interpolation (Oliveira *et al.* 2015, Ribeiro *et al.* 2016, Yang *et al.* 2013) with a resolution of 0.0083° (~1 km). To do this, we used the geographical coordinates included in the papers together with the coordinates that we obtained from the study sites as explained above. Therefore, each point in our kernel density maps corresponds to a sampling point with a specific coordinate. The official limits of the Brazilian biomes were acquired from the Brazilian Institute of Geography and Statistics (IBGE 2010a). The kernel interpolation method is based on the definition of circular areas of influence around occurrence points (i.e., sampling points) of a phenomenon. Within the area of influence, the occurrence of the phenomenon decreases from the point to the limits according to a Gaussian function (Silverman 1986). Thus, the kernel density calculates the density of points around each output raster cell and the kernel density values indicate the studies’ density per square kilometre. For example, the more the quantity of occurrence points within a given area of influence, the higher the density, whereas the more the spreading of points within a specific area, the larger the circular area around the points. We calculated a default search radius (bandwidth) based on the spatial configuration and number of input points, showing the best visual result of the data distribution (Silverman 1986). We generated four maps, each including either general or fragmentation papers on small mammals and antbirds, respectively, depicting areas with higher or lower density of studies by a red-to-blue (i.e., high-to-low) colour gradient. To determine differences in density among biomes for each of maps, we generated 50,000 uniformly random points within the whole country and subsequently calculated the mean kernel density values for each biome (Ribeiro *et al.* 2016). To test differences in mean kernel density values among biomes for each map, we conducted a Generalised Linear Model (GLM) assuming a quasi-Poisson distribution with subsequent Tukey’s post hoc test to compare significant differences among biomes. Within each map, we also included a smaller map showing the most current data for human population in Brazil (IBGE 2010b). Thus, our maps depict areas with higher or lower density of studies comparing with more or less

Density map of general papers for small mammals

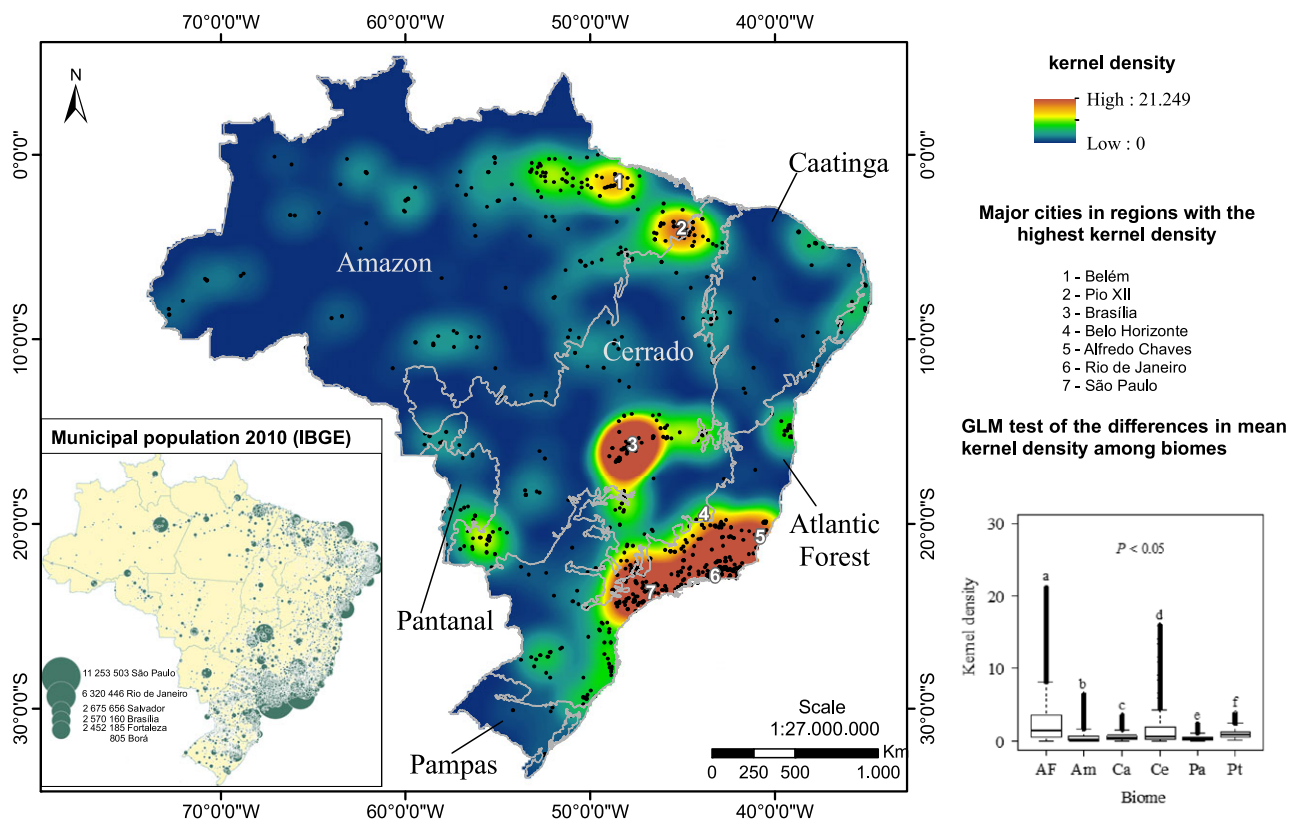


Figure 3. Mean kernel density across Brazilian biomes containing general papers for small mammals. The kernel density shows the number and distribution of sampling points (i.e., geographical coordinates included in the papers together with the coordinates that we obtained from the study sites using Google Earth, represented by the black dots), which is proportional to the number of studies for each biome (Table S1). The smaller map on the lower left margin shows the human population following the Brazilian Institute of Geography and Statistics (IBGE 2010b). Different letters in the boxplot show significant differences in mean kernel density ($P < 0.05$).

populated cities across the country, beyond merely showing differences in kernel density among biomes. Although the maps show sampling points rather than number of studies as most of the papers included several sampling points with a specific coordinate, density of studies is still depicted since the number of studies and sampling points were proportional for both antbirds and small mammals for each biome (Table S1).

