



UNIVERSIDADE  
ESTADUAL DE LONDRINA

---

ALAN DEIVID PEREIRA

**PRECURSORES DA DEFAUNAÇÃO NO ANTROPOCENO:  
FLORESTAS VAZIAS E FUNCIONALMENTE INSTÁVEIS DA  
MATA ATLÂNTICA SUL DO BRASIL**

ALAN DEIVID PEREIRA

**PRECURSORES DA DEFAUNAÇÃO NO ANTROPOCENO:  
FLORESTAS VAZIAS E FUNCIONALMENTE INSTÁVEIS DA  
MATA ATLÂNTICA SUL DO BRASIL**

Tese apresentada ao Programa de Pós-graduação em Ciências Biológicas da Universidade Estadual de Londrina - UEL, como requisito parcial para a obtenção do título de Doutor.

Orientador: Prof. Dr. Mário Luís Orsi  
Coorientador: Dr. Juliano André Bogoni

Londrina  
2020

Ficha de identificação da obra elaborada pelo autor, através do Programa de Geração Automática do Sistema de Bibliotecas da UEL

Pereira, Alan Deivid.

Precusores da defaunação no antropoceno: Florestas vazias e funcionalmente instáveis da Mata Atlântica sul do Brasil / Alan Deivid Pereira. - Londrina, 2020.  
146 f. : il.

Orientador: Mário Luís Orsi.

Coorientador: Juliano André Bogoni.

Tese (Doutorado em Ciências Biológicas) - Universidade Estadual de Londrina, Centro de Ciências Biológicas, Programa de Pós-Graduação em Ciências Biológicas, 2020.

Inclui bibliografia.

1. Ecologia - Tese. 2. Mamíferos - Tese. 3. Biologia da Conservação - Tese. 4. Espécies Invasoras - Tese. I. Orsi, Mário Luís . II. Bogoni, Juliano André. III. Universidade Estadual de Londrina. Centro de Ciências Biológicas. Programa de Pós-Graduação em Ciências Biológicas. IV. Título.

CDU 574

ALAN DEIVID PEREIRA

**PRECURSORES DA DEFAUNAÇÃO NO ANTROPOCENO:  
FLORESTAS VAZIAS E FUNCIONALMENTE INSTÁVEIS DA MATA  
ATLÂNTICA SUL DO BRASIL**

Tese apresentada ao Programa de Pós-graduação em Ciências Biológicas da Universidade Estadual de Londrina - UEL, como requisito parcial para a obtenção do título de Doutor.

**BANCA EXAMINADORA**

---

Orientador: Prof. Dr. Mário Luís Orsi  
Universidade Estadual de Londrina – UEL

---

Prof. Dr. Luciano Martins Verdade  
Universidade de São Paulo – USP

---

Prof. Dr. Vlamir José Rocha  
Universidade Estadual de Londrina – UEL

---

Profa. Dra. Margareth Lumy Sekiama  
Universidade Estadual de Londrina – UEL

---

Prof. Dr. Lucas Ribeiro Jarduli  
Universidade Estadual de Londrina – UEL

Londrina, 09 de abril de 2020

**Dedico esta tese a minha mãe Ana Cioczek Pereira**

## AGRADECIMENTOS

Aqui se encerra um ciclo de nove anos interrompidos de estudos e amor a biologia, destes três dedicados ao doutorado. Nestes anos de formação, tive o privilégio de nunca estar sozinho em minha jornada e fui agraciado pela companhia de pessoas maravilhosas em diversos aspectos. Neste sentido, penso que o ato de agradecer é ter ciência de que não conquistei nada sozinho e sou feliz por isso, assim, parafraseando o poeta americano Henry Thoreau “*A felicidade só é real quando é compartilhada*”, e sou grato por compartilhar tantos momentos com todos vocês. Minha lista de agradecimento é longa e peço desculpas antecipadamente aos esquecidos aqui, saibam que todos vocês tiveram um papel especial em minha jornada para me tornar um pesquisador e acima de tudo uma pessoa melhor.

Agradeço primeiramente a minha família. Minha querida mãe Ana Ciozeck Pereira, por assumir o papel de mãe e pai devido ao falecimento deste. Neste papel sempre será minha primeira orientadora e maior incentivadora de meus estudos, certamente este doutorado é uma homenagem a toda sua dedicação e apoio. Agradeço aos meus irmãos Alex e Patrik por me fornecerem toda a segurança e aporte emocional que mesmo distante de nossa família, vocês se encarregaram de manter nossos laços afetivos e contribuem para o bem-estar de todos. Agradeço também a minha namorada Jessica Hainosz, que sempre esteve ao meu lado nos momentos mais difíceis me fornecendo apoio em todas as minhas decisões, certamente você foi e é meu porto seguro nesta jornada chamada vida.

Agradeço imensamente ao meu orientador e amigo professor Dr. Mário Luís Orsi, por ter me aceitado como seu aluno, mesmo sendo um mastozoólogo “invasor” em seu Laboratório de Ecologia de Peixes e Invasões Biológicas (LEPIB). Certamente você é uma das maiores inspirações de profissional que eu tive o prazer de conhecer, espero seguir minha carreira com a mesma paixão, convicção e garra que o senhor demonstra todos os dias.

Também sou grato ao meu segundo orientador, Dr. Juliano André Bogoni, por aceitar me orientar e sanar horas de dúvidas, discussões sobre estatísticas e algoritmos inteligentes, seus trabalhos me fazem sentir orgulho e me incentivam a continuar na pesquisa tendo mamíferos como foco de estudo, e sua humildade me fazem crer que posso chegar ainda mais longe.

Agradeço a professora Dr. Ana Paula Vidotto- Magnoni por me apoiar, incentivar e inspirar a seguir com pesquisas com mamíferos na região norte do Paraná e pela parceria em diversas publicações científicas. Não menos importante agradeço ao professor Dr. Sérgio

Bazilio, por ser meu principal amigo e parceiro de longa data nas coletas e informações sobre a mastofauna paranaense, meu muito obrigado.

Aos amigos do Laboratório de Ecologia de Peixes e Invasões Biológicas (LEPIB), Harry, Armando, Lucas, Marcelo, João, Carol (mãe), Iago, Tuco, Felipinho (Victor), Matheus, Sarah, Carol (freakinha) e Gabi. Aos amigos de outros laboratórios Carol Blefari, Ricardo, Gabriel, Tati, Guilherme (sapos), Guilherme (aves), Larissa e Gisele. Por fim sou imensamente agradecido aos técnicos da UEL Aparecido de Souza, Edson Santana da Silva e Jurandir por sempre me auxiliarem em etapas de campo. Agradeço a todos meus amigos de fora da academia em especial aos amigos Marcos e Crislaine por estarem ao meu lado a anos, sempre me incentivando a nunca parar com minhas pesquisas.

Ao Programa de Pós Graduação em Ciências Biológicas da Universidade Estadual de Londrina, por todo o suporte oferecido de modo a possibilitar minha formação profissional. Ao corpo docente de professores da UEL e outras instituições por compartilharem todo seu conhecimento ao longo destes cinco anos de mestrado e doutorado, possibilitando o meu crescimento intelectual bem como a desenvolvimento do presente estudo.

Ao Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) pela autorização de pesquisa em unidades de conservação e ao Instituto Ambiental do Paraná (IAP) pela autorização de pesquisas nos demais fragmentos.

O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Código de Financiamento 1689817.

*Não devemos deixar que uma floresta cheia de árvores nos engane, acreditando que tudo está bem. Muitas dessas florestas estão "mortas-vivas" e, embora os satélites que passam por cima delas possam registrá-las tranquilamente como floresta, elas estão vazias de grande parte da riqueza da fauna valorizada pelos seres humanos. **Uma floresta vazia é uma floresta condenada.***

Kent H. Redford (1992)

Pereira, Alan Deivid. **Precursos da defaunação no antropoceno: florestas vazias e funcionalmente instáveis da Mata Atlântica Sul do Brasil**. 2020. 144 f. Tese (Doutorado em Ciências Biológicas) – Universidade Estadual de Londrina, Londrina, 2020.

## RESUMO

As lacunas de informações básicas sobre a distribuição de espécies bem como a ausência de dados de abundância em séries históricas dificultam a correta avaliação do estado de defaunação em comunidades de mamíferos, nas diferentes regiões do Brasil, como é o caso da porção Sul da Mata Atlântica brasileira. Em escalas locais, acredita-se que os principais precursores associados a defaunação são a caça, introdução de espécies não nativas e conversão do habitat. Considerando os dois últimos fatores citados o presente estudo teve como objetivos investigar os mecanismos relacionados ao declínio de mamíferos de médio e grande porte em remanescentes de Mata Atlântica do Sul do Brasil. Primeiramente realizamos o primeiro inventário da mastofauna de médio e grande porte do Parque Nacional dos Campos Gerais afim de entender como as espécies ocupam esta importante unidade de conservação. Com um esforço amostral de 780 horas de busca ativa e 157.516 horas em armadilhas fotográficas, foram registradas 31 espécies de 17 famílias e 8 ordens, sendo que destas espécies, 42% são ameaçadas de extinção em alguma esfera (estadual, nacional ou internacional). No segundo capítulo investigamos o impacto de uma rodovia de pequeno porte sobre a fauna de mamíferos da região norte do estado do Paraná. Monitoramos a PR-455 durante um ano, totalizando 7.296 km percorridos em 96 campanhas. Registramos 60 indivíduos atropelados pertencentes a 17 espécies, representando uma taxa de 0,151 indivíduo / km / dia. Nossos resultados indicaram que as regiões com maior incidência de atropelamentos no PR-445 são aquelas próximas a trechos sobre rios e com remanescentes de vegetação nativa. No terceiro capítulo, usamos modelos de nicho ambiental para entender a distribuição geográfica de *Myocastor coypus* com base em preditores bioclimáticos, identificando áreas com maior aptidão para a invasão dessa espécie. Observamos que as áreas de maior adequabilidade climática sendo que os maiores scores da avaliação de risco de invasão estão restritas às regiões sudeste e sul do Brasil, e ainda as modificações antropogênicas da paisagem são variáveis que melhor explicam a adequabilidade e ocorrência dessa espécie em novos ambientes. No último capítulo avaliamos efeitos da conversão do habitat no declínio de mamíferos de médio e grande porte em remanescentes de Mata Atlântica, através do índice de defaunação e modelos lineares generalizados. Encontramos um alto grau de defaunação em todos os fragmentos analisados com mais de 50% de todos os fragmentos analisados apresentando valores médios de defaunação superiores à média histórica esperada dos últimos 500 anos. Áreas com maior porcentagem de cobertura de solo destinadas a silvicultura e agricultura apresentam maiores valores de defaunação se comparadas com áreas com maior cobertura de florestas naturais. Concluímos que para a porção Sul da Mata Atlântica não há apenas um fator determinante de defaunação e sim um conjunto de fatores que exercem pressões cotidianas e constantes sobre as assembleias de mamíferos locais, de maneira que se medidas preventivas não forem adotadas e implementadas em curto prazo os fragmentos restantes passaram por severos processos de homogeneização de fauna.

**Palavras-chave:** Fragmentação; Floresta Tropical; Mamíferos; Perda da biodiversidade; Uso da terra

Pereira, Alan Deivid. **Precursors of defaunation in the Anthropocene: empty and functionally unstable forests in the South Atlantic Rainforest of Brazil**. 2020. 144 pp. Thesis (Doctorate in Biological Sciences) – Universidade Estadual de Londrina, Londrina, 2020.

## ABSTRACT

The gaps of basic information on the distribution of species as well as the absence of abundance data in historical series make it difficult to estimate the state of defaunation in many regions of Brazil, such as the southern portion of the Brazilian Atlantic Rainforest. At local scales, the main precursors associated with defaunation are believed to be hunting, the introduction of non-native species, and habitat conversion. Considering the last two factors mentioned, the present study aimed to investigate the mechanisms related to the decline of medium and large mammals in remnants of the southern Brazilian Atlantic Rainforest. Firstly, we carried out the first inventory of medium-sized and large mammals for Parque Nacional dos Campos Gerais, Paraná, Brazil to understand how species occupy this important conservation unit. With a 780-hour sampling effort in active research and 157,516 hours in camera traps, 31 species of 17 families and 8 orders were recorded. Of these species, 42% are threatened with extinction at state, national, or international level. In the second chapter, we investigate the impact of a small highway on the fauna of mammals in the northern region of the state of Paraná. We monitored the PR-455 for one year, totaling 7,296 km traveled in 96 trips. We recorded 60 roadkill mammals belonging to 17 species, representing a rate of 0.151 individual/km/day. Our results indicate that the regions with the highest incidence of roadkills on PR-445 are those close to stretches over rivers and with remnants of native vegetation. In the third chapter, we use environmental niche models to understand the geographic distribution of *M. coypus* based on bioclimatic predictors and to identify areas with greater suitability for the invasion of this species. We observed that the areas of greatest climatic suitability and with the highest scores for the risk of invasion assessment are restricted to the southeastern and southern regions of Brazil, and yet the anthropogenic changes in the landscape are variables that best explain the suitability and occurrence of this species in new environments. In the last chapters, we evaluated the effects of habitat conversion to the decline of medium-sized mammals in remnants of the southern Brazilian Atlantic Rainforest, through the defaunation index and generalized linear models. We found a high degree of defaunation in all analyzed fragments, with more than 50% of all analyzed fragments showing rates defaunation values higher than the expected historical average of the last 500 years. Areas with a higher percentage of soil cover for silviculture and agriculture have greater defaunation rates when compared to areas with natural forest cover. We conclude that for the South portion of the Brazilian Atlantic Rainforest there is not only one factor that determines defaunation, but a set of factors that exert daily and constant pressure on the assemblages of local mammals, so that if preventive measures are not adopted and implemented in the short term, the remaining fragments went through severe fauna homogenization processes.

**Key words:** Fragmentation; Land use; Loss of biodiversity; Mammals; Tropical forest

## LISTA DE FIGURAS

### CAPÍTULO 1

- Figura 1** – Map of the Parque Nacional dos Campos Gerais, state of Paraná, Brazil, with monitoring sites by camera traps during the 2013–2014 and 2015–2017 sampling periods..... 25
- Figura 2** – Figures 2–7. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. **2.** *Didelphis albiventris*. **3.** *Didelphis aurita*. **4.** *Myrmecophaga tridactyla*. **5.** *Tamandua tetradactyla*. **6.** *Dasypus novemcinctus*. **7.** *Euphractus sexcinctus*. ..... 27
- Figura 3** – Figures 8–13. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. **8.** *Mazama gouazoubira*. **9.** *Mazama americana*. **10.** *Mazama nana*. **11.** *Pecari tajacu*. **12.** *Sus scrofa*. **13.** *Sapajus nigritus*. ..... 28
- Figura 4** – Figures 14–19. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. **14.** *Alouatta guariba clamitans*. **15.** *Cerdocyon thous*. **16.** *Canis lupus familiaris*. **17.** *Leopardus pardalis*. **18.** *Leopardus guttulus*. ..... 29
- Figura 5** – Figures 20–25. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. **20.** *Puma concolor*. **21.** *Puma yagouaroundi*. **22.** *Eira barbara*. **23.** *Galictis cuja*. **24.** *Nasua nasua*. **25.** *Procyon cancrivorus*. ..... 30
- Figura 6** – Figures 26–30. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. **26.** *Lepus europaeus*. **27.** *Cuniculus paca*. **28.** *Dasyprocta azarae*. **29.** *Coendou spinosus*. **30.** *Guerlinguetus brasiliensis*. ..... 31
- Figura 7** – The rarefaction curve (observed and estimates by jackknife 1) of mammal species registered by identification of footprints and trap cameras. Vertical bars represent standard deviation. CT: Camera trap; F: footprints. .... 33

### CAPÍTULO 2

- Figura 1** – Location of Highway PR-445 in the state of Paraná, Brazil indicating the sector measured in this study from 2018 to 2019. The hotspots highlighted in red indicate

	places with high rates of mammal roadkill.....	46
<b>Figura 2 – Figure 2.</b>	Microstructural pattern of species of the family Felidae: <i>Leopardus wiedii</i> . (A) cuticular pattern and (B) medullar pattern; <i>Leopardus guttulus</i> ; (C) cuticular pattern and (D) medullar pattern; and <i>Puma yagouaroundi</i> (E) cuticular pattern and (F) medullar pattern.....	50
<b>Figura 3 –</b>	Boxplot illustrating the difference in roadkill rate for medium- to large-bodied mammals on Highway PR-445 between the municipalities of Londrina and Mauá da Serra, PR in relation to: (A) activity pattern; and (B) feeding habit. Acronyms are described in Table 1. A: a significant difference [p= 0.05] is shown between carnivores (CA) and frugivores/omnivores (Fr/On). B: a significant difference [p = 0.04] is shown between carnivores (CA) and insectivores/omnivores (In/On).....	51

### CAPÍTULO 3

<b>Figura 1 –</b>	<i>Myocastor coypus</i> records in Brazilian biomes and the suitability values for each record. ....	67
<b>Figura 2 –</b>	Suitability map for <i>Myocastor coypus</i> occurrences in Brazil (a). South and Southeast Brazil, with confirmed occurrences in the published scientific literature (b). Low suitability values are represented by green and high suitability values are represented by red. Highlighted, a photographic record of <i>M. coypus</i> through opportunistic observations in northern of the state of Santa Catarina and the record of a run-over specimen on the PR-538 highway, near the Cafezal River, in the municipality of Londrina, PR. ....	68
<b>Figura 3 –</b>	Surveillance map, combined binary map for the occurrence of <i>Myocastor coypus</i> in Brazil. (a) The southeastern and southern regions of Brazil are highlighted. (b) Record percentages in relation to risk assessment for Brazil areas.....	69

### Support Material

<b>Figura S1 –</b>	Occurrence points before and after spatial filter. <b>Blue bar</b> = Raw GBIF coordinate data points before spatial filter, <b>Purple</b> = Thinned GBIF coordinate data points after spatial filter, <b>Red</b> = Raw Brazil coordinate data points before spatial filter, <b>Green</b> = Thinned Brazil coordinate data points before spatial filter .....	76
<b>Figura S2 –</b>	Ordination plot of climate variables. All results were obtained only with	

native data according with IUCN.....	80
<b>Figura S3</b> – Ordination plot of climate variables. Loading values results with native and Brazil occurrences. ....	81
<b>Figura S4</b> – Suitability models calibrated with GBIF native occurrences and projected within Brazilian range. Color gradient shows suitability values from blue (i.e., low suitability) to yellow (i.e., Highest values). ....	83
<b>Figura S5</b> – Suitability models calibrated with Brazilian occurrences (i.e., data set two) and projected within Brazilian range. Color gradient shows suitability values from blue (i.e., low suitability) to yellow (i.e., Highest values). ....	84
<b>Figura S6</b> – Binary classification maps for the four different niche models used to model <i>M. coypus</i> . Each classification maps were obtained from GBIF occurrences in native range and projected within Brazilian range. Binary models use threshold values (i.e., here sensitivity = specificity) to classify grid cells in presence and absence class. Grey color indicate cell predicted as absence and red indicate cell predicted as presence. ....	85
<b>Figura S7</b> – Binary classification maps for the four different niche models used to model <i>M.coypus</i> . Each classification maps were obtained from Brazilian occurrences and projected within Brazilian range. Binary models use threshold values (i.e., here sensitivity = specificity) to classify grid cells in presence and absence class. Grey color indicate cell predicted as absence and red indicate cell predicted as presence ....	86
<b>Figura S8</b> – Pairwise correlation values of suitability values obtained by the ensemble approach and the environmental variables used in the modeling procedures for <i>Myocastor coypus</i> in Brazil. ....	87

#### CAPÍTULO 4

<b>Figura 1</b> – Map of the areas analyzed of the Atlantic Rainforest in southern Brazil, with special reference to EPA of the Devonian Escarpment. PCG: Parque Nacional dos Campos Gerais; RBA: Reserva Biológica das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN Corredor do Iguaçu; FSN: Fragmento São Nicolau; FPL: Fragmento Portão lajeado; FMS: Fragmento Monte Seletto; FCA: Fragmento Caxambu; FMI: Fragmento Mirante; FBM: Fragmento Barra Mansa; FGR: Fragmento da Gruta.....	95
<b>Figura 2</b> – Defaunation index for medium- and large-bodied mammals on study sites	

in the southern portion of the Brazilian Atlantic Forest biome: (a) all medium- and large-bodied mammal species; (b) high trophic level; (c) intermediate trophic level; (d) low trophic level; (e) frugivores; (f) large grazers; (g) mesocarnivores; (h) apex-predators; (i) small-bodied; (j) large-bodied; (k) boxplot illustrating the difference in defaunation index between non-protected and protected areas.....98

**Support Material**

**Figure S3** – Land use cover found in forest remnants of the South Atlantic Forest in Brazil...108

## LISTA DE TABELAS

### CAPÍTULO 1

**Tabela 1** – List of land medium-sized and large mammal species at the Parque Nacional dos Campos Gerais, Brazil. Record method; Footprint (F), Visualization (VI), Camera traps (CT), Vocalization (VO). Conservation status by (IUCN), Brazilian List of Threatened Species (BR), Paraná state List of Threatened Species (PR). Data Deficient (DD), Endangered (EN), Least Concern (LC), Not evaluated (NE), Near Threatened (NT), Vulnerable (VU) and Critically Endangered (CR). Species added in 2016 to 2017 (+). Exotic species (\*). Small species (\*\*). ..... 32

### CAPÍTULO 2

**Tabela 1** – List of roadkill medium- to large-bodied mammalian species on Highway PR-445. Acronyms are as follows. N: Total number of occurrences. F: Frequency of occurrence by species. Diet: carnivore (Ca); frugivore and folivore (Fr/Fo); frugivore and omnivore (Fr/On); herbivore or grazer (Hb); insectivore and omnivore (In/On) and myrmecophage (Myr). **Activity pattern:** crepuscular/nocturnal (CrN); diurnal (Dn); nocturnal (Nt). **Threat category:** data deficient (DD); endangered (EN); least concern (LC); not evaluated (NE); near threatened (NT) and vulnerable (VU). Exotic species (\*). Small-bodied species (\*\*). ..... 49

### CAPÍTULO 3

**Tabela 1** – Partial area under the curve (pAUC) and threshold values (sensitivity = specificity) for the four algorithms used to model the potential distribution of *Myocastor coypus* (models were combined if  $p \text{ AUC} > 1$ ). The relative importance of each variable used to model the distribution of *Myocastor coypus* are displayed below the table. .... 68

### SUPPORT MATERIAL

**Tabela S1** – *Myocastor coypus* coordinates occurrence records in Brazil. **Locality:** Municipality in which each species coordinate was observed, **State:** State in which each species coordinate was observed: Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP); Rio de Janeiro (RJ), **Biome:** landscape classification in which each species coordinate was observed, **Reference:** information source in which each species coordinate was gathered, **Map ID:** point label for each occurrence in map reference (see Fig. 2 in manuscript), NR indicate *ad libitum* observations by S. Bazilio or M. L. Orsi and DR indicate dead species founded in the road. **Suitability:** suitability values for each occurrence points in Brazil. .... 77

**Tabela S2** – PCA loading values of GBIF thinned data set inside native range. In bold, selected bioclimatic

variables names and values of retained variables. PC1 = first component of PCA, PC2 = second component of PCA. ....78

**Tabela S3** – PCA loading values from Brazilian thinned data set. In bold, loading bioclimatic variables names and values of retained variables. PC1 = first component of PCA, PC2 = second component of PCA. .... 79

#### **CAPÍTULO 4**

**Tabela 1** – Description of sampling effort employed on all study areas in the Atlantic Rainforest, Brazil.....96

**Tabela 2** – Results of GLM with a quasi-Poisson distribution of the best model for defaunation according to the covered-land use variables.....99

#### **SUPPORT MATERIAL**

**Tabela S1** – Landscape characterization of the analyzed areas. **Areas:** PCG: Parque Nacional dos Campos Gerais; RBA: Reversa Biológica das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN Corredor do Iguaçu; FSN: Fragmento São Nicolau; FPL: Fragmento Portão lajeado; FMS: Fragmento Monte Seletto; FCA: Fragmento Caxambu; FMI: Fragmento Mirante; FBM: Fragmento Barra Mansa; FGR: Fragmento da Gruta; **HB: Historical baseline**.....107

**Tabela S2** – List of medium-sized and large mammal species in the 11 areas analyzed along with the IUCN historical baseline. Trophic Guild: Ca: Carnivore; Fr: Frugivore; Fo: Folivore; Gr: Gumivore; Hb: Herbivore grazer; In: Insectivore; Myr: Myrmecophage; On: Omnivore; Os: Piscivore. **Areas:** PCG: Parque Nacional dos Campos Gerais; RBA: Reversa Biológica das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN Corredor do Iguaçu; FSN: Fragmento São Nicolau; FPL: Fragmento Portão lajeado; FMS: Fragmento Monte Seletto; FCA: Fragmento Caxambu; FMI: Fragmento Mirante; FBM: Fragmento Barra Mansa; FGR: Fragmento da Gruta; **HB: Historical baseline**.....112

**Tabela S3** – Defaunation values found in forest remnants of the South Atlantic Forest in Brazil.....115

## SUMÁRIO

<b>INTRODUÇÃO GERAL</b> .....	17
<b>REFERÊNCIAS</b> .....	20
<b>CAPÍTULO 1. Checklist of medium-sized to large mammals of Campos Gerais National Park, Paraná, Brazil</b> .....	23
<b>Abstract</b> .....	24
<b>Introduction</b> .....	24
<b>Methods</b> .....	25
Study area.....	25
Sampling.....	26
Data analysis.....	26
<b>Results</b> .....	26
Annotated list.....	27
<b>Discussion</b> .....	37
<b>Acknowledgements</b> .....	38
<b>References</b> .....	38
<b>CAPÍTULO 2. Narrow, short and deadly: Mammals roadkills on highway sections of PR-445, South of Brazil</b> .....	40
<b>Abstract</b> .....	42
<b>Introduction</b> .....	43
<b>Material and methods</b> .....	44
Study area.....	44
Sampling.....	45
Data analysis.....	47
<b>Results</b> .....	48
<b>Discussion</b> .....	51
<b>Acknowledgments</b> .....	55
<b>References</b> .....	55
<b>CAPÍTULO 3. Modeling the geographic distribution of <i>Myocastor coypus</i> (Mammalia, Rodentia) in Brazil: establishing priority areas for monitoring and an alert about the risk of invasion</b> .....	62
<b>Abstract</b> .....	64
<b>Introduction</b> .....	64

Material and methods.....	65
Native occurrence data.....	65
Brazilian occurrence data.....	65
Environmental data and variable selection.....	66
Environmental niche models (ENM).....	66
Model calibration and model evaluation.....	66
Surveillance map.....	66
<b>Results.....</b>	<b>67</b>
<b>Discussion.....</b>	<b>69</b>
<b>Acknowledgments.....</b>	<b>71</b>
<b>Disclosure statement.....</b>	<b>71</b>
<b>Funding.....</b>	<b>71</b>
<b>Orcid.....</b>	<b>71</b>
<b>References.....</b>	<b>71</b>
<b>Support material.....</b>	<b>74</b>
<b>CAPÍTULO 4. Mammalian defaunation in Devonian kniferidges and meridional plateaus of the Brazilian Atlantic Rainforest.....</b>	<b>91</b>
<b>Abstract.....</b>	<b>92</b>
<b>Introduction.....</b>	<b>93</b>
Material and methods.....	94
Study area.....	94
Mammal sampling and functional groups.....	95
Landscape characterization.....	97
Data analysis.....	97
<b>Results.....</b>	<b>98</b>
<b>Discussion.....</b>	<b>99</b>
<b>Acknowledgments.....</b>	<b>101</b>
<b>References.....</b>	<b>101</b>
<b>Support material.....</b>	<b>106</b>
<b>CONCLUSÃO GERAL.....</b>	<b>116</b>
<b>ANEXO A: Normas técnicas - revista Papéis Avulsos de Zoologia .....</b>	<b>118</b>
<b>ANEXO B. Normas técnicas - revista Biological Conservation.....</b>	<b>126</b>

## INTRODUÇÃO GERAL

Na biologia da conservação, o termo defaunação é utilizado como sinônimo da perda de espécies e populações de animais silvestres, bem como o declínio local da abundância de indivíduos (DIRZO et al., 2014). Apesar do termo já constar a mais de 25 anos no âmbito da conservação (*ver.* DIRZO e MIRANDA, 1990), a defaunação continua sendo um fenômeno amplamente pouco explorado (DIRZO et al., 2014) e entender a escala e as consequências da defaunação é uma prioridade crescente para ecologistas, gestores da vida selvagem e biólogos da conservação (YOUNG et al., 2016).

Os mecanismos que desencadeiam eventos de defaunação atuam em escala global (*e.g.*, mudanças climáticas e poluição de solo e água) e escalas locais, que incluem a caça comercial, introdução de espécies não nativas e conversão do habitat (DIRZO et al., 2014; YOUNG et al., 2016). Contudo, ainda não somos capazes de estabelecer um conjunto consistente de preditores universais de defaunação, particularmente em escalas locais (YOUNG et al., 2016). De maneira geral a defaunação pode afetar desproporcionalmente espécies de maior porte e baixa taxa reprodutiva, por exemplo, os grandes mamíferos (CARDILLO et al., 2005).

Mamíferos de médio e grande porte desempenham papéis importantes para a manutenção e equilíbrio dos ecossistemas florestais, mediante vários serviços ecológicos realizados por este grupo (STONER et al., 2007; MARKL et al., 2012). Isso inclui controle populacional de presas, polinização de plantas e dispersão de sementes, contribuindo para a regeneração das florestas (TERBORGH et al. 1999; GALETTI et al., 2015; DERHÉ et al., 2018). Sendo assim as consequências ecológicas de sua defaunação pode interferir em diferentes escalas ecológicas promovendo efeitos em cascata na abundância, composição e ecologia de outras espécies da fauna e flora (KURTEN, 2013; DIRZO et al., 2014).

Nas florestas tropicais as populações de mamíferos apresentam as maiores taxas de declínio em relação a outros lugares do mundo (DIRZO et al., 2014; BOGONI et al., 2018), sendo possível observar eventos crônicos e repetidos de defaunação (*i.e.*, defaunações locais). Como mencionado anteriormente, em escalas locais a defaunação é principalmente relacionada a perda e conversão do

habitat decorrentes da urbanização, mudanças no uso da terra para fins agrícolas, desenvolvimento de estradas, exploração de madeira, mineração e caça furtiva (DIRZO et al., 2014; YOUNG et al., 2016).

No Brasil, a Mata Atlântica é considerada um dos biomas mais afetados pelos processos de fragmentação e conversão de uso de terra (RIBEIRO et al., 2009). Devido à fragmentação e drástica redução da cobertura florestal que ocorreram neste bioma, as assembleias de mamíferos residem atualmente em remanescentes de florestas nativas tipicamente menores que 100 hectares e imersos em matrizes antropogênicas (RIBEIRO et al., 2009). Estima-se que 96% de todo o bioma da Mata Atlântica esteja sujeito a alguns efeitos de cascatas tróficas devido à defaunação de mamíferos (JORGE et al., 2013). Os principais impulsionadores da defaunação em toda a Mata Atlântica incluem uma longa e repetida história de pressão de caça, conversão e fragmentação de habitats, ou a combinação sinérgica de ambos (BOGONI et al., 2018).

O aumento da malha viária brasileira do último século é outro fator que deve ser considerado como causa direta para o declínio de populações de mamíferos terrestres em diversos biomas. As estradas são responsáveis por diversas mudanças ambientais, resultando em um grande impacto nas paisagens naturais (LAURANCE et al., 2014). O atropelamento é o principal impacto negativo das estradas na vida selvagem, com efeitos diretos nas populações locais, influenciando a abundância e distribuição das espécies (EIGENBROD et al., 2008). Os declínios populacionais causados pelos impactos das estradas têm efeitos sobre a variabilidade e viabilidade genética das espécies (JACKSON e FAHRIG, 2011). Estima-se que 5 milhões de animais de médio e grande porte são mortos anualmente nas estradas e rodovias do Brasil (CBEE, 2019), provando este ser um fator direto de mortalidade entre os vertebrados terrestres tão significativos quanto a caça (SEILER e HELDIN, 2006).

O impacto decorrente a introdução de espécies não nativas é outro fator citado com frequência como precursor do declínio de populações de fauna silvestre. Espécies invasoras representam uma das ameaças mais significativas à biodiversidade global e à função dos ecossistemas (CLOUT e RUSSELL 2007; YOUNG et al., 2016). De todos os animais extintos para

os quais a causa da extinção foi determinada, 54% incluíram efeitos de espécies invasoras (CLAVERO e GARCÍA-BERTHOU, 2005). As espécies exóticas invasoras comprometem as interações ecológicas nos ecossistemas, afetando negativamente as espécies nativas através da competição direta por recursos (GALETTI et al., 2015), indireta ou aparente (mediada por parasitas e patógenos) (LONG, 2003) predação (DA ROSA et al., 2017), modificação no habitat e alterações dos ciclos de nutrientes nas águas (LONG, 2003; CLOUT e RUSSELL 2007).

Na Mata Atlântica brasileira, estudos em escala regional demonstraram elevados níveis de defaunação em assembleias de mamíferos (GALETTI et al., 2006; CANALLE et al., 2012; BOGONI et al., 2016; GALETTI et al., 2017). A maioria dos estudos que avaliaram a defaunação na Mata Atlântica é concentrada nas regiões Centro-Oeste, Sudeste e Nordeste do Brasil (GALETTI et al., 2006, 2017; CANALE et al., 2012). Portanto, para a porção sul deste bioma ainda são escassas informações sobre os efeitos da conversão de habitats no declínio de mamíferos de médio e grande porte.

O presente estudo buscou investigar mecanismos relacionados ao declínio de mamíferos em remanescentes de Mata Atlântica do Sul do Brasil. Consideramos os precursores relacionados a defaunação em escala local (*e.g.*, introdução de espécies não nativas e conversão do habitat). Neste sentido, este estudo está dividido em quatro capítulos. Capítulo 1: inicialmente apresentamos o inventário da mastofauna de médio e grande porte do Parque Nacional dos Campos Gerais, PR. Consideramos que conhecimento sobre a diversidade e a distribuição das espécies é essencial para os estudos de ecologia e conservação (OLIVEIRA et al., 2017), sendo esta a primeira ferramenta necessária para a mensuração da defaunação em escala local. Capítulo 2: nesta sessão avaliamos o impacto de uma rodovia de pequeno porte (PR-445) sobre a mastofauna de uma região de Mata Atlântica considerada densamente fragmentada. Considerando os declínios populacionais causados por atropelamentos em estradas têm efeitos tão significativos quanto a caça (SEILER e HELLDIN, 2006). Capítulo 3: Sabendo que um dos fatores relacionados a eventos de defaunação é a introdução/estabelecimento de espécies não nativas em novas áreas, neste capítulo o objetivo foi entender a distribuição geográfica de *Myocastor coypus* (rato-do-banhado), e indicar áreas de maior

risco de estabelecimento, baseadas em preditores bioclimáticos e um mapa de vigilância. Capítulo 4: Por fim o último capítulo avaliamos efeitos da conversão do habitat em relação ao declínio de mamíferos de médio e grande porte da Mata Atlântica Sul, através do índice de defaunação.

## REFERÊNCIAS

- BOGONI, J. A. et al. Landscape features lead to shifts in communities of medium- to large-bodied mammals in subtropical Atlantic Forest. **Journal of Mammalogy**, v. 97, n. 3, p. 713–725, 2016.
- BOGONI, J. A. et al. Wish you were here: How defaunated is the Atlantic Forest biome of its medium- to largebodied mammal fauna? **PLoS ONE**, v. 13, n. 9, p. 1–23, 2018.
- CANALE, G. R. et al. Pervasive defaunation of forest remnants in a tropical biodiversity hotspot. **PLoS ONE**, v. 7, n. 8, 2012.
- CARDILLO, M. et al. Evolution: Multiple causes of high extinction risk in large mammal species. **Science**, v. 309, n. 5738, p. 1239–1241, 2005.
- CENTRO BRASILEIRO DE ESTUDOS EM ECOLOGIA DE ESTRADAS (CBEE). 2019. Disponível em: <http://cbee.ufra.br/portal/atropelometro/>.
- CLAVERO, M.; GARCÍA-BERTHOU, E. Invasive species are a leading cause of animal extinctions. **Trends in Ecology and Evolution**, v. 20, n. 3, p. 110, 2005.
- CLOUT, M. N.; RUSSELL, J. C. The invasion ecology of mammals: A global perspective. **Wildlife Research**, v. 35, n. March, p. 180–184, 2007.
- DA ROSA, C. A. et al. Alien terrestrial mammals in Brazil: current status and management. **Biological Invasions**, v. 19, n. 7, p. 2101–2123, 2017.
- DERHÉ, M. A. et al. Recovery of mammal diversity in tropical forests: a functional approach to measuring restoration. **Restoration Ecology**, v. 26, n. 4, p. 778–786, 2018.
- DIRZO, R.; MIRANDA, A. Contemporary Neotropical Defaunation and Forest to Structure, John and Diversity Sequel Terborgh. **Conservation Biology**, v. 4, n. 4, p. 444–447, 1990.
- DIRZO, R. et al. Defaunation in the Anthropocene. **Science**, v. 345, n. 6195, p. 401–406, 2014.

- EIGENBROD, F.; HECNAR, S. J.; FAHRIG, L. Accessible habitat: An improved measure of the effects of habitat loss and roads on wildlife populations. **Landscape Ecology**, v. 23, n. 2, p. 159–168, 2008.
- GALETTI, M. et al. Seed survival and dispersal of an endemic Atlantic forest palm: The combined effects of defaunation and forest fragmentation. **Botanical Journal of the Linnean Society**, v. 151, n. 1, p. 141–149, 2006.
- GALETTI, M.; BOVENDORP, R. S.; GUEVARA, R. Defaunation of large mammals leads to an increase in seed predation in the Atlantic forests. **Global Ecology and Conservation**, v. 3, p. 824–830, 2015.
- GALETTI, M. et al. Defaunation and biomass collapse of mammals in the largest Atlantic forest remnant. **Animal Conservation**, v. 20, n. 3, p. 270–281, 2017.
- JACKSON, N. D.; FAHRIG, L. Relative effects of road mortality and decreased connectivity on population genetic diversity. **Biological Conservation**, v. 144, n. 12, p. 3143–3148, 2011.
- JORGE, M. L. S. P. et al. Mammal defaunation as surrogate of trophic cascades in a biodiversity hotspot. **Biological Conservation**, v. 163, p. 49–57, 2013.
- KURTEN, E. L. Cascading effects of contemporaneous defaunation on tropical forest communities. **Biological Conservation**, v. 163, p. 22–32, 2013.
- LAURANCE, W. F. et al. A global strategy for road building. **Nature**, v. 513, n. 7517, p. 229–232, 2014.
- LONG, J. L. Introduced mammals of the world—their history, distribution and influence. **Csiro Publishing, Collingwood**. 2013.
- MARKL, J. S. et al. Meta-Analysis of the Effects of Human Disturbance on Seed Dispersal by Animals. **Conservation Biology**, v. 26, n. 6, p. 1072–1081, 2012.
- OLIVEIRA, U. et al. Biodiversity conservation gaps in the Brazilian protected areas. **Scientific Reports**, v. 7, n. 1, p. 1–9, 2017.

- RIBEIRO, M. C. et al. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. **Biological Conservation**, v. 142, n. 6, p. 1141–1153, 2009.
- SEILER, A.; HELLDIN, J.-O. Mortality in wildlife due to transportation. *In*: Devenport J. (Eds) **Devenport JL, The Ecology of Transportation: Managing Mobility for the Environment**. Netherlands, Springer, p. 165–189, 2006.
- STONER, C. et al. Changes in large herbivore populations across large areas of Tanzania. **African Journal of Ecology**, v. 45, n. 2, p. 202–215, 2007.
- TERBORGH, J. et al. (1999) The role of top carnivores in regulating terrestrial ecosystems. *In*: Soule ME, Terborgh J. (Eds) **Continental Conservation: Scientific Foundations of Regional Reserve Networks**. Washington DC,, Island Press, p. 39–64, 1999.
- YOUNG, H. S. et al. Patterns, Causes, and Consequences of Anthropocene Defaunation. **Annual Review of Ecology, Evolution, and Systematics**, v. 47, n. 1, p. 333–358, 2016.

## CAPÍTULO 1

### Checklist of medium-sized to large mammals of Campos Gerais National Park, Paraná, Brazil

Alan Deivid Pereira, Sergio Bazilio, Mário Luís Orsi

Capítulo redigido e publicado segundo as normas do periódico *Check List: the journal of biodiversity data*, disponível em: <https://doi.org/10.15560/14.5.785>



# Checklist of medium-sized to large mammals of Campos Gerais National Park, Paraná, Brazil

Alan Deivid Pereira<sup>1</sup>, Sergio Bazilio<sup>2</sup>, Mário Luís Orsi<sup>3</sup>

**1** Programa de Pós-Graduação em Ciências Biológicas, AC: Biodiversidade e Conservação de Habitats Fragmentados. Universidade Estadual de Londrina, Centro de Ciências Biológicas, Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 – Londrina, Paraná, Brazil. **2** Universidade Estadual do Paraná – UNESPAR, Campus de União da Vitória. Caixa Postal 241, CEP 84600-970, União da Vitória, PR, Brazil. **3** Laboratório de Ecologia de Peixes e Invasões Biológicas. Universidade Estadual de Londrina, Centro de Ciências Biológicas, Departamento de Biologia Animal e Vegetal, Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 – Londrina, Paraná, Brazil

**Corresponding author:** Alan Deivid Pereira, [alandeivid\\_bio@live.com](mailto:alandeivid_bio@live.com)

---

## Abstract

Campos Gerais National Park lies within the Brazilian Atlantic Rainforest, a biodiversity hotspot and a priority for conservation. Current analysis, featuring a list of large and medium-sized mammal species in the park, was conducted between July 2013 and July 2014 and between May 2016 and April 2017. With a 780-hour sampling effort in active research and 157,516 hours in camera traps, 31 species of 17 families and 8 orders were recorded. Furthermore, 42% of recorded mammals in the park proved to be endangered species at state, national, or international levels. Two exotic and 1 domestic species were reported in the park. Results contribute towards an in-depth knowledge of the fauna in south Brazil and may help in further research work and management, complying with conservation proposals in the biodiversity of the Campos Gerais region in the state of Paraná, Brazil.