We also regressed the number of general papers for both small mammals and antbirds against (1) the species richness for each taxonomic group and (2) human population density, thus considering biome area and population, which influences on the number of research institutions in Brazil (Ribeiro *et al.* 2016), for each biome. For both taxonomic groups, the percentages of papers and richness per biome over the total number of articles and number of species, respectively, and the percentage of human population density per biome were previously calculated and subsequently squared root-transformed to improve normality (Ribeiro *et al.* 2016). After the regression, a *t*-test was used to compare the slopes between the expected (i.e., $b \pm SE = 1 \pm 0$) and the observed relationship for each biome (Zar 1999). When the observed slope is significantly >1 , the bias is positive (i.e., the increase in number of papers is disproportionately higher than the increase in biome richness for each group), and when slope is <1 the bias is negative (i.e., the increase in number of papers is disproportionately lower than the increase in biome richness for each group). We followed the same procedure to evaluate

whether the number of fragmentation papers is proportional to the number of general papers. Thus, we regressed the squared root-transformed percentage of the number of fragmentation papers which each biome contributed against squared root-transformed percentage of the number of papers that included that biome. All analyses were conducted in R, version 3.6.2 (R Core Development Team 2018).

Results

Our search for general papers for the two taxonomic groups resulted in 566 articles published from 1945 to 2018. Small mammals were the most studied group, containing four times the number of publications of antbirds (451 vs. 115, respectively; Figure 2). The richness of small mammals and antbirds in Brazil is 254 and 188 species, respectively. However, some species occur in two or more biomes, so richness per biome does not show endemism (Figure 2). The greatest richness of small mammals is recorded for the Atlantic Forest, but both the Amazon and the Cerrado show a number of species close to the Atlantic Forest (Figure 2A). Otherwise, Amazon is clearly dominant for antbird richness in relation to the other biomes (Figure 2B).

The Atlantic Forest, the most densely populated biome, contained about 50% of general papers for both taxonomic groups, which represents about two times more publications on small mammals than the Amazon and the Cerrado, and 1.4 times more

Density map of general papers for antbirds

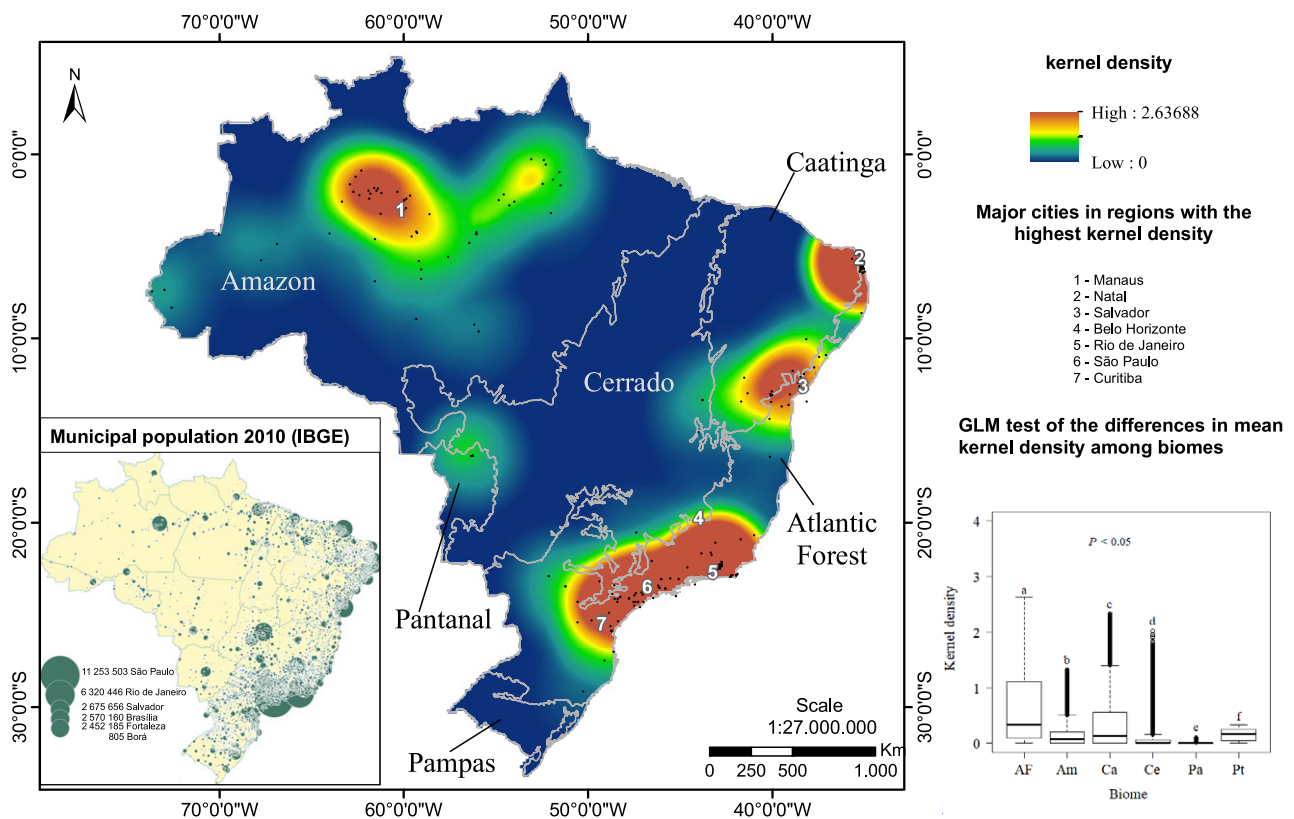


Figure 4. Mean kernel density across Brazilian biomes containing general papers for antbirds. The kernel density shows the number and distribution of sampling points (i.e., geographical coordinates included in the papers together with the coordinates that we obtained from the study sites using Google Earth, represented by the black dots), which is proportional to the number of studies for each biome (Table S1). The smaller map on the lower left margin shows the human population following the Brazilian Institute of Geography and Statistics (IBGE 2010b). Different letters in the boxplot show significant differences in mean kernel density ($P < 0.05$).

general papers on antbirds than the Amazon (Figure 2). Overall, the Atlantic Forest also showed the highest kernel mean density (i.e., higher number and spatial coverage of studies and corresponding sampling points), and studies were also mostly concentrated near the largest and most human-populated cities (Figures 3 and 4). However, the Amazon showed a disproportionately high number of studies considering its low human population density, whereas the biomes with the lowest number of species were also less researched (i.e., Caatinga, Pampa and Pantanal), specially for small mammals when comparing with the richest biomes (Figure 2). Following these patterns, we found a trend for a positive biogeographic bias for small mammals when considering their richness, as the number of studies tended to disproportionately increase with increasing the number of species across biomes (Figure 5A). For antbirds, we found a proportional research effort, that is, the number of studies tended to proportionately increase with richness across biomes (Figure 5B). Otherwise, we detected a biogeographic negative bias for both taxonomic groups when considering human population density (Figure 5C,D). This implies that less densely populated biomes (e.g., Amazon) contained disproportionately more studies than most densely populated biomes (e.g., Atlantic Forest).