## Key words

Atlantic Rainforest; conservation; inventories; Mixed Ombrophilous Forest; species richness; tropical forest.

---

**Academic editor:** Átilla Colombo Ferregueti | Received 19 May 2018 | Accepted 7 August 2018 | Published 28 September 2018

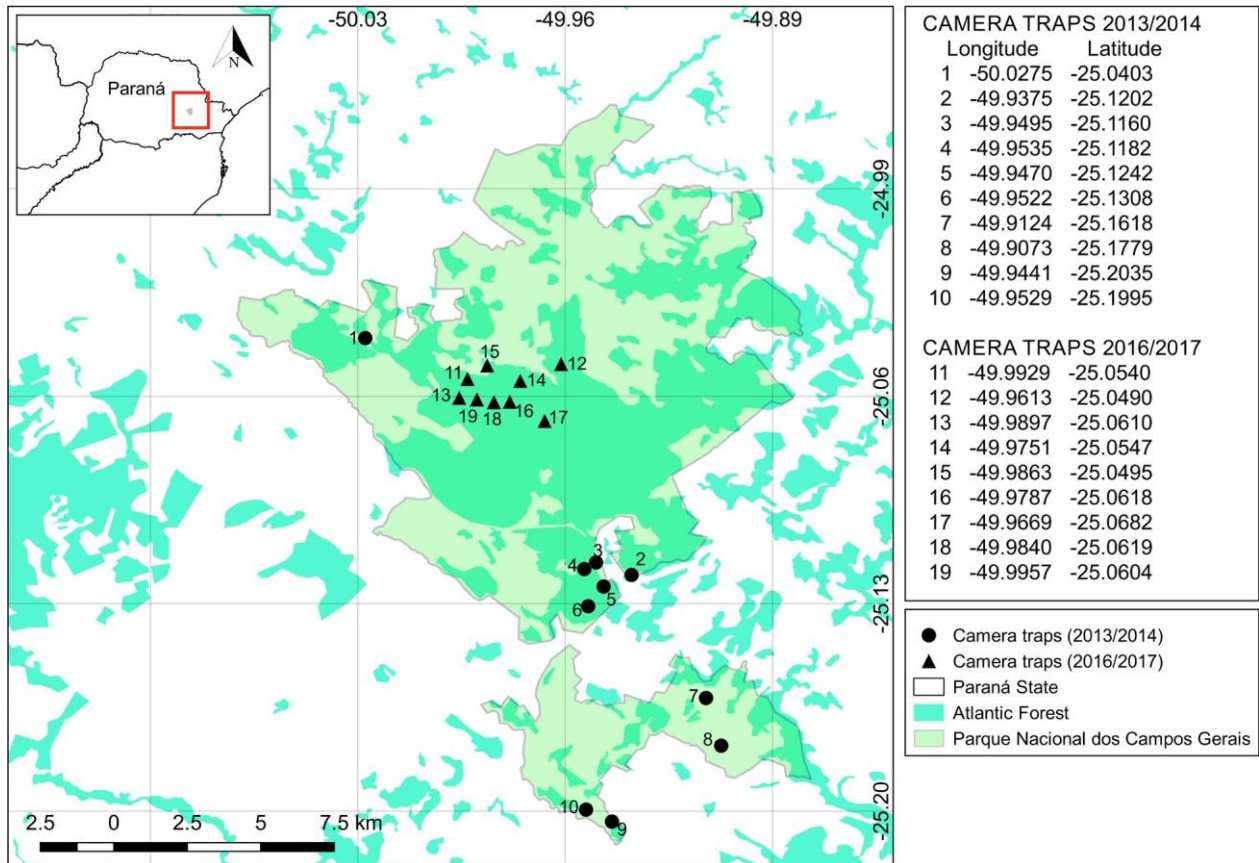
**Citation:** Pereira AD, Bazilio S, Orsi LM (2018) Checklist of medium-sized to large mammals of Campos Gerais National Park, Paraná, Brazil. *Check List* 14 (5): 785–799. <https://doi.org/10.15560/14.5.785>

---

## Introduction

The Brazilian Atlantic Rainforest Biome, which has only 12.4% of its original cover area, represented mostly by fragments less than 100 ha in area (SOS Mata Atlântica and INPA 2018), is a biodiversity hotspot and priority area for conservation (Myers et al. 2000). It is estimated that more than 298 mammal species are extant in the Atlantic Rainforest, with approximately 100 animals with an adult body mass of at least 1 kg, or rather, medium-sized and large animals (Paglia et al. 2012, Reis et al. 2014).

Mammals have an important role in the maintenance and equilibrium of forest ecosystems (Miller et al. 2001, Magioli et al. 2015), with several ecological services. These comprise prey population control, plant pollination and seed dispersal, contributing towards the regeneration of forests (Terborgh et al. 1999, Galetti et al. 2015, Derhé et al. 2017). However, owing to anthropogenic forest fragmentation, modification of habitats, introduction of exotic species and other factors, several species of this group are endangered in many Brazilian states (MMA 2014, IUCN 2018). The above factors plus hunting



**Figure 1.** Map of the Parque Nacional dos Campos Gerais, state of Paraná, Brazil, with monitoring sites by camera traps during the 2013–2014 and 2015–2017 sampling periods.

activities (Oliveira and Cassaro 2006) lead to loss of biodiversity, which cause the near extinction of several species (Mazzolli 2005).

The establishment of conservation units comprises a type of action taken by the Brazilian government for the preservation of biodiversity (SNUC 2000). Conservation units have several aims, such as the protection of terrestrial and marine ecosystems, the safeguarding of endangered species at the regional and national levels and defending the region's flora and fauna. In fact, conservation should exist parallel to the aims of forest production (SNUC 2000). National Parks (PARNA in Portuguese) feature among the models of conservation units. In fact, the aim of PARNAs is to protect the nature, subsidizing the natural sciences, allowing for tourist visits, and preserving forest and biodiversity for future generations (SNUC 2000). The state of Paraná, Brazil, is currently responsible for 5 National Parks, namely Parque Nacional do Iguaçu, Parque Nacional do Superagui, Parque Nacional de Ilha Grande, Parque Nacional Saint-Hilaire/Lange, and Parque Nacional dos Campos Gerais. The latter was the last to be established (Oliveira 2012).

Although the Parque Nacional dos Campos Gerais was established in 2006 to preserve remnants of the Mixed Ombrophilous Forest and native woods in the state of Paraná (Oliveira 2012), no inventory of medium-sized and large mammals has been produced after 12 years. There is a knowledge gap for the Paraná Devonian

Escarpment, as the region is scientifically called.

Increasing changes in land use and occupation, and low representativeness of protected areas, rank the ecosystems of the Campos Gerais among the most endangered in the Brazil (Almeida and Moro 2007). Because crucial requirements for the development of conservation actions depend on basic knowledge of species and their distribution (Kasper et al. 2007), and the Campos Gerais study area lacks deep scientific information on biodiversity, especially of medium-sized and large mammals, the current analysis provides a list of medium-sized and large mammals for Parque Nacional dos Campos Gerais, Paraná, Brazil.

## Methods

**Study area.** Parque Nacional dos Campos Gerais (hereafter PNCG), in the southern state of Paraná, Brazil, has an area of 21,298.91 hectares, partially covering areas in the municipalities of Ponta Grossa, Castro, and Carambeí. It lies on the Devonian Scarp region, with 2 sections on the first and second plateau of the Paraná (25°03.754' S, 049°57.693' W and 25°09.897' S, 049°56.281' W) (Oliveira 2012) (Fig. 1).

Yearly rainfall ranges between 100 and 300 mm, with the mean temperature at 17.8 °C (Maack 2017). Soils are constituted of acric red-yellow latosol and dystrophic haplic cambisol (Almeida and Moro 2007). Remnants

are frequently represented by almost circular patches of forests (regionally called “capões” in Portuguese), gallery forests or mixed woodland, particularly on slopes or diabase dikes (Moro 2001). The association between the Araucaria pine-tree forest and fields form the region’s typical landscape, combining significant forest areas and the last remnants of the Atlantic Rainforest (Maack 2017).

**Sampling.** Sampling occurred at 2 different stages, namely, between July 2013 and July 2014, (permit 37691-1 ICMBio for scientific activities) and between May 2016 and April 2017 (permit 53800-1 ICMBio), totaling more than 780 hours of search in approximately 815 km of trails and roads. The following methods were applied: (1) direct search for evidences using the active search method (Voss and Emmons 1996), which consists of walking at an average speed of 1 km/h, on trails and dirt roads, searching for direct (e.g., sightings, vocalizations) and indirect (e.g. footprints) evidences, and (2) camera traps.

The sand and clay soil in the park did not require sand plots to record footprints. Temporal independence of the samples or counting the number of recorded footprints by a single researcher at intervals of at least 300 m between the first footprint up to the next one, was avoided. Continuous sequences on the same road were avoided, following Pardini et al. (2004). Surveys were monthly, starting at 8:00 h and lasting for 4–6 hours, depending on the number of records. Footprints were identified in the field and photographed. They were based on measurements and print format, confirmed later by specific literature on the theme (e.g. Becker and Dalponte 2013, Reis et al. 2014).

Camera traps obtained information on nocturnal species and on those with difficult visualization, such as most medium-sized and large mammals (Srbek-Araujo and Chiarello 2013). Nineteen camera traps (Bushnell model) were distributed throughout the forest fragments, near water sprouts, on the treks and pathways of the park, taking into account the commonest trails used by species. Cameras were kept at a distance of at least 1 km and placed 50 cm above the ground on trees. The researchers also talked to local residents to complement information on their search on the species of the park. Camera traps were active during the 24 months of sampling, with a monthly change of memory cards and batteries during the study period. Sampling effort was equal to the number of camera traps multiplied by the number of sampling days (with 24 hours). An event was independent when there were (a) consecutive photographs by the same camera with an interval of at least 60 minutes and (b) non-consecutive photographs by the same camera (Srbek-Araujo and Chiarello 2013). Observations of species were opportunistically recorded in the study area to improve the species inventories obtained by camera-traps.

Species were identified by camera trap records and opportunistic photos based on specialized literature

(e.g. Oliveira and Cassaro 2006, Reis et al. 2011, 2014). Felines were identified by body size, pelage, nose, eyes and tail characteristics (for small felines) and by size and shape of footprint (for *Puma concolor* Linnaeus, 1771) (Oliveira and Cassaro 2006).

All the species with an adult body mass equal of 1 kg or more were considered medium-sized and large mammals (Reis et al. 2011) and included in the list. Conservation status was obtained for each species within state, country and international context (BRASIL 2010, MMA 2014, IUCN 2018). Trophic guild classification followed Reis et al. (2014). The taxonomic nomenclature followed Paglia et al. (2012). Furthermore, the recent distinction between *Leopardus guttulus* (Hensel, 1872) and *Leopardus tigrinus* (Schreber, 1775) in southern and southeastern Brazil was acknowledged (Trigo et al. 2013). Patton et al. (2015) was consulted for xenarthrans and rodents.

**Data analysis.** Records of footprints, camera traps and visual searches together made up the data for the list. Footprint records and photographs were separated to estimate expected richness according to different methodologies. By separating footprint and camera-trap records, 2 rarefaction curves of mammal species were drawn, with 1,000 randomizations and first-order jackknife (Jackknife 1) estimator by EstimateS 8.2 (Colwell 2009).

## Results

We recorded 31 medium-sized and large mammal species, distributed in 17 families and 8 orders (Figs 2–30; Table 1). Twenty-four species were recorded in 2013–2014 sampling, to which 7 additional species were added from the 2016–2017 surveys (Table 1). Twelve species belonged to the order Carnivora and 5 species from orders Rodentia and Cetartiodactyla, followed by the orders Cingulata, Didelphimorphia, Pilosa, Primates and Lagomorpha, which had 2 species each (Table 1).

Species were distributed in 5 trophic guilds, or rather, 45.16% of the species were omnivorous, followed by carnivores, herbivores and frugivores (16.13% each) and insectivores (6.45%) (Table 1). Among the species recorded in current study, 11 (35.4%) were threatened at the state level; 8 (25.8%) at the national level; 6 species (19.3%) at the international level (Table 1). There were also 2 exotic species (*Lepus europaeus* (Pallas, 1778) and *Sus scrofa* Linnaeus, 1758) and a domestic one (*Canis lupus familiaris*) present in PNCG.

Following the methodology in the current study, 54 footprint registrations were observed, with 10 species identified. Estimated richness was  $12.7 \pm 1.37$  species (Fig. 31). Furthermore, 16 species were recorded by opportunistic observations and 2 species of primates were identified by vocalization (Table 1).

Camera-trap sampling efforts from the 2013/2014 and 2016/2017 campaigns totaled 80,016 and 77,500 camera hours, respectively. Total sampling effort amounted to



Figures 2-7. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. 2. *Didelphis albiventris*. 3. *Didelphis aurita*. 4. *Myrmecophaga tridactyla*. 5. *Tamandua tetradactyla*. 6. *Dasypus novemcinctus*. 7. *Euphractus sexcinctus*

157,516 camera trap hours and 26 recorded species with an estimated richness of  $35 \pm 1.56$  (Fig. 31).

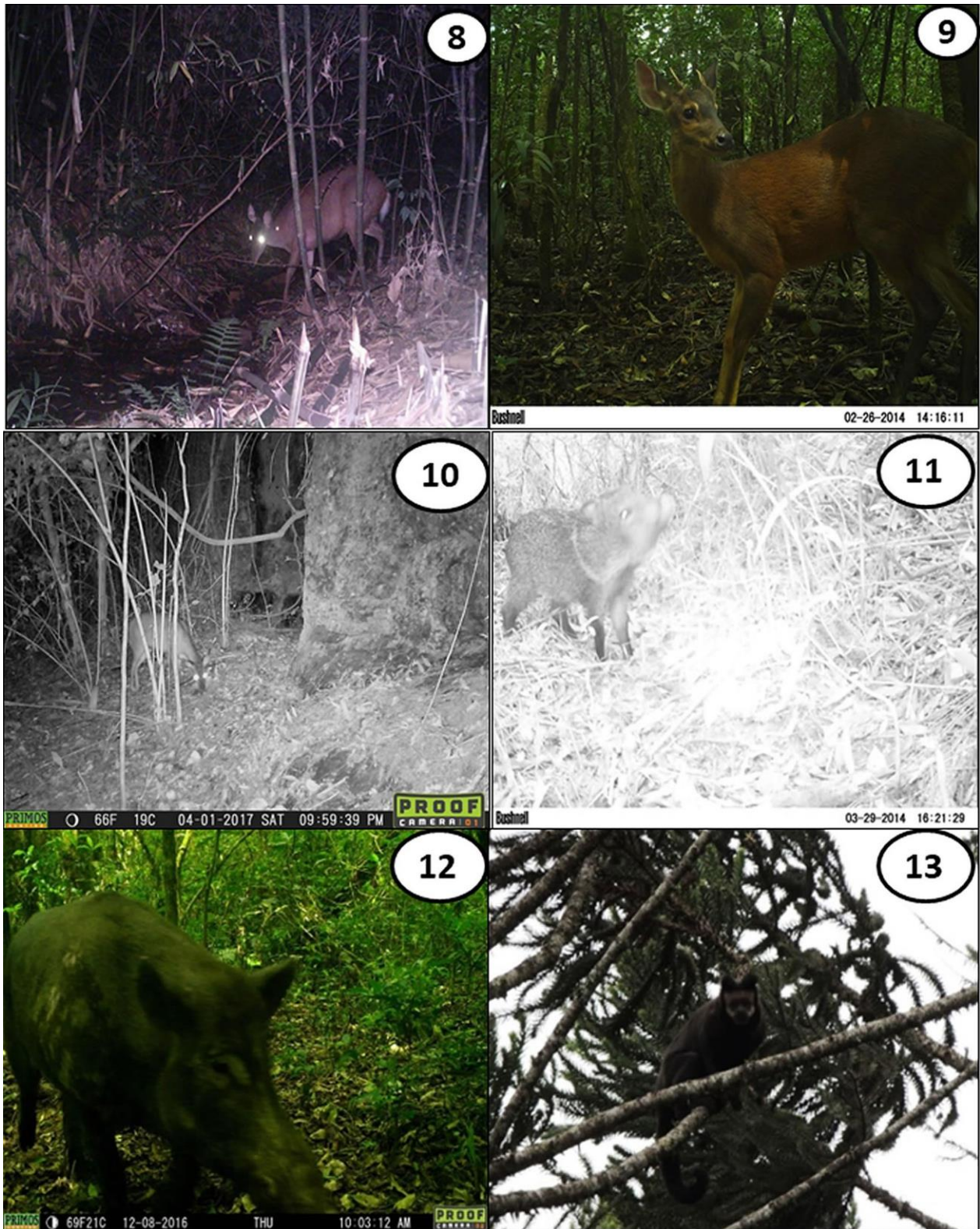
#### Annotated list

Didelphimorphia  
Didelphidae

#### *Didelphis albiventris* Lund, 1840

Figure 2

**Records.** First record was in July 09, 2013, camera trap 6 ( $25^{\circ}07.27' S$ ,  $049^{\circ}56.49' W$ ) and subsequently in the monitoring sites (camera traps 1, 2, 3, 4, 11, 12, 13, 14, 15, 16, 17, 19 and 19, see Fig. 1 for coordinates).



Figures 8-13. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. 8. *Mazama gouazoubira*. 9. *Mazama americana*. 10. *Mazama nana*. 11. *Pecari tajacu*. 12. *Sus scrofa*. 13. *Sapajus nigritus*.

**Identification.** *Didelphis albiventris* has totally white or black-tipped ears with whitish tips and no hair; face with yellowish-white coat with black spots around the eyes and a conspicuous stain on the central region of the head.

*Didelphis aurita* (Wied-Neuwied, 1826)  
Figure 3

**Records.** First record was in August 06, 2013, camera trap 3 (25°03.59 S, 049°57.26 W) and subsequently in the monitoring sites (camera traps 1, 2, 9 and 11, see Fig. 1 for coordinates).

**Identification.** *Didelphis aurita* has black hairless ears; variable head color, ranging from black to yellow. Black spots on the eyes and dark coloration on the dorsal region.



Figures 14-19. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. 14. *Alouatta guariba clamitans*. 15. *Cerdocyon thous*. 16. *Canis lupus familiaris*. 17. *Leopardus pardalis*. 18. *Leopardus guttulus*. 19. *Leopardus wiedii*.

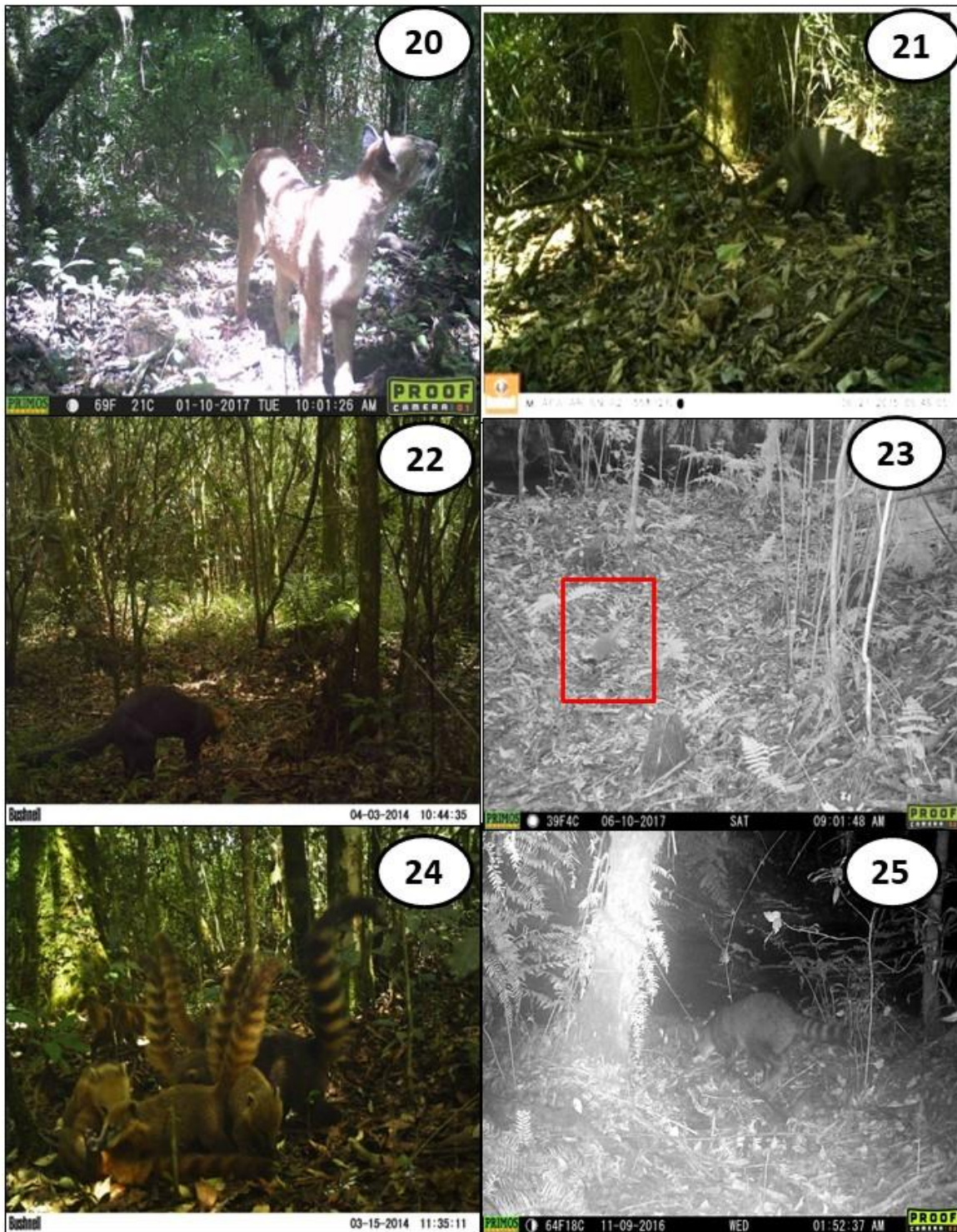
Pilosa  
Myrmecophagidae

***Myrmecophaga tridactyla* Linnaeus, 1758**

Figure 4

**Records.** First record was in August 08, 2016, camera trap 18 (25°03.37' S, 049°59.44' W) and subsequently in the same monitoring site.

**Identification.** Two species of anteaters are known in the region of PNCG, with each having different body size and color pattern of pelage. *Myrmecophaga tridactyla* is a large species and weighs up to 45 kg. It has small ears and small eyes, long snout and an extremely long tongue; the thick pelage varies from dark gray and black, but with the paws white paws and some black bands at the top. The tail is robust and covered by hair.



Figures 20-25. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. 20. *Puma concolor*. 21. *Puma yagouaroundi*. 22. *Eira barbara*. 23. *Galictis cuja*. 24. *Nasua nasua*. 25. *Procyon cancrivorus*.

*Tamandua tetradactyla* (Linnaeus, 1758)

Figure 5

**Records.** First record was in August 08, 2016, camera trap 11 (25°03.04' S, 049°59.33' W) and subsequently in the same monitoring site.

**Identification.** This is a smaller species, with an elongated snout and tongue (Fig. 5) and short, dense and

pale-yellow pelage. There are 2 black stripes on the scapular region towards the posterior region of the animal.

Cingulata  
Dasypodidae

*Dasyus novemcinctus* Linnaeus, 1758

Figure 6



Figures 26-30. Photographs of the medium-sized and large mammal species recorded in the Parque Nacional dos Campos Gerais, state of Paraná, Brazil. 26. *Lepus europaeus*. 27. *Cuniculus paca*. 28. *Dasyprocta azarae*. 29. *Coendou spinosus*. 30. *Guerlinguetus brasiliensis*.

**Records.** First record was in July 10, 2013, camera trap 1 (25°02.25' S, 050°01.39' W) and subsequently in the monitoring sites (camera traps 2, 3, 4, 7 and 11, see Fig. 1 for coordinates).

**Identification.** The species differentiation was based on characteristics of carapace that covers the body of the animals. Species-based variations exist in the moving bands

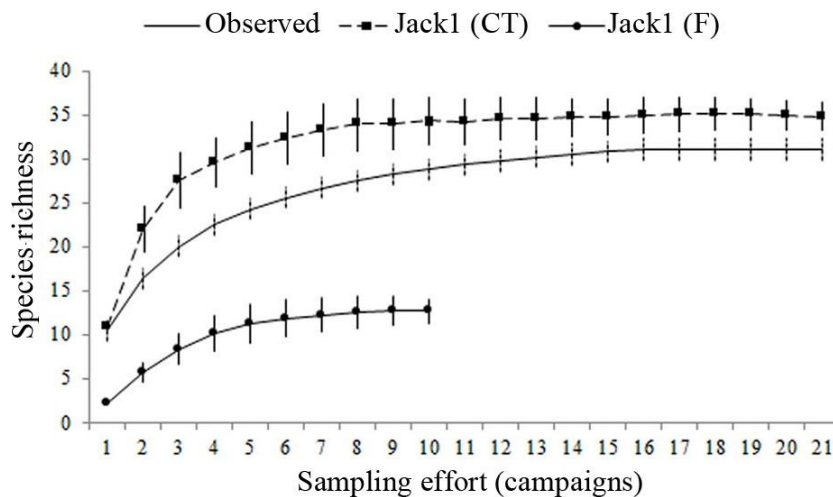
located in the median region of the body. *Dasypus novemcinctus* has long, pointed ears, about 50% of the length of the head, which has a pinkish-yellow plaque (Fig. 6); dark carapace, with yellowish dermal shields. Although 9 mobile bands are extant, the number may range from 8 to 11.

*Euphractus sexcinctus* Linnaeus, 1758

Figure 7

**Table 1.** List of land medium-sized and large mammal species at the Parque Nacional dos Campos Gerais, Brazil. Record method; Footprint (F), Visualization (VI), Camera traps (CT), Vocalization (VO). Conservation status by (IUCN), Brazilian List of Threatened Species (BR), Paraná state List of Threatened Species (PR). Data Deficient (DD), Endangered (EN), Least Concern (LC), Not evaluated (NE), Near Threatened (NT), Vulnerable (VU) and Critically Endangered (CR). Species added in 2016 to 2017 (+). Exotic species (\*). Small species (\*\*).

Taxon	Record	Trophic guild	Conservation status		
			IUCN	BR	PR
<b>Didelphimorphia</b>					
<b>Didelphidae</b>					
<i>Didelphis albiventris</i> Lund, 1840	VI-CT	Omnivore	LC	NE	LC
<i>Didelphis aurita</i> (Wied-Neuwied, 1826)	CT	Omnivore	LC	NE	LC
<b>Pilosa</b>					
<b>Myrmecophagidae</b>					
<i>Myrmecophaga tridactyla</i> Linnaeus, 1758*	CT	Insectivore	VU	VU	CR
<i>Tamandua tetradactyla</i> (Linnaeus, 1758)*	CT	Insectivore	LC	NE	LC
<b>Cingulata</b>					
<b>Dasypodidae</b>					
<i>Dasybus novemcinctus</i> Linnaeus, 1758	CT	Omnivore	LC	NE	LC
<i>Euphractus sexcinctus</i> Linnaeus, 1758	CT	Omnivore	LC	NE	LC
<b>Cetartiodactyla</b>					
<b>Cervidae</b>					
<i>Mazama americana</i> (Erxleben, 1777)	VI-CT	Herbivore	DD	NE	VU
<i>Mazama gouazoubira</i> (G. Fischer, 1814)	F-VI-CT	Herbivore	VU	VU	VU
<i>Mazama nana</i> (Hensel, 1872)*	CT	Herbivore	LC	NE	LC
<b>Tayassuidae</b>					
<i>Pecari tajacu</i> (Linnaeus, 1758)	CT	Omnivore	LC	LC	VU
<b>Suidae</b>					
<i>Sus scrofa</i> Linnaeus, 1758**	VI-CT	Omnivore	LC	NE	NE
<b>Primates</b>					
<b>Cebidae</b>					
<i>Sapajus nigritus</i> Goldfuss, 1809	VI-VO	Omnivore	NT	NE	DD
<b>Atelidae</b>					
<i>Alouatta guariba clamitans</i> (Humboldt, 1812)	VI-VO	Omnivore	LC	VU	NT
<b>Carnivora</b>					
<b>Canidae</b>					
<i>Canis lupus familiaris</i> Linnaeus 1758*	F-VI-CT	Omnivore	NE	NE	NE
<i>Cerdocyon thous</i> (Linnaeus, 1766)	F-VI-CT	Omnivore	LC	NE	LC
<i>Chrysocyon brachyurus</i> (Illiger, 1815)*	F-VI	Omnivore	NT	VU	VU
<b>Felidae</b>					
<i>Leopardus pardalis</i> (Linnaeus, 1758)	F-CT	Carnivore	LC	NE	VU
<i>Leopardus guttulus</i> Hensel, 1872	CT	Carnivore	VU	VU	VU
<i>Leopardus wiedii</i> (Schinz, 1821)	CT	Carnivore	NT	VU	VU
<i>Puma concolor</i> (Linnaeus, 1771)	F-VI-CT	Carnivore	LC	VU	VU
<i>Puma yagouaroundi</i> (É. Geoffroy Saint-Hilaire, 1803)	VI-CT	Carnivore	LC	VU	DD
<b>Mustelidae</b>					
<i>Eira barbara</i> (Linnaeus, 1758)	CT	Omnivore	LC	NE	LC
<i>Galictis cuja</i> (Molina, 1782)*	CT	Omnivore	LC	NE	NE
<b>Procyonidae</b>					
<i>Nasua nasua</i> (Linnaeus, 1766)	VI-CT	Omnivore	LC	NE	LC
<i>Procyon cancrivorus</i> (G. [Baron] Cuvier, 1798)	F-CT	Omnivore	LC	NE	LC
<b>Lagomorpha</b>					
<b>Leporidae</b>					
<i>Lepus europaeus</i> Pallas, 1778*	F-VI	Herbivore	LC	NE	NE
<b>Rodentia</b>					
<b>Caviidae</b>					
<i>Hydrochoerus hydrochaeris</i> (Linnaeus, 1766)	F-VI	Herbivore	LC	NE	LC
<b>Cuniculidae</b>					
<i>Cuniculus paca</i> (Linnaeus, 1766)	F-CT	Frugivore	LC	NE	EN
<b>Dasyproctidae</b>					
<i>Dasyprocta azarae</i> Lichtenstein, 1823	CT	Frugivore	DD	NE	LC
<b>Erethizontidae</b>					
<i>Coendou spinosus</i> (F. Cuvier, 1823)*	VI-CT	Frugivore	LC	NE	LC
<i>Guerlinguetus brasiliensis</i> (Gmelin, 1788)**	VI-CT	Frugivore	LC	NE	LC



**Figure 31.** The rarefaction curve (observed and estimates by jackknife 1) of mammal species registered by identification of footprints and trap cameras. Vertical bars represent standard deviation. CT: Camera trap; F: footprints.

**Records.** Record was in May 01, 2014 camera trap 1 (25°02.25' S, 050°01.39' W).

**Identification.** *Euphractus sexcinctus* has 6 to 8 moving bands on the back of the carapace; there are 2 to 4 orifices in the region of the pelvic girdle near the base of the tail.

Cetartiodactyla  
Cervidae

***Mazama americana* (Erxleben, 1777)**

Figure 8

**Records.** First record was in July 26, 2013, camera trap 6 (25°07.51' S, 049°57.08' W) and subsequently in the monitoring sites (camera traps 5 and 11, see Fig. 1 for coordinates).

**Identification.** The identification of species of the genus Cervidae was based on differences in body size, coat color and distribution area. *Mazama americana* is the largest species of the genus in Brazil, medium to moderately large, a factor that helps in the differentiation of the species. It has a reddish coloration, with white spots below the tail, inner face of limbs and ears.

***Mazama gouazoubira* (G. Fischer, 1814)**

Figure 9

**Records.** First record was in July 30, 2013, camera trap 1 (25°02.25' S, 050°01.39' W) and subsequently in the monitoring sites (camera traps 2, 3, 5, 6, 7, 14 and 15, see Fig. 1 for coordinates).

**Identification.** *Mazama gouazoubira* is a smaller species when compared to *M. americana*, weighing between 17 and 23 kg. The coloration is quite varied, with brown, gray and reddish variations.

***Mazama nana* (Hensel, 1872)**

Figure 10

**Records.** Record was in May 17, 2016 camera trap 15 (25°03.36' S, 049°59.44' W).

**Identification.** *Mazama nana* is the smallest species, with weight not exceeding 15 kg. The skin is characterized by an intense bright reddish hue.

Cetartiodactyla  
Tayassuidae

***Pecari tajacu* (Linnaeus, 1758)**

Figure 11

**Records.** First record was in July 31, 2013, camera trap 6 (25°07.51' S, 049°57.08' W) and subsequently in the monitoring sites (camera traps 1, 2, 4, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19, see Fig. 1 for coordinates).

**Identification.** The identification of the Brazilian native pig *Pecari tajacu* (Linnaeus, 1758) was based on pelage characteristics. A collar formed by slightly clear hair may be observed around its neck, differentiating the species from other native pigs.

Suidae

***Sus scrofa* Linnaeus, 1758**

Figure 12

**Records.** First record was on May 5, 2013, camera trap 16 (25°03.37' S, 049°58.43' W) and subsequently in the monitoring sites (camera traps 1, 2, 4, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19, see Fig. 1 for coordinates).

**Identification.** *Sus scrofa* is a swine native to Europe, Africa and Asia. Featuring great individual variations in body size and pelage color, it was introduced in the area under analysis. Although *S. scrofa* may be confused with *P. tajacu*, the species is usually larger.

Primates  
Cebidae

***Sapajus nigritus* (Goldfuss, 1809)**

Figure 13

**Records.** First record was in May 17, 2014, monitoring site 3 (25°03.59' S, 049°57.26' W) 12 individuals were recorded by opportunistic observations and subsequently in the monitoring sites 1, 2 and 11 (see Fig. 1 for coordinates).

**Identification.** *Sapajus nigritus* has a generally black coloration, even though hue may vary by region. The face is pigmented, usually light brown, and the coat of the head is rather blacker.

Atelidae

*Alouatta guariba clamitans* Cabrera, 1940

Figure 14

**Records.** Record was in March 16, 2014, monitoring site 9 (25°12.12' S, 049°56.39' W) 7 individuals were recorded by opportunistic observations.

**Identification.** *Alouatta guariba clamitans* is larger than *S. nigritus*. Males have a uniform reddish color, while the color of females ranges from blackish to dark-brown. The face is pigmented in darker shades of gray.

Carnivora

Canidae

*Cerdocyon thous* (Linnaeus 1766)

Figure 15

**Records.** First record was in October 12, 2013, camera trap 3 (25°03.59' S, 049°57.26' W) and subsequently in the monitoring sites (camera traps 1, 2, see Fig. 1 for coordinates).

**Identification.** *Cerdocyon thous* was identified by its small size, and short, dense coat with a gray to brown hue.

*Chrysocyon brachyurus* (Illiger, 1815)

**Records.** Record was in May 12, 2016, monitoring site 11 (25°03.04' S, 049°59.33' W) 1 individual was recorded by opportunistic observations.

**Identification.** *Chrysocyon brachyurus* is larger, with a small head in relation to body, small ears and tapering muzzle, with a general brown-orange coloration at the tip of the muzzle and end of the black limbs. The latter was only identified through footprints and personal reports of residents of farms near the PNCG.

*Canis lupus familiaris* Linnaeus 1758

Figure 16

**Records.** First record was in July 13, 2013, camera trap 1 (25°02.25' S, 050°01.39' W) and subsequently in the monitoring sites (camera traps 3, 5, 7, 10, 12, 13, 14, 15, 16 and 19, see Fig. 1 for coordinates).

Felidae

*Leopardus pardalis* (Linnaeus, 1758)

Figure 17

**Records.** First record was in October 14, 2013, camera trap 3 (25°03.59' S, 049°57.26' W) and subsequently in the monitoring sites (camera traps 5, 12, 13, 15 and 19, see Fig. 1 for coordinates).

**Identification.** Five feline species were identified, based on patterns of body size and pelage. *Leopardus pardalis* was identified by its large body size, elongated rosettes pattern on the side of the body and a relatively smaller tail, when compared with other *Leopardus* species.

*Leopardus guttulus* (Hensel, 1872)

Figure 18

**Records.** First record was in January 28, 2014, camera trap 6 (25°07.51' S, 049°57.08' W) and subsequently in the monitoring sites (camera traps 5, 13, 14, 15, 17 and 18, see Fig. 1 for coordinates).

**Identification.** *Leopardus guttulus* was identified by its relatively smaller tail with narrow rings, pink nose and pattern of circular shapes and eyespots on the sides of the body that differentiated the species from *Leopardus wiedii*.

*Leopardus wiedii* (Schinz, 1821)

Figure 19

**Records.** First record was in July 29, 2013, camera trap 1 (25°02.25' S, 050°01.39' W) and subsequently in the monitoring sites (camera traps 3, 4, 5, 9 and 12, see Fig. 1 for coordinates).

**Identification.** *Leopardus wiedii* is characterized by a long tail, large eyes, protruding muzzle and large paws.

*Puma concolor* (Linnaeus, 1771)

Figure 20

**Records.** First record was in December 09, 2013, camera trap 2 (25°08.02' S, 049°56.17' W) and subsequently in the monitoring sites (camera traps 3, 11, 13, 14, 15, and 16, see Fig. 1 for coordinates).

**Identification.** *Puma concolor* is distinguishable by its short and uniform coat of brown color, ranging from light to reddish tones.

*Puma yagouaroundi* (É. Geoffroy Saint-Hilaire, 1803)

Figure 21

**Records.** First record was in October 11, 2013, camera trap 5 (25°07.27' S, 049°56.49' W) and subsequently in the monitoring sites (camera trap 7, see Fig. 1 for coordinates).

**Identification.** *Puma yagouaroundi* was identified by its monochromatic long body and tail.

Mustelidae

*Eira barbara* (Linnaeus, 1758)

## Figure 22

**Records.** First record was in July 17, 2013, camera trap 3 (25°03.59' S, 049°57.26' W) and subsequently in the monitoring sites (camera traps 1, 4, 5, 12, 13, 15, 16, 18 and 19, see Fig. 1 for coordinates).

**Identification.** Two mustelids were registered in the PNCG. The identification of these animals was based on the pattern of the 2 species, namely, long body, short limbs and long tail. In the case of *Eira barbara* the color of the coat is dark brown throughout the entire body, with a lighter brown for head and neck, with regional variations.

***Galictis cuja* (Molina, 1782)**

## Figure 23

**Records.** First record was in May 03, 2017, camera trap 18 (25°03.37' S, 049°59.44' W) and subsequently in the monitoring site 11 (see Fig. 1 for coordinates).

**Identification.** *Galictis cuja* is smaller in size than *E. barbara*; paws, belly, throat and face are black, with a yellowish back.

## Procyonidae

***Nasua nasua* (Linnaeus, 1766)**

## Figure 24

**Records.** First record was in July 13, 2013, camera trap 1 (25°02.25' S, 050°01.39' W) and subsequently in the monitoring sites (camera traps 2, 3, 4, 5, 6, 12, 13, and 15, see Fig. 1 for coordinates).

**Identification.** Two species of the family Procyonidae were registered. *Nasua nasua*, an exclusive species of South America, has an enlarged head tapering into a narrow and prolonged pointed snout. Coloration varies according to group, although the general pattern ranges between light and dark brown, with a generally striped tail.

***Procyon cancrivorus* (G. Cuvier, 1798)**

## Figure 25

**Records.** First record was in August 23, 2013, camera trap 3 (25°03.59' S, 049°57.26' W) and subsequently in the monitoring sites (camera traps 6 and 18, see Fig. 1 for coordinates).

**Identification.** *Procyon cancrivorus* is easily identified by its black mask that descends from the eyes to the base of the mandible; its tail is characterized by several dark rings.

## Lagomorpha

## Leporidae

***Lepus europaeus* (Pallas, 1778)**

## Figure 26

**Records.** First record was in October 07, 2013, monitor-

ing site 3 (25°03.59' S, 049°57.26' W) individuals were recorded by opportunistic observations and subsequently in the monitoring sites 7, 8 and 18 (see Fig. 1 for coordinates).

**Identification.** *Lepus europaeus* is a species of European origin introduced in South America. It is larger in size than the native *Sylvilagus brasiliensis* (Linnaeus, 1758), with long ears and legs; general brownish gray color on the upper parts and of a somewhat lighter hue on the lower part. The above characteristics distinguish the hair of *S. brasiliensis*.

## Rodentia

## Caviidae

***Hydrochoerus hydrochaeris* (Linnaeus, 1766)**

**Records.** Record was in November 29, 2013, monitoring site 7 (25°09.42' S, 049°59.44' W).

**Identification.** *Hydrochoerus hydrochaeris* is the largest rodent in the world, easily identifiable due to the shape of the head with short ears and hue ranging between reddish to grayish brown. The species was recorded based on the analysis of footprints and opportunistic observations (Table 1)

## Cuniculidae

***Cuniculus paca* (Linnaeus, 1766)**

## Figure 27

**Records.** First record was in July 12, 2013, camera trap 5 (25°07.27' S, 049°56.49' W) and subsequently in the monitoring sites (camera traps 1, 2, 3, 6, 7, 8, 9, 11, 12, 13, 17, 18 and 19, see Fig. 1 for coordinates).

**Identification.** *Cuniculus paca* is a medium-sized rodent. Identification of the species was based on the pattern of the coat, ranging between brownish-red and dark brown, with a pattern of whitish rounded spots in longitudinal lines.

## Dasyproctidae

***Dasyprocta azarae* Lichtenstein, 1823**

## Figure 28

**Records.** First record was in July 12, 2013, camera trap 5 (25°07.27' S, 049°56.49' W) and subsequently in the all monitoring sites (see Fig. 1 for coordinates).