The number of fragmentation papers involving antbirds and small mammals was 55 and 43, respectively, published from 1989 to 2018. This entails about the half of general papers (48%) for antbirds and near 10% for small mammals. Across

the Brazilian biomes, most fragmentation papers studying small mammals or antbirds were conducted in the Atlantic Forest (about 70% for each group; Figure 2). The Caatinga and the Pampa for small mammals and the Pampa and the Pantanal for antbirds did not include any fragmentation-related paper (Figure 2).

Similar to general papers, this biogeographic bias translated into the highest kernel density in the Atlantic Forest concentrated near the most human-populated cities, but also near two cities in the Amazon (Manaus and Alta Floresta) for both groups (Figures 6 and 7). The number of fragmentation papers showed a trend to disproportionately increase in relation to the number of general papers for antbirds across biomes, but it was proportional for small mammals (Figure 8).

Discussion

Our study shows compelling evidence that research on small mammals and antbirds in Brazil is geographically biased. We demonstrate that the Atlantic Forest, the most densely populated biome with the most human-populated cities, contained the highest number and density of publications for both taxonomic groups, but studies included in the Amazon were disproportionately numerous considering the low human population density of this biome. Conversely, non-forest biomes were clearly undersampled, especially the Caatinga, Pampa and Pantanal. These findings

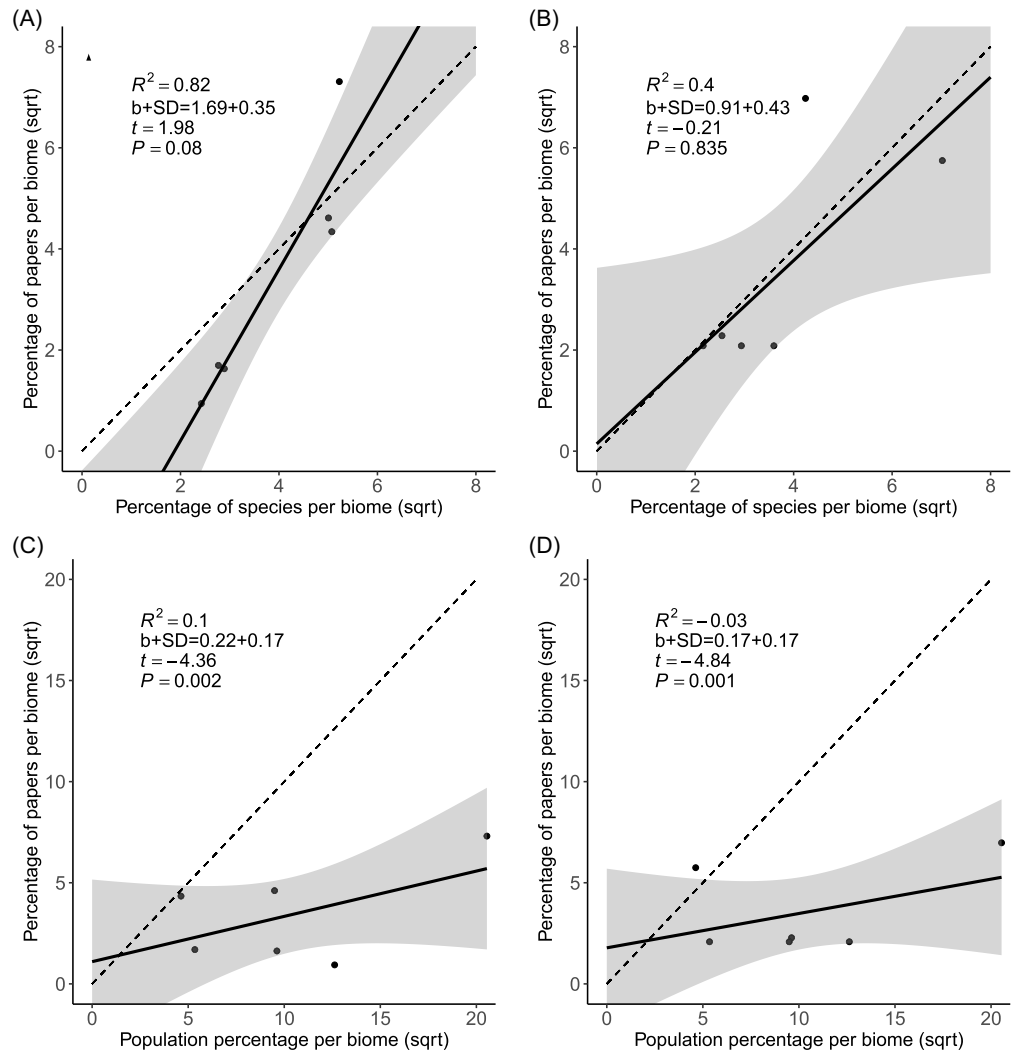


Figure 5. Relationship between the number of general papers and species richness for (A) small mammals and (B) antbirds, and between the number of general papers and human population density for (C) small mammals and (D) antbirds across Brazilian biomes. The black dots correspond to the biomes, the solid lines show the observed slope of the regression and the dashed lines show the expected slope (i.e., $b \pm SE = 1 \pm 0$).

reinforce the assumption that the Brazilian biodiversity research is unevenly distributed among biomes, concentrated near large cities (Oliveira *et al.* 2016, Ribeiro *et al.* 2016). In agreement with our general results, the Atlantic Forest, the most fragmented biome (Lapola *et al.* 2014), included a disproportional prevalence of fragmentation-related studies for small mammals and antbirds in relation to the number of fragmentation papers in other biomes. Although the effects of fragmentation on these groups and the number of threatened species considered were beyond of our scopes, our findings show practical evidence to guide research effort and overcome knowledge gaps, thus providing efficient management recommendations.