**Identification.** *Dasyprocta azarae* is a large orange-brown rodent with a rounded back and long skinny legs. Although 9 species of the genus *Dasyprocta* have been described for Brazil, *D. azarae* is the only species with a record of occurrences for the state of Paraná.

## Erethizontidae

***Coendou spinosus* (F. Cuvier, 1823)**

## Figure 29

**Records.** Record was in May 22, 2016 camera trap 12 (25°02.55' S, 049°57.41' W) and by opportunistic observations in the same monitoring site.

**Identification.** *Coendou spinosus* was identified by coat and body shape. The coat is formed by a mixture of rigid, aculeiform (cylindrical 'spines') hairs and finer hairs. The former are longer than the latter ones. Coloration varies from yellowish to dark brown at the back.

Sciuridae

***Guerlinguetus brasiliensis* (Gmelin, 1788)**

Figure 30

**Records.** First record was in February 02, 2014, camera trap 5 (25°07.27' S, 049°56.49' W) and subsequently 2 individuals were recorded by opportunistic observations in the monitoring sites 1 and 7 (see Fig. 1 for coordinates).

**Identification.** The squirrel *Guerlinguetus brasiliensis* may be included among the native species. Although small in size, it is easily identifiable through photographs. The species is an average sized squirrel with occurrences recorded in the Atlantic Rainforest. It is distinguished from other squirrels due to its intermediate body size and such characteristics as voluminous tail, longer than or equal to the body.

## Discussion

Because Parque Nacional dos Campos Gerais has the largest phytophysionomy area of the Campos Gerais in Paraná (Maack 2017), it is highly important for the conservation of biodiversity. In fact, it harbors endemic and threatened species within its borders (Oliveira 2012). Species richness recorded by us corresponds to 56% of all medium-sized and large mammals with current occurrence for the state of Paraná (Reis et al. 2009) and approximately 31% of medium-sized and large mammals for the Atlantic Rainforest (Paglia et al. 2012, Reis et al. 2014). Although there is a stabilization of the species accumulation curve in our study (Fig. 34), other species may also occur in the park. In fact, sampling in 2016–2017 also included *M. tridactyla*, *T. tetradactyla*, *M. nana*, *S. scrofa*, *C. brachyurus*, *G. brasiliensis*, and *C. spinosus* to the final list. According to Srbek-Araujo and Chiarello (2007), periods longer than 250 days are sufficient for a faunal survey.

The species richness recorded in the PNCG is similar to that observed in other studies carried out in conservation units nearby. Borges (1989) reported 40 species of medium-sized to large mammals in Parque Estadual de Vila Velha, which is located 20 km from PNCG. In Reserva Biológica das Araucárias some 56 km from PNCG, the richness amounted to 28 species (D’Bastiani et al. 2018). In the Floresta Nacional de Irati, some 70 km from PNCG, 24 species of medium-sized to large mammals were recorded (Pereira and Bazilio 2014). Species

such as *M. nana*, *C. brachyurus*, and *M. tridactyla* were not recorded at the Reserva Biológica das Araucárias and Floresta Nacional de Irati. Although these species have been reported by Borges (1989) for Parque Estadual de Vila Velha, he also included in his records sampling areas that are now part of PNCG.

The order Carnivora, with 12 species, is the order most recorded in our study. According to Chiarello (2000), the group occurs with frequency in fragmented forest remnants. Species of Carnivora have great mobility and capacity in exploring man-disturbed environments close to native vegetation (Lyra-Jorge et al. 2010). *Chrysocyon brachyurus* was recorded by footprints and from accounts by farm workers near the park, is the largest South American canid, with adults weighing between 20 and 30 kg (Rodden et al. 2004). Although *C. brachyurus* is found mainly in the Campos Gerais region, it is there has been a reduction in its population numbers over the last decades. In fact, it has become scarce (Cherem and Perez 1996, Bazilio et al. 2011).

Five of the 7 species of felines in Paraná (Reis et al. 2009) occurred in the study area, specifically *L. guttulus*, *L. pardalis*, *L. wiedii*, *P. yagouaroundi*, and *P. concolor*. Our results corroborate those by Bastiani et al. (2015), who recorded practically the same species in the Floresta Nacional de Piraí (a 150 ha fragment some 83km distance from PNCG). The low detection of several species of felines, such as *L. guttulus* and *L. wiedii*, may be due to competition for resources with large felines (Oliveira et al. 2010).

The presence of medium-sized and large mammals carnivore and herbivore species in the area studied indicates that the characteristics of the forest fragment enhance ecological processes for its maintenance. Herbivore animals disperse and control plant populations, whilst carnivores maintain herbivore populations (Santos et al. 2004, Pardini et al. 2004).

Of the threatened species in the PNCG, the presence of *M. americana*, *M. nana*, *P. tajacu* and *C. paca* is especially important because of their high conservation status in the state of Paraná, which is linked to illegal hunting and trade in pelts (Cullen et al. 2000). PNCG offers protection for these and other species.

According to Mazzolli (2006), *P. tajacu* is indicative of environmental quality because it has a low tolerance for disturbed habitats, and as a corollary, its absence is suggestive of highly disturbed habitat. Desbiez et al. (2012) demonstrated that the overlap in food resources and habitat use in Brazil between feral pigs and *Tayassu pecari* (Link, 1795) were lower than expected. In the Brazilian Pantanal, Galetti et al. (2015) found a great overlap in diets of *T. pecari* and feral pigs, but less overlap between *P. tajacu* and feral pigs. Nevertheless, feral pigs may impact the natural community in several other ways, such as eating eggs, destroying by rooting, and serving as vectors for disease (Desbiez et al. 2012, Galetti et al. 2015).

The wild boar is in the list of 100 invading and heavily impacting species worldwide (Lowe et al. 2000). Loss of biodiversity and the extinction of native species caused by the introduction of wild pigs have already been documented (Wolf and Conover 2003). Competitive interaction with the wild boar mainly excludes peccaries (Gabor and Hellgren 2000, Galetti et al. 2015). At least 4 java pigs have been reported in the Alagadas Reservoir in northwestern PNCG. Piglets with spots characteristic of the java pig are common among other piglets with spots or common features of domestic pigs.

The domestic dog (*C. lupus familiaris*) has been recorded on trails and roads, as well as within forests in PNCG. The presence of domestic animals may have serious ecological consequences for native fauna in conservation units (Rangel and Neiva 2013, Doherty et al. 2017). The predation of wild fauna by almost savage domestic dogs is compounded by direct competition for resources with native carnivores (Galetti and Sazima 2006). Exotic species are nowadays acknowledged to be the secondmost important threat to biodiversity, but also cause economic losses and pose serious risks to human health (Dorcas et al. 2012).

In the wake of processes that alter habitat, knowledge of biodiversity in conservation units is a basic requirement for management plans, proposals for conservation, and studies on ecological patterns and species distribution, (Silveira et al. 2010, Oliveira et al. 2017). Our study demonstrates the importance of PNCG as a haven for Paraná's medium-sized and large mammals. However, the occurrence of exotic and domestic species and the presence of hunters in the conservation unit underscore the need for more surveillance and monitoring, the repression of hunting, the control of exotic species, and the development of environmental education within the local community.

## Acknowledgements

We thank the ICMBio team of the Parque Nacional dos Campos Gerais for its support in our research. Thanks are due to Juliane Coimbra Bczuska, Denise Bener, and Elvira D'Bastiani for their assistance in data collection. Thanks are also due to the Coordination for the Upgrading of Higher Education Personnel (Capes), the Araucária Foundation, and the Fundação Boticário for the Protection of Nature (in our second sampling year) for funding.

## References

- Almeida CG, Moro RS (2007) Análise da cobertura florestal no Parque Nacional dos Campos Gerais, Paraná, como subsídio ao seu plano de manejo. *Terr@ Plural* 1 (1): 115–122.
- Bastiani E, Bazilio S, Barros KF, Nabrzecki G (2015) Felinos da Floresta Nacional de Piraí do Sul, Paraná–Brasil. *Acta zoológica mexicana* 31 (1): 23–26.
- Bazilio S, Schemczssen Z, Marques AC (2011) Registro visual do lobo-guará, *Chrysocyon brachyurus* (Illiger, 1815) (Mammalia: Carnivora: Canidae) na Floresta Nacional de Três Barras, SC. *Biotemas* 22 (4): 133–137. <https://doi.org/10.5007/2175-7925.2009v22n4p133>
- Becker M, Dalponte JC (2013) *Rastros de mamíferos silvestres brasileiros – Um guia de campo*. Technical Books, Rio de Janeiro, 172 pp.
- Borges CRS (1989) *Composição mastofaunística do Parque Estadual de Vila Velha, Ponta Grossa, Paraná, Brasil*. Master thesis, Federal University of Curitiba, Curitiba, 358 p.
- BRASIL (2010) Publicado no Diário Oficial nº 8233, de 1 de junho de 2010. Reconhece e atualiza Lista de Espécies de Mamíferos pertencentes à Fauna Silvestre Ameaçadas de Extinção no Estado do Paraná e dá outras providências, atendendo o Decreto Nº 3.148, de 2004.
- Cherem JJ, Perez DM (1996). Mamíferos terrestres de floresta de araucária no município de Três Barras, Santa Catarina, Brasil. *Biotemas* 9 (2): 29–46.
- Chiarello AG (2000) Density and population size of mammals in remnants of Brazilian Atlantic Forest. *Conservation Biology* 14 (6): 1649–1657. <https://doi.org/10.1111/j.1523-1739.2000.99071.x>
- Colwell RK (2009) *EstimateS 8.2 User's Guide: Statistical estimation of species richness and shared species from samples*. Version 8.2. [http://priede.bf.lu.lv/ftp/pub/TIS/datu\\_analize/EstimateS/EstimateSUsersGuide.htm](http://priede.bf.lu.lv/ftp/pub/TIS/datu_analize/EstimateS/EstimateSUsersGuide.htm) Accessed on: 2017-12-12.
- Cullen JRL, Bodmer RE, Pádua CV (2000) Effects of hunting in habitat fragments of the Atlantic Forest, Brazil. *Biological Conservation* 95 (1): 49–56. [https://doi.org/10.1016/S0006-3207\(00\)00011-2](https://doi.org/10.1016/S0006-3207(00)00011-2)
- Derhé MA, Murphy HT, Preece ND, Lawes MJ, Menéndez R (2017) Recovery of mammal diversity in tropical forests. *Restoration Ecology* 26 (4): 778–786. <https://doi.org/10.1111/rec.12582>
- Desbiez ALJ, Santos SA, Keuroghlian A, Bodmer RE (2012). Niche partitioning among white-lipped peccaries (*Tayassu pecari*), collared peccaries (*Pecari tajacu*), and feral pigs (*Sus scrofa*). *Journal of Mammalogy* 90 (1): 119–128. <https://doi.org/10.1644/08-MAMM-A-038.1>
- Doherty TS, Dickman CR, Glen AS, Newsome TM, Nimmo DG, Ritchie EG, Vanak AT, Wirsing AJ (2017) The global impacts of domestic dogs on threatened vertebrates. *Biological Conservation* 210: 56–59. <https://doi.org/10.1016/j.biocon.2017.04.007>
- Dorcas ME, Willson JD, Reed RN, Snow RW, Rochford MR, Miller MA, Meshaka WE, Andreadis PT, Mazzotti FJ, Romagosa CM, Hart KM (2012) Severe mammal declines coincide with proliferation of invasive Burmese pythons in everglades National Park. *Proceedings of the National Academy of Sciences* 109 (7): 2418–2422. <https://doi.org/10.1073/pnas.1115226109>
- Gabor TM, Hellgren EC (2000) Variation in peccary populations: landscape composition or competition by an invader? *Ecology* 81 (9): 2509–2524. [https://doi.org/10.1890/0012-9658\(2000\)081\[2509:VI PPLC\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2000)081[2509:VI PPLC]2.0.CO;2)
- Galetti M, Sazima I (2006) Impacto de cães ferais em um fragmento urbano de Floresta Atlântica no sudeste do Brasil. *Natureza & Conservação* 4 (1): 58–63.
- Galetti M, Camargo H, Siqueira T, Keuroghlian A, Donatti CI, Jorge MLSP, Pedrosa F, Kanda CZ, Ribeiro MC (2015) Diet Overlap and Foraging Activity between Feral Pigs and Native Peccaries in the Pantanal. *Plos ONE* 10: e0141459. <https://doi.org/10.1371/journal.pone.0141459>
- IUCN (2018) International Union for Conservation of Nature and Natural Resources. Red List of Threatened Species. Version 2018. <http://www.iucnredlist.org/>. Accessed on: 2018-12-1.
- Kasper CB, Mazim FD, Soares JBG, Oliveira TG, Fabián ME (2007) Composição e abundância relativa dos mamíferos de médio e grande porte no Parque Estadual do Turvo, Rio Grande do Sul, Brasil. *Revista Brasileira de Zoologia* 24 (4): 1087–1100. <https://doi.org/10.1590/S0101-81752007000400028>
- Lowe S, Browne M, Boudjelas S, Poorter M (2000) 100 of the world's worst invasive alien species a selection from the global invasive species database. Nova Zelandia: The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), Gland, 12 pp.

- Lyra-Jorge MC, Ribeiro MC, Ciochetti G, Tambosi LR, Pivello VR (2010) Influence of multi-scale landscape structure on the occurrence of carnivorous mammals in a human-modified savanna. *Brazilian Journal of Wildlife Research* 56 (3): 359–368. <https://doi.org/10.1007/s10344-009-0324-x>
- Maack R (2017) *Geografia Física do Estado do Paraná*. 4.ed. Editora UEPG, Ponta Grossa, 526 pp.
- Maglioli M, Ribeiro MC, Ferraz KMPMB, Rodrigues MG (2015) Thresholds in the relationship between functional diversity and patch size for mammals in the Brazilian Atlantic Forest. *Animal Conservation* 18 (6): 499–511 <https://doi.org/10.1111/acv.12201>
- Mazzolli M (2005) Efeito de gradientes de floresta nativa em sistemas agropecuários sobre a diversidade de mamíferos vulneráveis. Relatório Técnico, WWF, Brasília 26 pp.
- Mazzolli M (2006) Persistência e riqueza de mamíferos focais em sistemas agropecuários no planalto meridional brasileiro. PhD thesis, Federal University of Rio Grande do Sul, Porto Alegre, 105 pp.
- Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858. <https://doi.org/10.1038/35002501>
- Miller B, Dugelby B, Foreman D, Del Río CM, Noss R, Phillips M, Reading R, Soulé ME, Terborgh J, Willcox L (2001) The Importance of Large Carnivores to Healthy Ecosystems. *Endangered Species Update* 18 (5): 1–10.
- MMA (2014) Portaria do Ministério do Meio Ambiente nº 444, de 17 de dezembro de 2014. Lista Nacional Oficial de Espécies da Fauna Ameaçadas de Extinção. Diário Oficial da União, Brasília, n. 245, 18 dez. 2014. Seção I, p. 121–126.
- Moro RS (2001) A vegetação dos Campos Gerais da escarpa devoniana. In: Ditzel CDHM, Sahr CLL (Eds) Espaço e Cultura: Ponta Grossa e os Campos Gerais. Editora UEPG, Ponta Grossa, 481–503.
- Oliveira TG, Cassaro K (2006) Guia de campo dos felinos do Brasil. Instituto Pró – Carnívoros: Fundação Parque Zoológico de São Paulo: Sociedade de Zoológicos do Brasil, Pró -Vida Brasil, São Paulo, 80 pp.
- Oliveira EA (2012) O Parque Nacional dos Campos Gerais: processo de criação, caracterização ambiental e proposta de priorização de áreas para regularização fundiária. PhD thesis, Federal University of Paraná, Curitiba, 293 pp.
- Oliveira U, Soares-Filho BS, Paglia AP, Brescovit AD, Carvalho CJB, Silva DP, Rezende DT, Leite FSF, Batista JAN, Barbosa JPPP, Stehmann JR, Ascher JS, Vasconcelos MF, De Marco P, Löwenberg-Neto P, Ferro VG, Santos AJ (2017) Biodiversity conservation gaps in the Brazilian protected areas. *Scientific Reports* 7: 9141. <https://doi.org/10.1038/s41598-017-08707-2>
- Oliveira TG, Tortato MA, Silveira L, Kasper CB, Mazim FD, Lucherini M, Jácomo AT, Soares JBG, Marques RV, Sunquist M (2010) Ocelot ecology and its effect on the small-felid guild in the lowland neotropics. In: Macdoweld DW, Loveridge AJ (Eds) *Biology and conservation of wild cats*. Oxford University Press, Oxford, 559–580.
- Paglia AP, Fonseca GAB, Rylands AB, Herrmann G, Aguiar LMS, Chiarello AG, Leite YLR, Leite YLR, Costa LP, Siciliano S, Kierulff MCM, Mendes SL, Tavares V, Mittermeier RA, Patton JL (2012) Annotated checklist of Brazilian mammals. *Occasional Papers in Conservation Biology* 6: 1–82.
- Pardini R, Ditt EH, Cullen Junior L, Bassi C, Rudran R (2004) Levantamento rápido de mamíferos terrestres de médio e grande porte. In: Cullen Junior L, Rudran R, Valladares-Pádua C (Eds) *Métodos de estudos em Biologia da Conservação e Manejo da Vida Silvestre*. Ed. da UFPR, Fundação O Boticário de Proteção à Natureza, Curitiba, 181–201.
- Patton JL, Pardiñas, UF, D'Elia G (2015) *Mammals of South America*. Volume 2. Rodents. University of Chicago Press, Chicago, 1384 pp.
- Rangel CH, Neiva CHMB (2013) Predação de Vertebrados por Cães *Canis lupus familiaris* (Mammalia: Carnivora) no Jardim Botânico do Rio de Janeiro, RJ, Brasil. *Biodiversidade Brasileira* 3 (2): 261–269.
- Reis NR, Peracchi AL, Fragonezi MN, Rossaneis BK (2009) *Guia ilustrado mamíferos do Paraná - Brasil*. Editora USEB, Pelotas, 264 pp.
- Reis NR, Peracchi AL, Pedro WA, Lima IP (2011) *Mamíferos do Brasil*, 2 ed. Nélio R. dos Reis, Londrina, 439 pp.
- Reis NR, Fragonezi MN, Peracchi AL, Shibatta OA, Sartore ER, Rossaneis BK, Santos VR, Ferracioli P (2014) *Mamíferos terrestres de médio e grande porte da Mata Atlântica: guia de campo*. Technical Books, Rio de Janeiro, 146 pp.
- Rodden M, Rodrigues FHG, Bestelmeyer SV (2004) Maned wolf (*Chrysocyon brachyurus*). In: Sillero-Zubiri C, Hoffmann M, Macdonald DW (Eds) *Canids: foxes, wolves, jackals and dogs: Status Survey and Conservation Action Plan*. IUCN/SSC Canid Specialist Group, IUCN, Gland, Switzerland and Cambridge, 38–44.
- Santos MFM, Pellanda M, Tomazzoni AC, Hasenack H, Hartz SM (2004) Mamíferos carnívoros e sua relação com a diversidade de habitats no Parque Nacional dos Aparados da Serra, sul do Brasil. *Iberingia Série Zoológica* 94 (3): 235–245. <https://doi.org/10.1590/S0073-47212004000300003>
- Silveira LF, Beisiegel BM, Curcio FF, Valdujo PH, Dixo M, Verdade VK, Mattox GMT, PTM Cunningham (2010) Para que servem os inventários de fauna? *Estudos Avançados* 24 (68): 173–207. <https://doi.org/10.1590/S0103-40142010000100015>
- SNUC (2000) Sistema Nacional de Unidades de Conservação; Lei 9.985 de 18 de julho de 2000; Ministério do Meio Ambiente. <http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=322>. Accessed on: 2018-10-1.
- SOS Mata Atlântica & INPA - Instituto Nacional de Pesquisas Espaciais. 2018. Atlas dos remanescentes florestais da Mata Atlântica - Período 2016-2017. Relatório técnico, São Paulo, 66 pp.
- Srbek-Araujo AC, Chiarello AG. 2007. Armadilhas fotográficas na amostragem de mamíferos: considerações metodológicas e comparação de equipamentos. *Revista Brasileira de Zoologia* 24 (3): 647–656. <https://doi.org/10.1590/S0101-81752007000300016>.
- Srbek-Araujo AC, Chiarello AG (2013) Influence of camera-trap sampling design on mammal species capture rates and community structures in southeastern Brazil. *Biota Neotropica* 13 (2): 51–62. <https://doi.org/10.1590/S1676-06032013000200005>
- Terborgh J, Estes J, Paquet P, Ralls K, Boyd-Heger D, Miller B, Noss R (1999) The role of top carnivores in regulating terrestrial ecosystems. In: Soule ME, Terborgh J. (Eds) *Continental Conservation: Scientific Foundations of Regional Reserve Networks*. Island Press, Washington, DC, 39–64.
- Trigo TC, Schneider A, Oliveira TG, Lehugeur LM, Silveira L, Freitas, TRO, Eizirik E (2013) Molecular data reveal complex hybridization and cryptic species of Neotropical wild cat. *Current Biology* 23 (24): 2528–2533. <https://doi.org/10.1016/j.cub.2013.10.046>
- Wolf T, Conover MR (2003) *Feral pigs and the environment: an annotated bibliography*. Berryman Institute Publication 21. Utah State University, Logan, and Mississippi State University, Starkville, 92 pp.

## CAPÍTULO 2

### **Narrow, short and deadly: Mammals roadkills on highway sections of PR-445, South of Brazil**

Alan Deivid Pereira, Marcelo Hideki Shigaki Yabu, Iago Vinicios Geller, Carolina Prado, Carlos Rodrigo Lehn, Ana Paula Vidotto-Magnoni, Juliano André Bogoni, Mário Luís Orsi.

Capítulo redigido segundo as normas do periódico *Papéis Avulsos de Zoologia data*, disponível em: <http://www.revistas.usp.br/paz/about/submissions#authorGuidelines>

**Narrow, short and deadly: Mammals roadkills on highway sections of PR-445, South of Brazil**

Running Title: Mammals roadkills on highway sections of PR-445

*Alan Deivid Pereira*<sup>1\*</sup> <https://orcid.org/0000-0002-3182-2344>

*Marcelo Hideki Shigaki Yabu*<sup>2</sup> <https://orcid.org/0000-0002-9931-9008>

*Iago Vinicios Geller*<sup>1</sup> <https://orcid.org/0000-0003-2838-8724>

*Carolina Prado*<sup>2</sup> <https://orcid.org/0000-0002-6477-6962>

*Carlos Rodrigo Lehn*<sup>1</sup> <https://orcid.org/0000-0003-2865-1019>

*Ana Paula Vidotto-Magnoni*<sup>2</sup> <https://orcid.org/0000-0003-1819-7019>

*Juliano André Bogoni*<sup>3</sup> <https://orcid.org/0000-0002-8541-0556>

*Mário Luís Orsi*<sup>2</sup> <https://orcid.org/0000-0001-9545-4985>

<sup>1</sup> Universidade Estadual de Londrina, Programa de Pós-Graduação em Ciências Biológicas, Rodovia Celso Garcia Cid, PR 445, Km 380, Campus Universitário, CP 10.011, CEP 86057-970, Londrina, PR, Brazil.

<sup>2</sup> Universidade Estadual de Londrina, Laboratório de Ecologia de Peixes e Invasões Biológicas, Rodovia Celso Garcia Cid, PR 445, Km 380, Campus Universitário, CP 10.011, CEP 86057-970, Londrina, PR, Brazil.

<sup>3</sup> Universidade de São Paulo, Escola Superior de Agricultura “Luiz de Queiroz”, Laboratório de Ecologia, Manejo e Conservação de Fauna Silvestre (LEMaC), Piracicaba, São Paulo, Brazil.

## ABSTRACT

Animal-vehicle collisions are the main negative impact of roads on wildlife, where they cause population declines, changes in the structuring of communities, and potential changes in species behavior. Here, we determined mammal roadkill rates and the hotspots with higher rates for medium- and large-bodied mammals on Highway PR-445 in the state of Paraná, Brazil. We also evaluated possible differences in the frequency of roadkills concerning the activity pattern and feeding habit of species. In doing so, we monitored PR-455 weekly on average twice a week from March 2018 to March 2019, totaling 7296 km traveled during 96 trips over 12 months. We recorded 60 roadkill mammals belonging to 17 species, representing a rate of 0.151 individual/km/day. The orders Carnivora, Cingulata, and Didelphimorphia showed the most common roadkills. Omnivores were more prone to getting hit by vehicles than herbivorous and carnivorous species. The type of mammal activity pattern was not a determinant in explaining the differences in roadkill rates. Highways in Paraná are among the roads that register the most vertebrate-vehicle collisions in the country. This issue, together with extensive habitat conversion and fragmentation, increases the threats to the relictual fauna. Our results indicate that the regions with the highest incidence of roadkills on PR-445 are those close to stretches over rivers and with remnants of native vegetation. Thus, we emphasize that more comprehensive measures (*e.g.*, wildlife passages and speed reducers) are essential to mitigate the impact of roads on wildlife.

**Keywords:** Animal-vehicle collisions; mammals; activity period; species diet; diversity loss

## INTRODUCTION

In the 21<sup>st</sup> century, roads account for some of the most important environmental changes resulting in a high impact on natural landscapes (Laurance *et al.*, 2014). These impacts include an increase in noise and light pollution, erosion, and loss of natural environment and the character of the land, aggravating the edge effect of forest fragments (Forman & Alexander, 1998; Orlandin *et al.*, 2015). The consequences of roads on wildlife reach different ecological scales, including changes in the structure of communities (Laurance *et al.*, 2009) and behavioral dynamics (Ascensão *et al.*, 2014; Poessel *et al.*, 2014), influencing the presence and persistence of species in surrounding forest fragments (Borda-de-Água *et al.*, 2011) and also causing considerable economic losses (Abra *et al.*, 2019).

Besides the abovementioned road-related threats to animals, roadkill is the main negative impact of roads on wildlife, with direct effects on local populations, influencing species abundance and distribution (Eigenbrod *et al.*, 2008). Population declines caused by road impacts have effects on the variability and genetic viability of species (Jackson & Fahrig, 2011). Roadkill is the primary cause of death for some species, including threatened species (Forman *et al.*, 2003), proving to be a direct factor of mortality among terrestrial vertebrates as significant as hunting (Seiler & Heldin, 2006).

Brazil has one of the most extensive road networks in the world, covering more than 200,000 km of surfaced roads (ANTT, 2019). According to the estimates provided by the Brazilian Center for Road Ecology Research (CBEE), more than 15 animals die on Brazilian roads every second. It is estimated that 5 million medium- and large-bodied animals such as giant anteaters, peccaries, deer, jaguars, monkeys, and maned wolves are killed annually on the roads and highways of Brazil (CBEE, 2019). Therefore, road monitoring and implementation of mitigation strategies are essential to minimize the harm of road to native biota (Costa *et al.*, 2015; Abra *et al.*, 2019). This action is even more crucial in areas of great value for biodiversity conservation, such as the Atlantic Forest biome.

In the northern part of the state of Paraná, the predominant vegetation is seasonal semideciduous forest (SSF), which is one of the most rarefied ecosystems in the Atlantic Forest occurring in refuge areas of South and Southeast Brazil (SOS Mata Atlântica & INPE, 2018). Recent estimates have shown

that only 7% of the area covered initially by SSF remains, being represented by small fragments (typically less than 50 ha), immersed in matrices of areas of intensive farming and urban areas crisscrossed by extensive road networks with intense traffic (SOS Mata Atlântica & INPE, 2018). Within Paraná, studies involving mammal roadkills have been conducted in the surroundings of Iguaçu National Park (Brocardo & Cândido-Junior, 2012), in the coastal region (*i.e.*, Serra do Mar) (Leite *et al.*, 2012; Belão *et al.*, 2014) and in the region of Campos Gerais (*i.e.*, central plateaus) (Zeliski *et al.*, 2009; Weiss & Vianna, 2012). However, no studies have extensively explored the impact of roads on mammalian fauna in the northern region. This meta-region represents an important interest in biodiversity conservation owing to its location in a transition zone between the tropical and subtropical portion of the Atlantic Forest.

Evaluating the importance of animal-vehicle collisions is a complex challenge in conservation ecology, involving ecological, economic, social and technical perspectives, and considering both wide-ranging and small spatial scales (Seiler & Heldin, 2006). The information collected from road data surveys is often used to choose the best strategies for reducing collisions with animals and to evaluate their effectiveness (Cureton & Deaton, 2012; Lesbarreres & Fahrig, 2012; Costa *et al.*, 2015). Thus, this study determined roadkill rates and pointed out the hotspots with a higher incidence of roadkills of medium- and large-bodied mammals along Highway PR-445, located in the subtropical portion of the Atlantic Forest in South Brazil. We also evaluated the possible variation in the frequency of roadkills according to the activity pattern and feeding habit of mammalian species.

## **MATERIAL AND METHODS**

### **Study area**

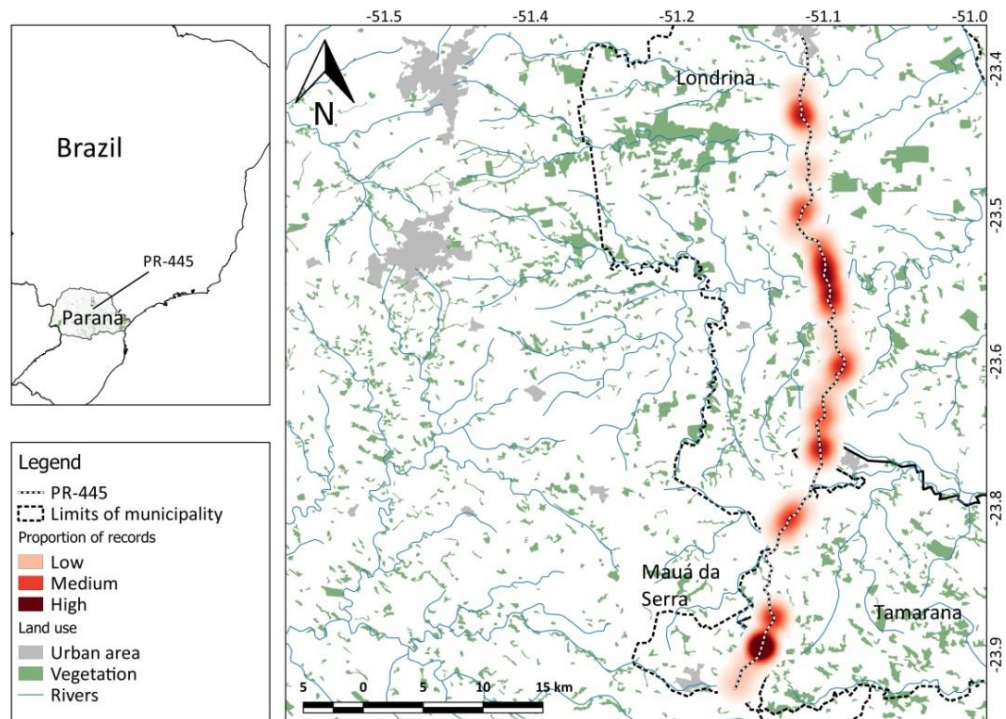
Highway PR-445 (also called Celso Garcia Cid) is 95 km long, located between the municipalities of Mauá da Serra and Warta in northern Paraná (23.30°S, 51.17°W). This highway is marked by being located in the transition zone between the tropical and subtropical Atlantic Rainforest (Tropic of Capricorn, 23.26°S). It is a state-administered 2-lane highway with a short 4-lane section in the city of

Londrina. The maximum speed is 80 km/h, being controlled by electronic radar and mobile surveillance. The metropolitan region of Londrina is the fourth largest metropolis in southern Brazil, with an estimated population of more than one million, and it has heavy traffic. Traffic with heavy vehicles (e.g.,  $\geq 3500$  kg) is constant mainly due to the transport of crops during harvest time.

The predominant vegetation in the region is seasonal semideciduous forest. The climate of the region is classified as humid subtropical mesothermal (Cfa), with an annual average temperature around 21°C, and an annual rainfall of 1450 mm (Peel *et al.*, 2007). Highway PR-445 is surrounded mainly by an agricultural matrix (soybean, wheat and corn crops), eucalyptus monocultures, pastures and urban areas, along with small native remnants of SSF (SOS Mata Atlântica & INPE, 2018).

### **Sampling**

The data on mammal roadkills were obtained between kilometers 1 and 76 of PR-445 (80% of the whole road), which includes the counties of Londrina, Mauá da Serra and Tamarana (Fig. 1). We adopted a monitoring protocol according to Costa *et al.* (2015), using mixed protocols (monthly and weekly samplings) to achieve an inventory of the species with no marked peak mortality (*i.e.*, species with higher activity in warmer periods [southern hemisphere summer]).



**Figure 1.** Location of Highway PR-445 in the state of Paraná. Brazil indicating the sector measured in this study area from 2018 to 2019. The hotspots highlighted in red indicate places with high rates of mammal roadkill.

We monitored PR-445 on average twice a week, from March 2018 to March 2019, totaling 7296 km on 96 trips over 12 months. The search for medium- to large-bodied mammal carcasses was done by car in the morning period (from 7:00 a.m. to 12:00 p.m.) with an average speed of 80 km/h.

The roadkill mammals found were photographed and identified *in situ* whenever possible. Accordingly, we used specific field guides for the taxonomic groups (Reis *et al.*, 2009, 2014). For the carcasses with advanced decomposition or showing damage that hindered accurate species identification, we collected samples of hairs for species identification on slides based on microstructural characteristics, namely cuticular and medullary patterns. The hairs were collected manually from each carcass. We extracted small tufts of guard hairs from the back at the intersection of the median line and scapular waistline, following the identification protocol described by Quadros & Monteiro-Filho (2006). Species identification was confirmed using the identification keys of Quadros & Monteiro-Filho (2010) and Miranda *et al.* (2014).

The alpha taxonomic nomenclature followed Paglia *et al.* (2012) and considering recent taxonomic changes (*e.g.*, *Leopardus guttulus* (Hensel, 1872) based on Trigo *et al.* (2013) and in the genus *Sapajus* according to Lych-Alfaro *et al.* (2012). For the orders Pilosa and Rodentia we also consulted Patton *et al.* (2015) for accurate identification. All species with an adult body mass  $\geq 1$  kg was considered medium-to large-bodied mammals (Paglia *et al.*, 2012). Mammalian activity pattern was defined as follows: (1) crepuscular/nocturnal (CrN), (2) diurnal (D) and (3) nocturnal (N) (Reis *et al.*, 2011). Feeding habits were according to Paglia *et al.* (2012), as follows: (i) carnivore (Ca), (ii) frugivore and folivore (Fr/Fo), (iii) frugivore and omnivore (Fr/On), (iv) herbivore or grazer (Hb), (v) insectivore and omnivore (In/On) and (vi) myrmecophage (Myr). Moreover, for each species, we obtained the conservation status according to the Brazilian Wildlife Red Book (MMA, 2018), the List of Threatened Fauna in the State of Paraná (Paraná, 2010) and IUCN Red List of Threatened Species (IUCN, 2019).

### Data analysis

The location of each animal was recorded using a Global Positioning System (GPS). To analyze the regions of the highway with the highest concentration of roadkills (*i.e.*, hotspots), we created a density map of records. Accordingly, we used the kernel density estimator. The kernel approach allows estimating the number of events per unit area in each cell of a regular grid covering the study area, in addition to filtering the variability of a dataset (Wand & Jones, 1995). The analysis was performed using software R based on the "MASS version 2.23-15" package and "KernSmooth" function (Wand, 2015).

The frequency (F) of roadkills for each recorded species was calculated by the formula:

$$F_i = \left( \frac{N_i}{N} \right) 100$$

where:  $F_i$  = frequency of occurrence for the  $i^{\text{th}}$  species;  $N_i$  = number of records of the  $i^{\text{th}}$  species;  $N$  = total number of records.

We used the non-parametric test of Kruskal-Wallis, the non-parametric equivalent of ANOVA, due to non-normal data determined *a priori* by frequency histogram and Shapiro-Wilk test (Shapiro & Wilk 1965) to evaluate possible differences in the number of records in about activity patterns and feeding habits. Since we identified a statistically significant difference, we performed pairwise comparisons using the Tukey and Kramer (Nemenyi) test with Tukey-Dist approximation for independent samples (Nordstokke & Stelnicki, 2014). All analyses were performed using software R based on the "Vegan version 2.4-1" package (Oksanen *et al.*, 2019).

## RESULTS

We recorded 60 specimens of mammal roadkill on PR-445, resulting in 17 species distributed in 12 families and 7 orders (Table 1), corresponding to a roadkill rate of 0.151 individual/km/day. The kernel density estimator indicated three points along the highway with the highest concentration of records of roadkill animals, i.e., hotspots. One hotspot was between Mauá da Serra and Tamarana (km 4; 23° 83 S, 51° 16 W), a stretch near the bridge over the Taquaruna River (Km 40; 23° 56 S, 51°11 W), and another eight kilometers perpendicular to the conservation unit Parque Estadual Mata dos Godoy, towards the urban area of Londrina (km 58; 23° 43 S, 51°13 W) (Fig. 1).

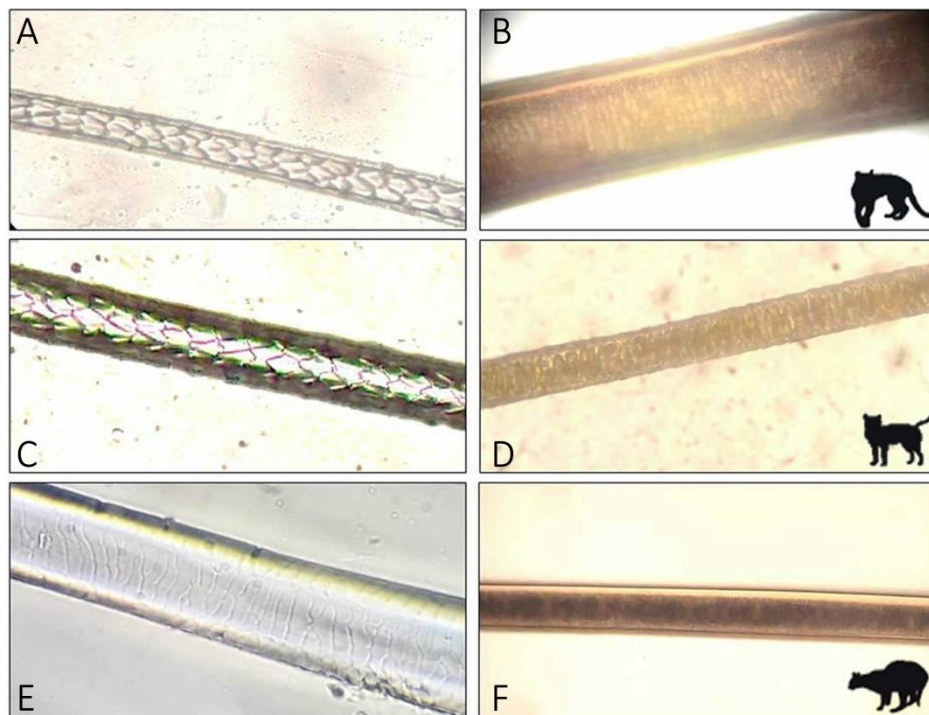
The higher numbers of roadkill events were found for the orders Carnivora (48.3% of roadkill records), Cingulata (16.7%) and Didelphimorphia (15%). The other roadkill records included the orders Lagomorpha (6.7%), Primates and Rodentia (5% each) and Myrmecophagidae (3.3%). Of the 17 species recorded, five are included in a category with some degree of threat, from the state to international level according to the criteria established by the IUCN (Table 1).

**Table 1.** List of roadkill medium- to large-bodied mammalian species on Highway PR-445. Acronyms are as follows. N: Total number of occurrences. F: Frequency of occurrence by species. Diet: carnivore (Ca); frugivore and folivore (Fr/Fo); frugivore and omnivore (Fr/On); herbivore or grazer (Hb); insectivore and omnivore (In/On) and myrmecophage (Myr). **Activity pattern:** crepuscular/nocturnal (CrN); diurnal (Dn); nocturnal (Nt). **Threat category:** data deficient (DD); endangered (EN); least

concern (LC); not evaluated (NE); near threatened (NT) and vulnerable (VU). Exotic species (\*). Small-bodied species (\*\*).