Several non-exclusive reasons are feasible to account for the predominance of studies for small mammals and antbirds in the Atlantic Forest: the highest human population density and largest cities (Rio de Janeiro and São Paulo) in Brazil and, subsequently, more research institutions, easy accessibility to sampling areas, and high fragmentation rates. Oversampling in highly human-populated locations is a prevalent issue in biodiversity studies (e.g., Pautasso & McKinney 2007) and it has been previously reported in Brazil (Arruda *et al.* 2018, Oliveira *et al.* 2016). Some of the main research centres in the country (e.g., USP, UNIFESP, UNESP, UFRJ or National Museum of Brazil) are in cities within the Atlantic Forest biome, so researchers therein tend to focus field

collections and studies on sites near their institutions (see Oliveira *et al.* 2016). Likewise, the Atlantic Forest has been traditionally altered by human pressure, resulting in high fragmentation rates of native vegetation (Lapola *et al.* 2014). This elevated habitat alteration associated with high human population density in this biome may potentially explain the overrepresentation of fragmentation-related studies for antbirds and small mammals in the Atlantic Forest, mainly concentrated on forest remnants (see Bovendorp *et al.* 2017 for small mammals).

However, representation of studies in the Amazon, the largest and least densely populated biome, showed a disproportional increase in relation to the other biomes when considering human population density. This finding suggests that accessibility, especially through navigable rivers, is not so restricted as previously reported to perform research in the Amazon Basin (Mendes-Oliveira *et al.* 2015, Oliveira *et al.* 2016). Additionally, fragmentation research on antbirds and small mammals in the Amazon, concentrated near Manaus and Alta Floresta, demonstrates that fragmentation-related studies have been mostly conducted by two important research projects, the BDFFP (Biological Dynamics of Forest Fragments Project) and the PETRA (*Plataforma Experimental para Gestão dos Territórios Rurais na Amazônia Legal*), respectively. Specifically, the BDFFP is the world's largest and ancient project about habitat fragmentation

Density map of fragmentation papers for small mammals

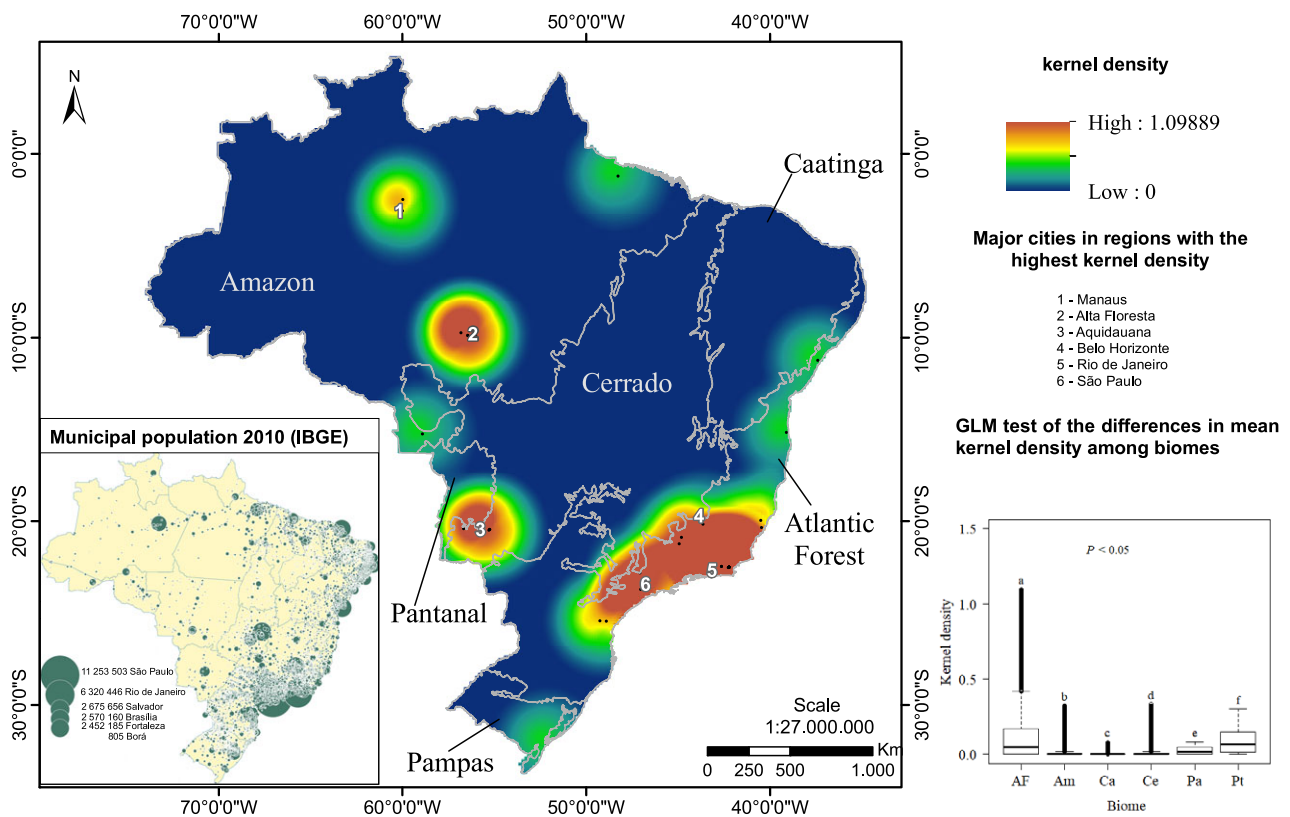


Figure 6. Mean kernel density across Brazilian biomes containing fragmentation papers for small mammals. The kernel density shows the number and distribution of sampling points (i.e., geographical coordinates included in the papers together with the coordinates that we obtained from the study sites using Google Earth, represented by the black dots), which is proportional to the number of studies for each biome (Table S1). The smaller map on the lower left margin shows the human population following the Brazilian Institute of Geography and Statistics (IBGE 2010b). Different letters in the boxplot show significant differences in mean kernel density ($P < 0.05$).

and its impacts on the Amazon biodiversity (Laurance *et al.* 2011).

Studies for antbirds and small mammals were mostly overlooked in the non-forest Brazilian biomes, especially in relation to fragmentation. Biological and ecological research in non-forest biomes in this country has been historically neglected (Overbeck *et al.* 2007, Santos *et al.* 2011), and a similar pattern has been recently reported to fragmentation research (Teixido *et al.* 2020), but they include large areas of native vegetation transformed into pasture and crops (Overbeck *et al.* 2015). The intensive and traditional land use for farming in the Caatinga and the Pampa grasslands have resulted in high habitat loss rates in these biomes (IBGE 2018b). Even in the Pantanal, the Brazil’s best-conserved and least-populous biome, the spread of pastures and invasive species has considerably reduced the area of the native vegetation during the last 30 years (MapBiomias 2017). The Cerrado, the second largest and most densely human-populated biome, was especially undersampled for antbirds. This pattern may be due to the low number of specialists working on this group in the Cerrado, when compared to its richness. Given that the Cerrado is a biodiversity and priority conservation hotspot (Myers *et al.* 2000, Strassburg *et al.* 2017), and the third most degraded biome in Brazil due to increasing expansion of agriculture, livestock and mining (Lapola *et al.* 2014), the low number of studies conducted is somewhat worrying. Overall, our results reinforce the importance of increasing research and overcoming knowledge gaps, as well as

monitoring fragmentation-related studies in the growing anthropogenic degradation of non-forest Brazilian biomes.

The knowledge shortfalls in the studied animal groups resulting from biased research in Brazil may depict subsequent gaps related to biological, ecological and/or functional responses of species to the impact of human-induced environmental changes and ecosystem services they provide (Chapin III *et al.* 2000, Mason *et al.* 2005, Whelan *et al.* 2015). Antbirds regulate insect populations and reduce damage to plants due to their insectivorous diet (Sekercioglu 2006, Van Bael *et al.* 2003, Whelan *et al.* 2015), whereas small mammals play important roles in the trophic web and seed or mycorrhizal fungus dispersal (Galetti *et al.* 2015, Grenha *et al.* 2010). Therefore, overcoming knowledge gaps on antbirds and small mammals and assessing their responses to fragmentation across different biomes are of paramount importance to fully understand the consequences of habitat degradation in forest and non-forest ecosystems.

In summary, the results reported here show that there are major gaps resulting of uneven research on antbirds and small mammals, mostly across non-forest biomes containing a lower number of species. Still, these biomes have been traditionally managed or are increasingly being degraded by anthropogenic actions and, consequently, further research determining the effects of fragmentation on these animal groups, especially relevant to ecosystem services, is required. We call future investigation to consider more studies across non-forest biomes and vast unexplored areas within

Density map of fragmentation papers for antbirds

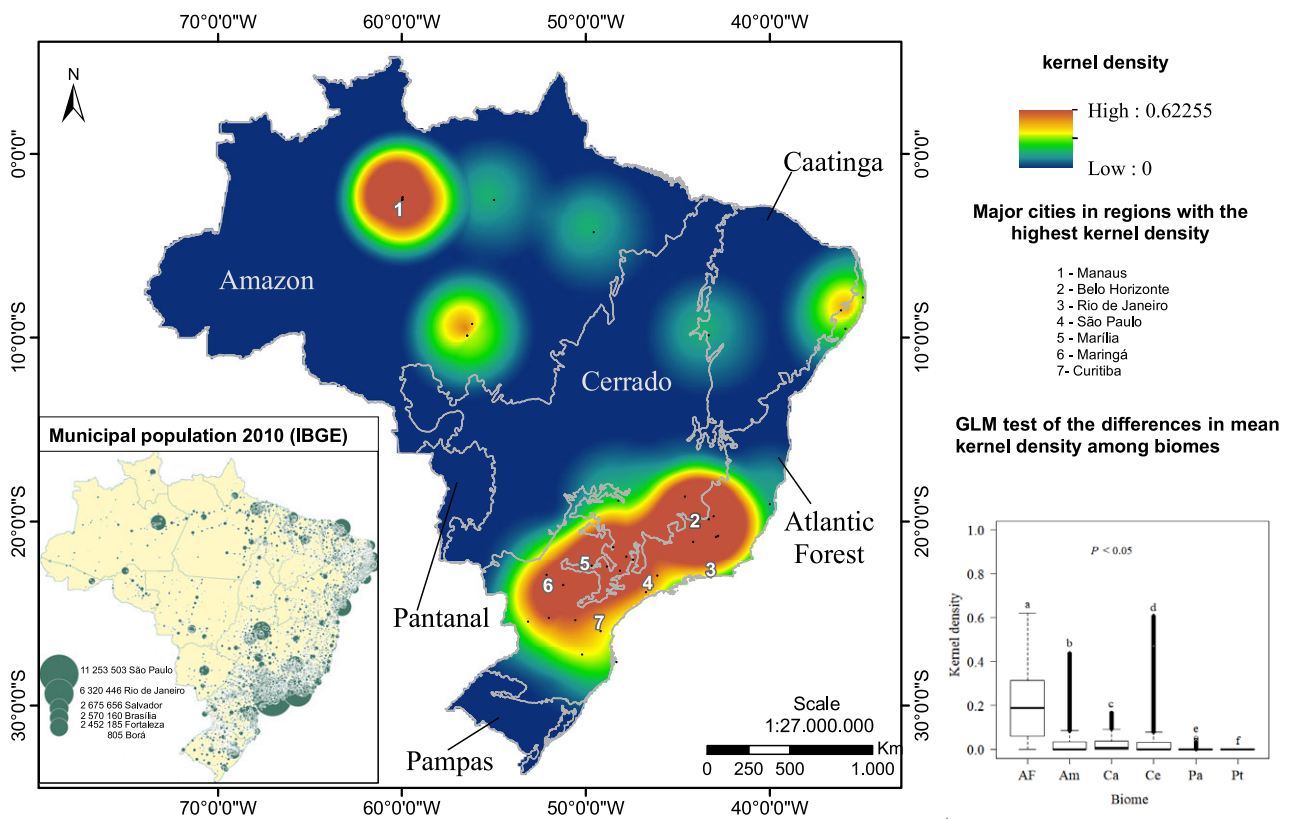


Figure 7. Mean kernel density across Brazilian biomes containing fragmentation papers for antbirds. The kernel density shows the number and distribution of sampling points (i.e., geographical coordinates included in the papers together with the coordinates that we obtained from the study sites using Google Earth, represented by the black dots), which is proportional to the number of studies for each biome (Table S1). The smaller map on the lower left margin shows the human population following the Brazilian Institute of Geography and Statistics (IBGE 2010b). Different letters in the boxplot show significant differences in mean kernel density ($P < 0.05$).