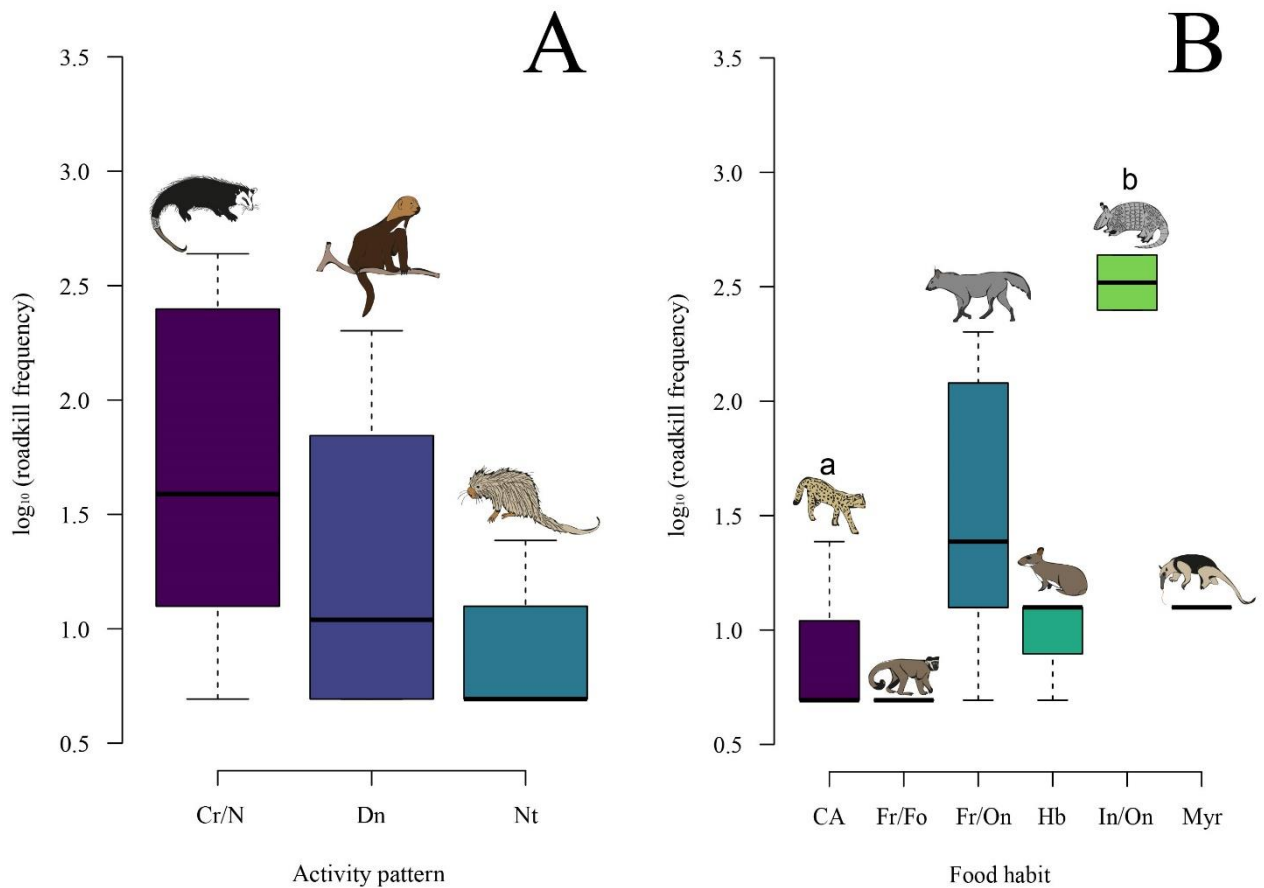
Taxon	Number		Diet	Activity pattern	Threat category		
	of records				IUCN	BR	PR
	N	F					
<b>Didelphimorphia</b>							
<b>Didelphidae</b>							
<i>Didelphis albiventris</i> Lund, 1840	7	11.7	Fr/On	CrN	LC	NE	LC
<i>Didelphis aurita</i> Wied-Neuwied, 1826	2	3.3	Fr/On	Nt	LC	NE	LC
<b>Pilosa</b>							
<b>Myrmecophagidae</b>							
<i>Tamandua tetradactyla</i> (Linnaeus, 1758)	2	3.3	Myr	Nt	LC	NE	NE
<b>Cingulata</b>							
<b>Dasypodidae</b>							
<i>Dasypus novemcinctus</i> Linnaeus, 1758	10	16.7	In/On	CrN	LC	NE	LC
<b>Primates</b>							
<b>Atelidae</b>							
<i>Sapajus nigritus</i> (Goldfuss, 1809)	3	5	Fr/On	Dn	NT	NE	DD
<b>Carnivora</b>							
<b>Canidae</b>							
<i>Cerdocyon thous</i> (Linnaeus, 1766)	13	21.7	In/On	CrN	LC	NE	LC
<b>Felidae</b>							
<i>Leopardus guttulus</i> (Hensel, 1872)	3	5	Ca	Nt	VU	VU	VU
<i>Leopardus wiedii</i> (Schinz, 1821)	1	1.7	Ca	Nt	NT	VU	VU
<i>Puma yagouaroundi</i> (E. Geoffroy, 1803)	1	1.7	Ca	Dn	LC	VU	DD
<b>Mustelidae</b>							
<i>Eira barbara</i> (Linnaeus, 1758)	1	1.7	Fr/On	Dn	LC	NE	LC
<i>Galictis cuja</i> (Molina, 1782)	1	1.7	Ca	CrN	LC	NE	LC
<b>Procyonidae</b>							
<i>Nasua nasua</i> (Linnaeus, 1766)	9	15	Fr/On	Dn	LC	NE	LC
<b>Lagomorpha</b>							
<b>Leporidae</b>							
<i>Lepus europaeus</i> Pallas, 1778*	2	3.3	Hb	CrN	LC	NE	NE
<i>Sylvilagus brasiliensis</i> (Linnaeus, 1758)	2	3.3	Hb	CrN	LC	NE	VU
<b>Rodentia</b>							
<b>Cuniculidae</b>							
<i>Cavia aperea</i> Erxleben, 1777**	1	1.7	Hb	Nt	LC	NE	LC
<b>Erethizontidae</b>							
<i>Coendou spinosus</i> (F. Cuvier, 1823)	1	1.7	Fr/Fo	Nt	DD	NE	LC
<b>Myocastoridae</b>							
<i>Myocastor coypus</i> (Molina, 1782)*	1	1.7	Fr/On	Nt	LC	NE	LC

Based on the analysis of the cuticular and medullary patterns of mammal hair microstructure, we were able to perform an accurate identification of feline species (Fig. 2). We found three cuticular patterns, namely wide rhombus (*Puma yagouaroundi*), narrow rhombus (*Leopardus guttulus*) and narrow leaf shape (*Leopardus wiedii*), and also two medullary patterns, namely trabecular fimbriate with vacuoles in *P. yagouaroundi* and *L. guttulus*, and trabecular fimbriate without vacuoles for *L. wiedii* (Fig. 2).



**Figure 2.** Microstructural pattern of species of the family Felidae: *Leopardus wiedii*. (A) cuticular pattern and (B) medullary pattern; *Leopardus guttulus*; (C) cuticular pattern and (D) medullary pattern; and *Puma yagouaroundi* (E) cuticular pattern and (F) medullary pattern.

We did not find significant differences in the frequency of roadkills with regard to activity pattern of mammals [ $H = 3.2919$ ;  $DF = 2$ ;  $p > 0.05$ ] (Fig. 3A). However, we found significant differences in the frequency of roadkills with regard to feeding habit [ $H = 6.869$ ;  $DF = 5$ ;  $p < 0.05$ ] (Fig. 3B).



**Figure 3.** Boxplot illustrating the difference in roadkill rate for medium- to large-bodied mammals on Highway PR-445 between the municipalities of Londrina and Mauá da Serra, PR in relation to: (A) activity pattern; and (B) feeding habit. Acronyms are described in Table 1. A: a significant difference [ $p= 0.05$ ] is shown between carnivores (CA) and frugivores/omnivores (Fr/On). B: a significant difference [ $p = 0.04$ ] is shown between carnivores (CA) and insectivores/omnivores (In/On).

## DISCUSSION

Direct mortality is the most widespread and significant effect of roads on wildlife (Bissonette, 2002), which can be evidenced throughout our study. However, the number of roadkills presented here may be underestimated, since larger animals may not die immediately after the collision, moving to areas away from the road, making it difficult to include them in the count (Bruinderink & Hazebroek, 1996).

We found a rate of 0.151 dead animals per day for each kilometer traveled along PR-445. Considering this crude rate, >5200 mammals succumb during a year on this highway alone, and at this same rate applied to the entire network of paved roads in Brazil, the number of roadkill mammals is as high as 11.7 M individuals. However, the rate determined in our study is higher than the value of 0.017 found for the PR-406 and PR-508 highways in the coastal region of Paraná (Leite *et al.*, 2012). Even studies of short stretches of highway have been shown to have a similar significant impact on wildlife as those of longer stretches (Magioli *et al.*, 2019). The high roadkill rate for many species is appalling and indicates that these accidents are commonplace and widespread (Seiler & Heldin, 2006). Yet, the Brazilian Atlantic Forest has high rates of defaunation of medium- to large-bodied mammals (Bogoni *et al.*, 2018), especially in highly fragmented areas of the present study, so that the impact of roads on wildlife is a crucial factor to be considered in conservation strategies.

A series of empirical studies showed that roads have substantial impacts on species abundance and species composition in ecosystems (Polak *et al.*, 2014). Among the roadkilled species recorded in our study, 43% belonged to the order Carnivora. Presumably, the high number of Carnivora roadkills may be related to their ecological and behavioral aspects. Species of the order Carnivora depend on a large area to prosper, since having large home ranges (a powerful descriptor of spatial requirements of species or populations). Moreover, Carnivora species show the ability to explore human-disturbed environments neighboring native vegetation (Lyra-Jorge *et al.*, 2010). Studies indicate that roads affect the movement and wide distribution of carnivores, including felids, particularly those living in habitats near urbanized areas (Poessel *et al.*, 2014). The population declines of carnivores due to roadkills compromises the stability of forests and ecosystem functioning. Failure to thrive in landscapes highly modified by humans leads to non-random changes that propagate throughout all communities and ecosystems (*i.e.*, cascade effects) because Carnivora animals play an important role in providing ecosystem services (*e.g.*, disease control), being considered apex predators or mesopredators in food chains, contributing to the regulation of other populations (Terborgh *et al.*, 1999).

The most frequent roadkilled mammals were particularly *Cerdocyon thous*, *Dasybus novemcinctus*, *Nasua nasua* and *Didelphis albiventris*. In the Atlantic Forest, these species are easily found in altered environments and have a preference for open areas (Reis *et al.*, 2014). Although *C. thous* does not appear in the Brazil Red Book of Threatened Species of Fauna (MMA, 2018), the high roadkill rates for this species is cause for concern regarding its conservation, since in many studies *C. thous* leads statistics for species most affected by roadkills throughout Brazil (Zeliski *et al.*, 2009; Cunha *et al.*, 2010; Belão *et al.*, 2014; Brum *et al.*, 2018; Zanzini *et al.*, 2018).

The other species did not have high frequencies of vehicle collisions compared to *C. thous*, *D. novemcinctus*, *N. nasua* and *D. albiventris*. In theory, the number of animal-vehicle collisions should depend on the density and activity of animals and number of vehicles (Seiler & Heldin, 2006). For some species, the low number of roadkill events is mainly related to its low abundance in nature (*e.g.*, the large felines that in general have their population rarefied in an area) (Jaeger *et al.*, 2005). In addition, records of roadkills may reinforce the vulnerability of some species to landscape modifications. Among the 17 species roadkilled on PR-445, four of them (*Sapajus nigritus*, *Leopardus guttulus*, *Leopardus wiedii*, *Herpailurus yagouaroundi*) are listed in the "Vulnerable" or "Nearly threatened" categories, both on national and international scales (MMA, 2018; IUCN, 2019) and *Sylvilagus brasiliensis* is listed in the "Vulnerable" category on a regional scale (Paraná, 2010).

Although it is expected that species with nocturnal habit are more susceptible to being run over on highways than those of diurnal habit (Bruinderink & Hazebroek 1996), this was not evident in our study. We did not find significant differences in roadkills in relation to species activity patterns. Moreover, peaks in activity pattern are strongly related to climatic conditions and are most evident in groups of amphibians, reptiles and migratory birds (Costa *et al.*, 2015).

Our initial hypothesis was that herbivorous and carnivorous mammals were more run over because they tend to walk and cover larger areas than omnivorous and insectivorous animals for food (Tucker *et al.* 2014). However, our results indicate that omnivorous species are more prone to being run over than herbivorous or carnivorous (figure 2 B). The answer to this pattern may be related to the fact that

for the Brazilian Atlantic Forest most mammal species are omnivorous and have a generalist and opportunistic behavior (Reis et al. 2009, Paglia et al. 2012), and even in a region densely fragmented and with small forest remnants surrounded by an agricultural matrix as the region of our study, mammals tend to look for resources in other landscapes outside the forests such as the edges of roads in search of resources such as the remains of food discarded by humans, fruits of edge trees and open area insects.

Our results also indicate that the analysis of the cuticular and medullary pattern of mammal hairs is a useful tool for identifying roadkill mammals. This technique allows the confirmation of species identification considering non-intact individuals — particularly small wild felines — because the loss of the main characters utilized in species identification can be destroyed by vehicle collisions. While there are few reports using this tool for roadkill studies, this technique is limited to studies exclusively related to mammals (Quadros & Monteiro-Filho, 2010).

In Brazil, there are initiatives such as the monitoring of vehicle collisions with wildlife carried out by the Brazilian Center for Road Ecology Research (CBEE) at the Federal University of Lavras (UFLA), including a monitoring system through citizen science (*i.e.*, Urubu System App) providing information for mitigation measures for animal accidents on Brazilian roads. Other important actions have been developed by the environmental enterprise ViaFauna in São Paulo, called Passa-Bicho (“Animal Pass”). This initiative enables the detection of animals based on positioning a set of sensors on stretches of roadway with high animal traffic (Vasconcelos, 2017; Abra *et al.*, 2019). Still, the responsibility of managing the roads rests on concessionaires, either private or stat, to develop conservation strategies and public policies to reduce road impacts on biodiversity.

The roads in Paraná are among those that have the highest roadkill records in Brazil (CBEE, 2019). Our results indicate the sections of higher incidence of animals run over on PR-445 (See Fig. 1). Thus, density analysis based on kernel estimation proves to be an important tool for the planning of actions, where the most likely areas of collisions can be accurately indicated. We emphasize that all along this highway, there are no basic systems to avoid collisions with wild animals. The installation of

underpasses and external fences could be suitable mitigation measures for mammals (Rytwinski *et al.*, 2016), especially in regions of the road near bridges crossing over rivers and streams, as well as in regions with higher concentrations of native vegetation. We also suggest placing speed reducers (warning signs, speed cameras and speed bumps) and road fencing, which should be installed mainly in the places where this study indicated the highest roadkill density. We emphasize that the installation of these fences must be in strategic locations along the highway that lead to underground passages. Thus, forcing animals to use them to safely access the other side of the road and reduce the risk of collision for cars. Finally, it is necessary to increase incisive advertising campaigns aimed at drivers, so that is a way between the road transport authority and the public, it is possible to reduce collisions between vehicles and animals.

#### **ACKNOWLEDGMENTS**

We thank the Postgraduate Program in Biological Sciences of the Universidade Estadual de Londrina and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES- Funding Code 1689817), for logistical and financial support. JAB is supported by a postdoctoral fellowship grant 2018-05970-1, São Paulo Research Foundation (FAPESP). Dr. A. Leyva (USA) provided English editing of the manuscript.

#### **REFERENCES**

Abra, F.D.; Granziera, B.M.; Huijser, M.P.; De Barros Ferraz, K.M.P.M.; Haddad, C.M. & Paolino, R.M. 2019. Pay or prevent? Human safety, costs to society and legal perspectives on animal-vehicle collisions in São Paulo state, Brazil. *PLoS ONE*, 14: 1-22.

Agência Nacional de Transportes Terrestres (ANTT) 2019. Rodovias. Available at: <http://www.antt.gov.br/rodovias/index.html>

- Araújo, D.R.; Ribeiro, P. & Teles, L.T. 2019. Can Human Demographic or Biological Factors Influence Mammal Roadkill? a Case Study in the Go-060 Highway. *Oecologia Australis*, 23: 16-27.
- Ascensão, F.; Grilo, C.; LaPoint, S.; Tracey, J.; Clevenger, A.P. & Santos-Reis, M. 2014. Inter-individual variability of stone marten behavioral responses to a highway. *PLoS ONE*, 9: 1-9.
- Bazilio, S.; Bastiani, E.De. & Golec, C. 2014. New records and description of the microstructural patterns of guard hair in *Conepatus chinga* (Molina, 1782) (Carnivora, Skunk) for the states of Paraná and Santa Catarina, southern Brazil. *Biotemas*, 28: 79-84.
- Belão, M.; Bóçon, R.; Christo, S.W.; Souza, M.A.M.de. & Júnior, J.L.S. 2014. Incidentes De Mamíferos Na Rodovia Br-277, Paraná – Brasil. *Publicatio UEPG: Ciências Biológicas e Da Saude*, 20: 37-41.
- Bissonette, J. 2002. Scaling roads and wildlife: the Cinderella principle. *Zeitschrift Fur Jagdwissenschaft*, 48: 208-214.
- Bogoni, J.A.; Pires, J.S.R.; Graipel, M.E.; Peroni, N. & Peres, C. A. 2018. Wish you were here: How defaunated is the Atlantic Forest biome of its medium- to largebodied mammal fauna? *PLoS ONE*, 13: 1-23.
- Borda-de-Água, L.; Navarro, L.; Gavinhos, C. & Pereira, H.M. 2011. Spatio-temporal impacts of roads on the persistence of populations: Analytic and numerical approaches. *Landscape Ecology*, 26: 253-265.
- Brocardo, C.R. & Cândido Júnior, J.F. 2012. Persistência de mamíferos de medio e grande porte em fragmentos de Floresta Ombrófila Mista no estado do Parana, Brasil. *Revista Árvore*, 36: 301–310.
- Brum, T.R.; Santos-Filho, M.; Canale, G.R. & Ignácio, A.R.A. 2018. Brazilian Journal of Biology Effects of roads on the vertebrates diversity of the Indigenous Territory Paresi and its surrounding. *Brazilian Journal of Biology*, 78: 125-132.
- Bruinderink, G.W.T.A.G. & Hazebroek, E. 1996. Ungulate Traffic Collisions in Europe. *Conservation Biology*, 10: 1059-1067.
- Centro Brasileiro de Estudos em Ecologia de Estradas (CBEE). 2019. Available at: <http://cbee.ufla.br/portal/atropelometro/>.

- Cherem, J.J.; Kammers, M.; Ghizoni-Jr, I.R. & Martins, A. 2007. Mamíferos de médio e grande porte atropelados em rodovias do Estado de Santa Catarina, sul do Brasil. *Biotemas*, 20: 81-96.
- Costa, A.S.; Ascensão, F. & Bager, A. 2015. Mixed sampling protocols improve the cost-effectiveness of roadkill surveys. *Biodiversity and Conservation*, 24: 2953-2965.
- Cunha, H.F.da.; Moreira, F.G.A. & Silva, S.D.S. 2010. Roadkill of wild vertebrates along the GO-060 road between Goiânia and Iporá, Goiás State, Brazil. *Biological Sciences: Acta Scientiarum*, 32: 257-263.
- Cureton, J.C. & Deaton, R. 2012. Hot moments and hot spots: Identifying factors explaining temporal and spatial variation in turtle road mortality. *Journal of Wildlife Management*, 76: 1047-1052.
- Eigenbrod, F., Hecnar, S. J., & Fahrig, L. 2008. Accessible habitat: An improved measure of the effects of habitat loss and roads on wildlife populations. *Landscape Ecology*, 23: 159-168.
- Forman, R.T.T. & Alexander, L.E. 2002. Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics*, 29: 207-231.
- Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., Winter, T.C., 2003. *Road Ecology: Science and Solutions*. Island Press, Washington.
- Ministério do Meio Ambiente (MMA). 2018. *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Mamíferos, v.2*. Brasília, ICMBio/MMA.
- International Union for the Conservation of Nature (IUCN ). 2019. The IUCN Red List of Threatened Species. Version 2019-1. Available at: <http://www.iucnredlist.org>.
- Jackson, N.D. & Fahrig, L. 2011. Relative effects of road mortality and decreased connectivity on population genetic diversity. *Biological Conservation*, 144(12), 3143-3148.
- Jaeger, J.A.G.; Bowman, J.; Brennan, J.; Fahrig, L.; Bert, D.; Bouchard, J.; Charbonneau, N.; Frank, K.; Gruber, B. & Von Toschanowitz, K.T. 2005. Predicting when animal populations are at risk from roads: An interactive model of road avoidance behavior. *Ecological Modelling*, 185: 329-348.
- Laurance, W.F.; Goosem, M. & Laurance, S.G.W. 2009. Impacts of roads and linear clearings on tropical forests. *Trends in Ecology and Evolution*, 24: 659-669.

Laurance, W.F.; Clements, G.R.; Sloan, S.; O'Connell, C.S.; Mueller, N.D.; Goosem, M.; Venter, O.; Edwards, D.P.; Phalan, B.; Balmford, A.; Van Der Ree, R. & Arrea, I.B. 2014. A global strategy for road building. *Nature*, 513: 229-232.

Leite, R.M.S.; Bóçon, R.; Belão, M. & Silva, J.C. 2012. Atropelamento de mamíferos silvestres de médio e grande porte nas rodovias PR-407 e PR-508, Planície Costeira do estado do Paraná, Brasil. *In*: Bager, A. (Ed.). *Ecologia de Estradas - Tendências e Pesquisas*. Lavras: UFLA. p. 193-205..

Lesbarreres, D. & Fahrig, L. 2012. Measures to reduce population fragmentation by roads: What has worked and how do we know? *Trends in Ecology and Evolution*, 27: 374-380.

Lynch Alfaro, J.W.; Boubli, J.P.; Olson, L.E.; Di Fiore, A.; Wilson, B.; Gutiérrez-Espeleta, G.A.; Chiou, K.L.; Schulte, M.; Neitzel, S.; Ross, V.; Schwochow, D.; Nguyen, M.T.T.; Farias, I.; Janson, C.H. & Alfaro, M.E. 2012. Explosive Pleistocene range expansion leads to widespread Amazonian sympatry between robust and gracile capuchin monkeys. *Journal of Biogeography*, 39: 272-288.

Lyra-Jorge, M.C.; Ribeiro, M.C.; Ciocheti, G.; Tambosi, L.R. & Pivello, V.R. 2010. Influence of multi-scale landscape structure on the occurrence of carnivorous mammals in a human-modified savanna, Brazil. *European Journal of Wildlife Research*, 56: 359-368.

Magioli, M.; Bovo, A.A. A.; Huijser, M.P.; Abra, F.D.; Miotto, R.A.; Andrade, V.H.V.P.; Nascimento, A.M.; Martins, M.Z.A. & Ferraz, K.M.P.M.B. 2019. Short and Narrow Roads Cause Substantial Impacts on Wildlife. *Oecologia Australis*, 23: 99-111.