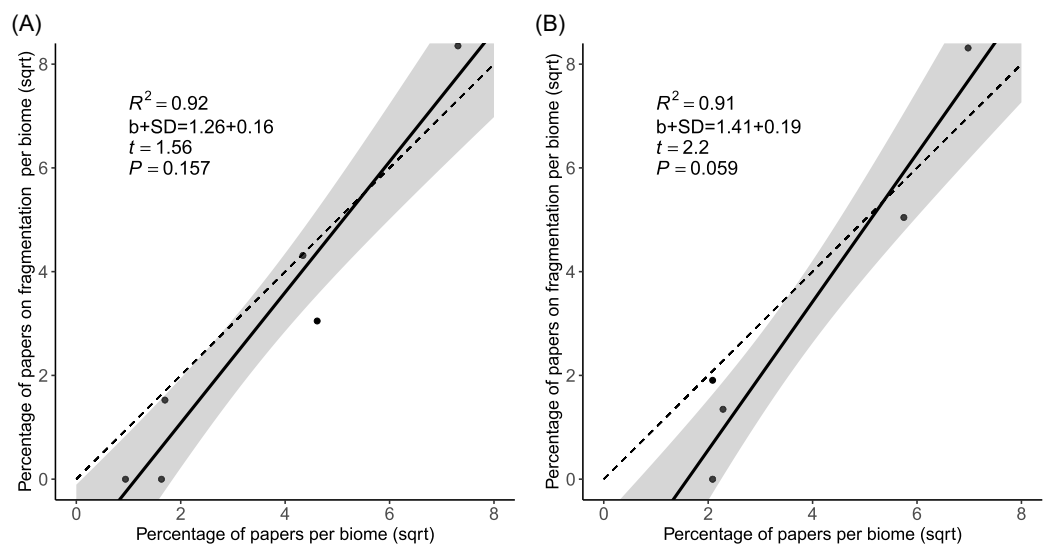


Figure 8. Relationship between the number of fragmentation papers and general papers for (A) small mammals and (B) antbirds across Brazilian biomes. The black dots correspond to the biomes, the solid lines show the observed slope of the regression and the dashed lines show the expected slope (i.e., $b \pm SE = 1 \pm 0$).

forest biomes (e.g., Amazon) to better understand the diversity, distribution and ecology of antbirds and small mammals in Brazil, a megadiverse, unevenly sampled, country.

Supplementary material. To view supplementary material for this article, please visit <https://doi.org/10.1017/S0266467421000250>

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References

- Arruda FV, Sousa DG, Teresa FB, Prado VHM, Cunha HF and Izzo TJ (2018) Trends and gaps of the scientific literature about the effects of fire on Brazilian Cerrado. *Biota Neotropica* **18**, e20170426.
- Avenant N (2011) The potential utility of rodents and other small mammals as indicators of ecosystem 'integrity' of South African grasslands. *Wildlife Research* **38**, 626–639.
- Bovendorp RS, Villar N, Abreu-Junior EF, Bello C, Regolin AL, Percequillo AR and Galetti M (2017) Atlantic small-mammal: a dataset of communities of rodents and marsupials of the Atlantic forests of South America. *Ecology* **98**, 2226–2226.
- Brewer SW and Rejmánek M (1999) Small rodents as significant dispersers of tree seeds in a Neotropical forest. *Journal of Vegetation Science* **10**, 165–174.
- Chapin III FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC and Díaz S (2000) Consequences of changing biodiversity. *Nature* **405**, 234–242.
- Clark JA and May RM (2002) Taxonomic bias in taxonomic research. *Science* **297**, 191–192.
- Deikumah JP, McAlpine CA and Maron M (2014) Biogeographical and taxonomic biases in tropical forest fragmentation research. *Conservation Biology* **28**, 1522–1531.
- Delciellos AC, Vieira MV, Grelle CEV, Cobra P and Cerqueira R (2016) Habitat quality versus spatial variables as determinants of small mammal assemblages in Atlantic Forest fragments. *Journal of Mammalogy* **97**, 253–265.
- Didham RK, Kapos V and Ewers RM (2012) Rethinking the conceptual foundations of habitat fragmentation research. *Oikos* **121**, 161–170.
- Eisenberg JF and Redford KH (1999) *Mammals of the Neotropics – The central neotropics: Ecuador, Peru, Bolivia, Brazil*. Chicago: The University of Chicago Press.
- Fahrig L (2003) Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics* **34**, 487–515.
- Fahrig L (2017) Ecological responses to habitat fragmentation per se. *Annual Review of Ecology, Evolution, and Systematics* **48**, 1–23.
- Fahrig L, Arroyo-Rodríguez V, Bennett JR, Boucher-Lalonde V, Cazetta E, Currie DJ, Eigenbrod F, Ford AT, Harrison SP, Jaeger JAG, Koper N, Martin AE, Martin JL, Metzger JP, Morrison P, Rhodes JR, Saunders DA, Simberloff D, Smith AC, Tischendorf L, Vellend M and Watling JI (2019) Is habitat fragmentation bad for biodiversity? *Biological Conservation* **230**, 179–186.
- Fletcher RJ, Didham RK, Banks-Leite C, Barlow J, Ewers RM, Rosindell J, Holt RD, Gonzalez A, Pardini R, Damschen EI, Melo FPL, Ries L, Prevedello JA, Tscharntke T, Laurance WF, Lovejoy TE and Haddad NM (2018) Is habitat fragmentation good for biodiversity? *Biological Conservation* **226**, 9–15.
- Galetti M, Guevara R, Galbiati LA, Neves CL, Rodarte RR and Mendes CP (2015) Seed predation by rodents and implications for plant recruitment in defaunated Atlantic Forests. *Biotropica* **47**, 521–525.
- Grenha V, Macedo MV, Pires AS and Monteiro RF (2010) The role of *Cerradomys subflavus* (Rodentia, Cricetidae) as seed predator and disperser of the palm *Allagoptera arenaria*. *Mastozoologia Neotropical* **17**, 61–68.
- Hanski I (2015) Habitat fragmentation and species richness. *Journal of Biogeography* **42**, 989–993.
- IBGE (1992) *Manual técnico da vegetação brasileira*. Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística. Available in <https://biblioteca.ibge.gov.br/visualizacao/monografias/GEBIS%20-%20RJ/ManuaisdeGeociencias/Manual%20Tecnico%20da%20Vegetacao%20Brasileira%20n.1.pdf> (accessed on 11 May 2021).
- IBGE (2010a) *Biomass do Brasil 1:5.000.000*. Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística. Available in <http://portaldemapas.ibge.gov.br/portal.php#mapa778> (accessed on 10 April 2020).
- IBGE (2010b) *Censo demográfico 2010*. Instituto Brasileiro de Geografia e Estatística. Available in <https://censo2010.ibge.gov.br/resultados.html> (accessed on 12 January 2021).
- IBGE (2018a) *Síntese descrição biomas*. Instituto Brasileiro de Geografia e Estatística. Available in https://geoftp.ibge.gov.br/informacoes_ambientais/estudos_ambientais/biomas/documentos/Sintese_Descricao_Biomas.pdf (accessed on 11 May 2021).
- IBGE (2018b) *Monitoramento da cobertura e uso da terra do Brasil*. Brasília: Instituto Brasileiro de Geografia e Estatística. Available in https://biblioteca.ibge.gov.br/visualizacao/livros/liv101703_folder.pdf (accessed on 10 April 2020).
- Kruess A and Tscharntke T (1994) Habitat Fragmentation, Species Loss, and Biological Control. *Science* **264**, 1581–1584.
- Lapola DM, Martinelli LA, Peres CA, Ometto JPHB, Ferreira ME, Nobre CA, Aguiar APD, Bustamante MMC, Cardoso MF, Costa MH, Joly CA, Leite CC, Moutinho P, Sampaio G, Strassburg BBN and Vieira ICG (2014) Pervasive transition of the Brazilian land-use system. *Nature Climate Change* **4**, 27–35.
- Laurance WF, Camargo J, Luizão R, Laurance SG, Pimm SL, Bruna E, Stouffer PC, Williamson GB, Benitez-Malvido J, Vasconcelos H, Van Houtan K, Zartman CE, Boyle S, Didham RK, Andrade A and Lovejoy TE (2011) The fate of Amazonian forest fragments: a 32-year investigation. *Biological Conservation* **144**, 56–67.
- Lepage D (2018) *AviBase: the world bird database*. AviBase. <http://avibase.bsc-eoc.org/>.
- Lopes M, Mendes-Oliveira AC (2015) *A Amazônia brasileira e os pequenos mamíferos não voadores*. In Mendes-Oliveira AC and Miranda CL (eds), *Os Pequenos Mamíferos Não Voadores da Amazônia Brasileira*. Rio de Janeiro: Sociedade Brasileira de Mastozoologia, pp. 15–20.
- MapBiomias (2017) *Project MapBiomias. Collection of Brazilian Land Cover and Use Map Series*. MapBiomias. <http://mapbiomas.org>.
- Mason NWH, Mouillot D, Lee WG and Wilson JB (2005) Functional richness, functional evenness and functional divergence: The primary components of functional diversity. *Oikos* **111**, 112–118.
- Mendes-Oliveira AC, Bobrowiec PED, Silva CR, Pinto LC and Trevelin LC (2015) *Estudos sobre pequenos mamíferos não-voadores da Amazônia brasileira: amostragens e lacunas de conhecimento*. In Mendes-Oliveira AC and Miranda CL (eds), *Os Pequenos Mamíferos Não Voadores da Amazônia Brasileira*. Rio de Janeiro: Sociedade Brasileira de Mastozoologia, pp. 21–49.
- Mendonça A, Percequillo AR, Camargo NF, Ribeiro JF, Palma AR, Oliveira LC, Câmara EM and Vieira EM (2018) Cerrado small mammals: abundance and distribution of marsupials, lagomorphs, and rodents in a Neotropical savanna. *Ecology* **99**, 1900–1900.
- Moerman DE and Estabrook GF (2006) The botanist effect: counties with maximal species richness tend to be home to universities and botanists. *Journal of Biogeography* **33**, 1969–1974.
- Mokany K and Ferrier S (2011) Predicting impacts of climate change on biodiversity: a role for semi-mechanistic community-level modelling. *Diversity and Distributions* **17**, 374–380.
- Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB and Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858.
- Nemésio A, Seixas DP and Vasconcelos HL (2013) The public perception of animal diversity: what do postage stamps tell us? *Frontiers in Ecology and the Environment* **11**, 9–10.
- Oliveira U, Brescovit AD and Santos AJ (2015) Delimiting areas of endemism through kernel interpolation. *PLoS ONE* **10**, e0116673.
- Oliveira U, Paglia AP, Brescovit AD, Carvalho CJ, Silva DP, Rezende DT, Leite FS, Batista JA, Barbosa JP, Stehmann JR, Ascher JS, Vasconcelos MF, De Marco P, Löwenberg-Neto P, Dias PG, Ferro VG and Santos AJ (2016) The strong influence of collection bias on biodiversity knowledge shortfalls of Brazilian terrestrial biodiversity. *Diversity and Distributions* **22**, 1232–1244.
- Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GV, Underwood EC, D'Amico JA., Itoua I, Strand HE, Morrison JC, Loucks CJ, Allnutt TF, Ricketts TH, Kura Y, Lamoreux JF, Wettengel WW,

- Hedao P, Kassem KR (2001) Terrestrial ecoregions of the World: A new map of life on Earth. *BioScience* **51**, 933–938.
- Overbeck GE, Müller SC, Fidelis AT, Pfadenhauer J, Pillar VD, Blanco C, Boldrini II, Both R and Forneck ED (2007) Brazil's neglected biome: the South Brazilian Campos. *Perspectives in Plant Ecology, Evolution and Systematics* **9**, 101–116.
- Overbeck GE, Vélez-Martin E, Scarano FR, Lewinsohn TM, Fonseca CR, Meyer ST, Müller SC, Ceotto P, Dadalt L, Durigan G, Ganade G, Gossner MM, Guadagnin DL, Lorenzen K, Jacobi CM, Weisser WW and Pillar VD (2015) Conservation in Brazil needs to include non-forest ecosystems. *Diversity and Distributions* **21**, 1455–1460.
- Paglia AP, Fonseca GAB, Rylands AB, Herrmann G, Aguiar LMS, Chiarello AG, Leite YLR, Costa LP, Siciliano S, Kierulff MCM, Mende SL, Tavares VC, Mittermeier RA and Patton JL (2012) *Lista Anotada dos Mamíferos do Brasil /Annotated Checklist of Brazilian Mammals*. 2. Belo Horizonte: Conservação Internacional.
- Pardini R, Bueno AA, Gardner TA, Prado PI and Metzger JP (2010) Beyond the Fragmentation Threshold Hypothesis: Regime Shifts in Biodiversity Across Fragmented Landscapes. *Plos ONE* **5**, e13666.
- Pautasso M and McKinney ML (2007) The Botanist Effect Revisited: Plant Species Richness, County Area, and Human Population Size in the United States. *Conservation Biology* **21**, 1333–1340.
- Piacentini VQ, Aleixo ALP, Agne CEQ, Maurício GN, Pacheco JF, Bravo G, Brito GRR, Naka LN, Olmos F, Posso S, Silveira LF, Betini G, Carrano E, Franz I, Lees A, Lima L, Pioli D, Schunck F, Amaral FR, Bencke GA, Cohn-Haft M, Figueiredo LF, Straube F and Césari E (2019) *Thamnophilidae in Catálogo Taxonômico da Fauna do Brasil*. PNUD. <http://fauna.jbrj.gov.br/fauna/faunadobrasil/138244> (accessed on 12 January 2020).
- Piratelli A, Sousa SD, Corrêa JS, Andrade VA, Ribeiro RY, Avelar LH and Oliveira EF (2008) Searching for bioindicators of forest fragmentation: passerine birds in the Atlantic forest of southeastern Brazil. *Brazilian Journal of Biology* **68**, 259–268.
- Prugh LR, Hodges KE, Sinclair ARE and Brashares JS (2008) Effect of habitat area and isolation on fragmented animal populations. *Proceedings of the National Academy of Sciences of the United States of America* **105**, 20770–20775.
- R Core Development Team (2018) *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. <http://www.R-project.org/>.
- Reis NR, Peracchi AL, Pedro WA and Lima IP (2011) *Mamíferos do Brasil*. 2nd ed. Londrina: N.R.Reis Publishing. 439p.
- Ribeiro GV, Teixido AL, Barbosa NP and Silveira FA (2016) Assessing bias and knowledge gaps on seed ecology research: implications for conservation agenda and policy. *Ecological Applications* **26**, 2033–2043.
- Santos JC, Leal IR, Almeida-Cortez JS, Fernandes GW and Tabarelli M (2011) Caatinga: The Scientific Negligence Experienced by a Dry Tropical Forest. *Tropical Conservation Science* **4**, 276–286.
- Santos-Filho M, Peres CA, Da Silva DJ and Sanaiotti TM (2012) Habitat patch and matrix effects on small-mammal persistence in Amazonian forest fragments. *Biodiversity and Conservation* **21**, 1127–1147.
- Sekercioglu CH (2006) Increasing awareness of avian ecological function. *Trends in Ecology and Evolution* **21**, 464–471.
- Shine R and Bonnet X (2000) Snakes: a new 'model organism' in ecological research? *Trends in Ecology and Evolution* **15**, 221–222.
- Sick H (1997) *Ornitologia brasileira*. Rio de Janeiro: Nova Fronteira.
- Silverman BW (1986) *Density estimation for statistics and data analysis*. London: Chapman and Hall.
- Strassburg BB, Brooks T, Feltran-Barbieri R, Iribarrem A, Crouzeilles R, Loyola R, Latawiec A, Oliveira Filho FJ, Scaramuzza CM, Scarano F, Filho B and Balmford A (2017) Moment of truth for the Cerrado hotspot. *Nature Ecology & Evolution* **1**, 1–3.
- Teixido AL, Gonçalves SRA, Fernández-Arellano GJ, Dáttilo W, Izzo TJ, Layme VMG, Moreira LFB and Quintanilla LG (2020) Major biases and knowledge gaps on fragmentation research in Brazil: implications for conservation. *Biological Conservation* **251**, 108749. <https://doi.org/10.1016/j.biocon.2020.108749>
- Trimble MJ and Van Aarde RJ (2010) Species inequality in scientific study. *Conservation Biology* **24**, 886–890.
- Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R and Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. *Scientific Reports* **7**, 1–14.
- Van Bael SA, Brawn JD and Robinson SK (2003) Birds defend trees from herbivores in a Neotropical forest canopy. *Proceedings of the National Academy of Sciences of the United States of America* **100**, 8304–8307.
- Whelan CJ, Şekercioglu ÇH and Wenny DG (2015) Why birds matter: from economic ornithology to ecosystem services. *Journal of Ornithology* **156**, 227–238.
- Wintle BA, Kujala H, Whitehead A, Cameron A, Veloz S, Kukkala A, Moilanen A, Gordon A, Lentini PE, Cadenhead NCR and Bekessy SA (2019) Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity. *Proceedings of the National Academy of Sciences of the United States of America* **116**, 909–914.
- Yang W, Ma K and Kreft H (2013) Geographical sampling bias in a large distributional database and its effects on species richness–environment models. *Journal of Biogeography* **40**, 1415–1426.
- Zar JH (1999) *Biostatistical analysis*. New Jersey: Prentice Hall.
- Zimmer K and Isler ML (2018) *Family Thamnophilidae (Typical Antbirds)*. In: Del Hoyo J, Elliot A and Christie D (eds), *Handbook of the Birds of the World*, v. 8: Broadbills to Tapaculos (pp. 448–681). Lynx Edicions.