Miranda, G.; Rodrigues, F. & Paglia, A. 2014. *Guia de Identificação de Pelos de Mamíferos Brasileiros*. Brasília: Ciências Forense.

Nordstokke, D. & Stelnicki, A.M. 2014. Pairwise Comparisons. *In*: Michalos, A.C. (Ed.). *Encyclopedia of Quality of Life and Well-Being Research*. Dordrecht- NL: Springer. p. 198-311

Oksanen, A.J.; Blanchet, F.G.; Friendly, M.; Kindt, R.; Legendre, P.; Mcglinn, D.; Minchin, P.R.; Hara, R.B.O.; Simpson, G.L.; Solymos, P.; Stevens, M.H.H. & Szoecs, E. 2019. Package 'vegan'.

Orlandin, E.; Piovesan, M.; Favretto, M.A. & D'Agostini, F.M. 2015. Mamíferos de Médio e Grande Porte Atropelados no Oeste de Santa Catarina, Brasil. *Biota Amazônia*, 5: 125-130.

Paglia, A.P.; Fonseca, G.A.B.; Rylands, A.B.; Herrmann, G.; Aguiar, L.M.S.; Chiarello, A.G.; Leite, Y.L.R.; Costa, L.P.; Siciliano, S.; Kierulff, M.C.M.; Mendes, S.L.; Mittermeier, R.A. & Patton, J.L. 2012. Annotated checklist of Brazilian mammals 2ª Edição. *Occasional Papers in Conservation Biology*. 6: 1-76.

Paraná. 2010. Publicado no Diário Oficial Nº 8233, de 1 de junho de 2010. *Reconhece e atualiza Lista de Espécies de Mamíferos pertencentes à Fauna Silvestre Ameaçadas de Extinção no Estado do Paraná e dá outras providências, atendendo o Decreto Nº 3.148 de 2004*. Available at: [http://www.planalto.gov.br/ccivil\\_03/\\_Ato2004-2006/2004/Decreto/D5025compilado.htm](http://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2004/Decreto/D5025compilado.htm)

Patton, J.L.; Pardiñas, U.F. & D'Elia G. 2015. *Mammals of South America: Rodents. 2nd ed.* Chicago, IL: University of Chicago Press.

Peel, M.C.; Finlayson, B.L. & McMahon, T.A. 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, 11: 1643-1644.

Poessel, S.A.; Burdett, C.L.; Boydston, E.E.; Lyren, L.M.; Alonso, R.S.; Fisher, R.N. & Crooks, K.R. 2014. Roads influence movement and home ranges of a fragmentation-sensitive carnivore, the bobcat, in an urban landscape. *Biological Conservation*, 180: 224-232.

Polak, T.; Rhodes, J.R.; Jones, D. & Possingham, H.P. 2014. Optimal planning for mitigating the impacts of roads on wildlife. *Journal of Applied Ecology*, 51: 726-734.

Quadros, J. & Monteiro-Filho, E.L.A. 2006. Coleta e preparação de pêlos de mamíferos para identificação em microscopia óptica. *Revista Brasileira de Zoologia*, 23: 274-278.

Quadros, J. & Filho, E.L.A.M. 2010. Identificação dos mamíferos de uma área de floresta atlântica utilizando a microestrutura de pelos-guarda de predadores e presas. *Arquivos Do Museu Nacional, Rio de Janeiro*, 68: 47-66.

Reis, N.R.; Peracchi, A.L.; Fragonezi, M.N. & Rossaneis, B.K. 2009. *Guia ilustrado dos mamíferos do Paraná - Brasil*. Pelotas, RS: Editora USEB.

Reis, N.R.; Peracchi, A.L.; Pedro, W.A. & Lima, I. P. 2011. *Mamíferos do Brasil, 2 ed.* Nélío R. dos Reis. Londrina.

- Reis, N. R.; Fragonezi, M.N.; Peracchi, A.L.; Shibatta, O.A.; Sartore, E.R.; Rossaneis, B.K.; Santos, V.R. & Ferracioli, P. 2014. *Mamíferos terrestres de médio e grande porte da Mata Atlântica: guia de campo*. Rio de Janeiro, RJ: Technical Books.
- Rytwinski, T.; Soanes, K.; Jaeger J.A.G; Fahrig, L.; Findlay, S.C.; Houlihan, J.; van der Ree, R. & van der Grift, E.A. 2016. How effective is road mitigation at reducing road-kill? A metaanalysis. *Plos ONE*, 11: e0166941
- Shapiro, S. S., & Wilk, M. B. 1965. An Analysis of Variance Test for Normality (Complete Samples). *Biometrika*, 52(3/4), 591–611.
- Seiler, A. & Helldin, J. 2006. Mortality in wildlife due to transportation. *In: Davenport, J., & Davenport, J.L. (eds.). The ecology of transportation: managing mobility for the environments*. Ireland: University College Cork. p. 165-190.
- SOS Mata Atlantica & Instituto Nacional de Pesquisas Espaciais (INPA). 2018. *Atlas dos remanescentes florestais da Mata Atlântica - Período 2016-2017*. Relatório técnico, São Paulo.
- Terborgh, J.; Estes, J.; Paquet, P.; Ralls, K.; Boyd-Heger, D.; Miller, B. & Noss, R. 1999. The role of top carnivores in regulating terrestrial ecosystems. *In: Soule, M.E. & Terborgh, J. (Eds.). Continental Conservation: Scientific Foundations of Regional Reserve Networks*. Washington, DC: Island Press. p. 39–64.
- Trigo, T.C.; Schneider, A.; De Oliveira, T.G.; Lehugeur, L.M.; Silveira, L.; Freitas, T.R.O. & Eizirik, E. 2013. Molecular data reveal complex hybridization and a cryptic species of Neotropical wild cat. *Current Biology*, 23: 2528-2533.
- Tucker, M.A; Ord, T.J. & Rogers, T.L. 2014. Evolutionary predictors of mammalian home range size: Body mass, diet and the environment. *Global Ecology and Biogeography*, 23(10), 1105–1114.
- Vasconcelos, Y. 2017. Animais na pista. *Revista Pesquisa FAPESP*, 260: 69-71.
- Zanzini, A.C.S.; Machado, F.S.; de Oliveira, J.E. & de Oliveira, E.C.M. 2018. Roadkills of medium and large-sized mammals on highway BR-242, midwest Brazil: A proposal of new indexes for evaluating animal roadkill rates. *Oecologia Australis*, 22: 248-257.

Zeliski, T.; Rocha V.J; Filipaki, S.A. & Monteiro-Filho, E.L.A. 2009. Run-over of wild mammals in the area of Telêmaco Borba, Paraná, Brazil. *Natureza & Conservação*, 07: 195-2007.

Wand, M. 2015. KernSmooth. Functions for Kernel Smoothing Supporting Wand & Jones (1995). *R Package Version 2.23-15.*, 2: 19-22.

Wand, M.P. & Jones, M.C. 1995. *Kernel Smoothing (Chapman & Hall/CRC Monographs on Statistics and Applied Probability)*. Chapman and Hall/CRC press.

Weiss, L.P. & Vianna, V.O. 2013. Levantamento do impacto das rodovias BR-376, BR-373 e BR-277, trecho de Apucarana a Curitiba, Paraná, no atropelamento de animais silvestres. *Publicatio UEPG: Ciências Biológicas e Da Saúde*, 18: 121-133.

### CAPÍTULO 3

## Modeling the geographic distribution of *Myocastor coypus* (Mammalia, Rodentia) in Brazil: establishing priority areas for monitoring and an alert about the risk of invasion

Alan Deivid Pereira, Ricardo, José Ricardo Pires Adelino, Diego Azevedo  
Zoccal Garcia, Armando Cesar Rodrigues Casimiro, Ana Carolina Vizintim  
Marques, Ana Paula Vidotto-Magnoni, Sergio Bazilio & Mário Luís Orsi

Capítulo redigido e publicado segundo as normas do periódico *Studies on Neotropical Fauna  
and Environment*, disponível em: <https://doi.org/10.1080/01650521.2019.1707419>





# Modeling the geographic distribution of *Myocastor coypus* (Mammalia, Rodentia) in Brazil: establishing priority areas for monitoring and an alert about the risk of invasion


Alan Deivid Pereira, José Ricardo Pires Adelino, Diego Azevedo Zoccal Garcia, Armando Cesar Rodrigues Casimiro, Ana Carolina Vizintim Marques, Ana Paula Vidotto-Magnoni, Sergio Bazilio & Mário Luís Orsi



To cite this article: Alan Deivid Pereira, José Ricardo Pires Adelino, Diego Azevedo Zoccal Garcia, Armando Cesar Rodrigues Casimiro, Ana Carolina Vizintim Marques, Ana Paula Vidotto- Magnoni, Sergio Bazilio & Mário Luís Orsi (2020): Modeling the geographic distribution of *Myocastor coypus* (Mammalia, Rodentia) in Brazil: establishing priority areas for monitoring and an alert about the risk of invasion, Studies on Neotropical Fauna and Environment, DOI: [10.1080/01650521.2019.1707419](https://doi.org/10.1080/01650521.2019.1707419)

To link to this article: <https://doi.org/10.1080/01650521.2019.1707419>

 View supplementary material 

 Published online: 01 Jan 2020. 

Submit your article to this journal 

 View related articles 

 View Crossmark data   
CrossMark



# Modeling the geographic distribution of *Myocastor coypus* (Mammalia, Rodentia) in Brazil: establishing priority areas for monitoring and an alert about the risk of invasion

Alan Deivid Pereira<sup>a</sup>, José Ricardo Pires Adelino<sup>a</sup>, Diego Azevedo Zoccal Garcia<sup>b</sup>, Armando Cesar Rodrigues Casimiro<sup>a</sup>, Ana Carolina Vizintim Marques<sup>a</sup>, Ana Paula Vidotto-Magnoni<sup>b</sup>, Sergio Bazilio<sup>c</sup> and Mário Luís Orsi<sup>b</sup>

<sup>a</sup>Programa de Pós-Graduação em Ciências Biológicas, Centro de Ciências Biológicas, Departamento de Biologia Animal e Vegetal, Universidade Estadual de Londrina, Londrina, Brazil; <sup>b</sup>Centro de Ciências Biológicas, Departamento de Biologia Animal e Vegetal, Laboratório de Ecologia de Peixes e Invasões Biológicas, Universidade Estadual de Londrina, Londrina, Brazil; <sup>c</sup>Campus de União da Vitória, Universidade Estadual do Paraná – UNESPAR, União da Vitória, Brazil

## ABSTRACT

*Myocastor coypus* is a large semi-aquatic rodent ranked as one of the 100 most invasive species in the world. In Brazil, few ecological studies have been proposed to understand the relationship of this species with the environment. To date, drivers that facilitate its establishment in new areas remain unknown. However, it is generally accepted that the natural distribution of this species is limited to far southern Brazil. The present study aimed to understand the geographic distribution of *M. coypus* and indicate areas of greater risk of establishment based on bioclimatic predictors and a surveillance map. We observed that *M. coypus* suitability and risk assessment areas are restricted to the southeastern and southern regions of Brazil and that anthropogenic landscape modifications are an adequate variable to explain the occurrence of the species. Due to the environmental impacts caused by this species, monitoring in environments where it has been introduced is required. The model used herein presented efficient applicability and fit for Brazil. Preventive actions and the management of *M. coypus* in predicted regions prior to its establishment are recommended.

## ARTICLE HISTORY

Received 16 January 2019  
Accepted 15 December 2019

## KEYWORDS

Biological distribution;  
ecosystem engineering;  
invasion; risk assessment;  
nutria

## Introduction

Popularly known as coypu or nutria, *Myocastor coypus* (Molina 1782) is a large semi-aquatic rodent and the only species comprising the Myocastoridae family (Mammalia, Rodentia) (Woods et al. 1992). Native to South America, typically near the Maipo River in the Santiago province (Chile), the species was originally distributed from Patagonia (a sub-region of northern Argentina) to Bolivia, Paraguay, Uruguay, and Chile, as well as in far southern Brazil (Woods et al. 1992). *Myocastor coypus* was also introduced to Europe, Asia, Africa, and North America for fur farming and meat production. It is considered a highly invasive species in many countries today (Carter & Leonard 2002).

This species can alter natural habitats by feeding on aquatic vegetation, destroying nests, and preying on the eggs of several aquatic birds (Scaravelli 2002). Additionally, it can feed on a variety of crops and

weaken riverbanks through its burrowing activity (Carter & Leonard 2002; Guichón & Cassini 2005). Due to the negative impact of this species to the economy, freshwater environments, and agricultural activities (Bertolino 2009), it is ranked as one of the top 100 worst invasive species in the world (Lowe et al. 2000). Several countries carry out permanent population control campaigns (Carter & Leonard 2002; Pepper et al. 2017), with successful eradication undertaken in two small regions of the United States (Carter & Leonard 2002; Jarnevich et al. 2017; Pepper et al. 2017), as well as larger areas within the United Kingdom (Jarnevich et al. 2017). In this context, it is crucial to investigate the relationship between *M. coypus* and the non-native environments it inhabits in order to anticipate and avoid potential negative environmental and economic impacts.

Few ecological studies on this species were performed in Brazil, and, to date, its geographical limits and facilitating factors concerning access to new areas

remain unknown. Among the few studies that reported the economic or environmental impacts caused by *M. coypus* in Brazil, Odebrecht et al. (2013) reported that, during the El Niño of 2002 and 2003, *M. coypus* reduced the biomass of smooth cordgrass (*Spartina alterniflora* Loisel) by 80% from the low marshes at Lagoa dos Patos in the state of Rio Grande do Sul. In the state of Santa Catarina, *M. coypus* has been pointed out as responsible for the disruption of fish farming ponds (S. Bazilio, pers. comm., 2018). Due to the limited information about the occurrence of this species in Brazil, it is difficult both to estimate its relationship with the environment and to develop the appropriate management and conservation responses. Therefore, it is necessary to employ statistical tools that can be prioritized for decision-making instead.

Environmental niche models (ENMs) are a common tool in ecology, and a practical approach to understanding potential species distribution based on the relationship between occurrences and environmental information (Franklin & Miller 2010). As ENMs allows for spatial and temporal transferability, a large number of studies use niche models in a biological invasion context (Jiménez-Valverde et al. 2011). The main purposes of these models are 1) to anticipate species introductions (Farashi & Najafabadi 2015, 2017; Adelino et al. 2017; Hiltz et al. 2019); 2) build risk assessment models (Jiménez-Valverde et al. 2011; West et al. 2018; Hiltz et al. 2019), and 3) generate conservation and decision-making information (Venette et al. 2010; Hiltz et al. 2019). Thus, ENMs are useful tools to detect areas with higher quality environmental conditions for *M. coypus*. Therefore, with the knowledge that *M. coypus* currently occurs in non-native areas (based on IUCN data), we aimed to 1) understand the geographic distribution of *M. coypus* based on bioclimatic predictors, and 2) create a surveillance map to indicate the areas in which this species is more likely to establish itself once it has access to them.

## Material and methods

### Native occurrence data

Native species occurrence data (N = 9,563) was obtained from the Global Biodiversity Facility Database ([www.gbif.com](http://www.gbif.com)). Species locality data attached in digital databases are often biased (Maldonado et al. 2015) as sampling is undertaken in easily accessible areas, or within close proximity to roads (Kadmon et al. 2004). Therefore, sampling bias can affect the accuracy of the prediction of environment niche models (Peterson et al. 2008). In order to

control the negative effects of spatial sampling biases in environment niche models, we applied a spatial filter analysis (Boria et al. 2014).

The spatial filter uses randomization algorithms to optimize the geographical distance between each occurrence record within a required geographical distance. This approach allows for controlling the spatial correlation in the occurrence data and is crucial to reduce the effects of uneven or biased occurrence points for a given species (Aiello-Lammens et al. 2015). Here, we run the spatial filter algorithm implemented in the R package (spThin) as proposed by Aiello-Lammens et al. (2015) using a minimum distance parameter of 10 km.

Although the minimum distance from each occurrence point can be controlled according to the species' movement ability, for our focal species, we understand that a 10 km distance accounts for this (Woods et al. 1992). Therefore, it is useful to ensure the spatial independence of observed occurrences. In order to maximize the number of independent spatial occurrences, we repeated the procedure 100 times and used the repetition that presented the greatest number of occurrences (N = 104). This occurrence data (Native data hereafter) was used to model the environmental niche relating to the *M. coypus* native occurrence range (Supplementary Material 01).

### Brazilian occurrence data

Species occurrences in Brazil were obtained through the following steps: 1) Searching published data available in scientific journals (N = 17), and 2) Field observation (N = 5) using an ad libitum technique (Altman 1974). The latter was obtained through field incursions in the northern and southern regions of the state of Paraná (PR), and in the northern region of the state of Santa Catarina (SC) between 2012 and 2017. In order to formally record the presence of the species in a new area, one specimen sampled in Londrina (PR) was deposited in the Museum of Zoology of the Universidade Estadual de Londrina, Londrina, PR (Voucher Number MZUEL 376). The searches for available scientific articles were performed using the advanced research tool in Web of Science, Scopus, Google Scholar, and Scielo databases. For each one, we used the following keyword combinations: i) 'Myocastor coypus' and 'Brazil,' 'Ratão do banhado' and 'Brazil,' 'Myocastor coypus' and 'Brazilian Territory,' and 'Myocastor coypus' and 'occurrence.' For all useful articles, we collected the geographical coordinates, locality (municipality), state, and biome (Supplementary Material 02). These occurrences

(Brazil data hereafter) were used to model the environmental niche of *M. coypus* occurrence range in Brazil.

### *Environmental data and variable selection*

Climate data were obtained from the WorldClim database version 2.0 (Fick & Hijmans 2017). We use Principal Component Analysis (PCA) to select, reduce and producing uncorrelated variables (Legendre & Legendre 1998; Peterson et al. 2011; Adelino et al. 2017). This was done by keeping the variable with the highest loading when variables were correlated (Supplementary Material 03), considering variables that are relevant to the ecology of the *M. coypus*. The procedure was performed independently by each dataset (i.e. Native and Brazil data set).

Additionally, because of the presence of *M. coypus* in human-associated landscapes, we chose to input the human footprint environmental layer as additional environmental information (Wildlife Conservation Society, Center for International Earth Science Information Network, 2005; available at <http://sedac.ciesin.columbia>) for measuring the Human Influence Index (HII) in the landscapes.

### *Environmental niche models (ENM)*

Because of the differences in the approaches to modeling the species environmental niche (Franklin & Miller 2010), a combination of different algorithms in the form of an ensemble model should be employed (Araújo & New 2007). Ensemble models are used as a means of combining different algorithms in a weighted approach. Furthermore, because niche models can be grouped by the level of complexity (Rangel & Loyola 2012) and type of data used for the model, we used three different classes of algorithms (i.e. confidence interval, distance measure, and machine learning) to model the potential distribution of *M. coypus*.

We used the following environmental niche models: Bioclim (Nix 1986; Booth et al. 2014), Domain (Carpenter et al. 1993), Support Vector Machine (Guo et al. 2005; Drake et al. 2006), and Maxent (Phillips et al. 2004). We chose these distribution models due to their capacity for model species-environment relationships using presence-only data (Franklin & Miller 2010)

In order to generate the information modeled by each dataset, we combined the native-only and the Brazilian-only models into one final model (i.e. ensemble). The ensemble approach helps to reduce the dissimilarity

between the models and enables an improvement in the predictive capacity of the final model (Araújo & New 2007). For each dataset, we ran 100 repetitions by each algorithm and used the mean suitability values overall models to generate the final suitability model (see Supplementary Material 04 for more details).

### *Model calibration and model evaluation*

For each model, we used 75% of the occurrence data ( $N_{\text{native}} = 78$ ,  $N_{\text{Brazil}} = 16$ ) to calibrate the models, and 25% of the occurrence data ( $N_{\text{native}} = 26$ ,  $N_{\text{Brazil}} = 6$ ) to validate the models. Because we had presence-only information, we used the pseudo absence technique to simulate the absence data in the geographical space. Pseudo absence randomly samples the cells within the geographical region to create background information, which is then used to test the accuracy of the model (Franklin & Miller 2010).

The most traditional measure of accuracy in niche models is the Area Under the Receiver Operating Characteristic Curve (ROC), which measures the capacity of the model to discriminate between true positive values and false positives (Fielding & Bell 1997). However, this measure can be overestimated (Peterson et al. 2008), and different approaches can be used to measure the accuracy of the model (Allouche et al. 2006; Peterson et al. 2008).

In order to reduce the evaluation biases, we evaluated the model fit using the partial area under the ROC curve (Peterson et al. 2008). This was performed in the 'Partial ROC' software (Barve 2008). We performed the Partial ROC approach using 1,000 iterations. For each one, 50% of the test data (i.e. bootstrap) was re-sampled, and a 95% error was accepted. Models that had partial pAUC ratio  $>1$  were considered as being better than a random performance and were combined in one final model (Peterson et al. 2008).

### *Surveillance map*

To estimate the potential distribution of the species in Brazil, we used the sensitivity = specificity threshold. This allowed us to identify all the grid cells that can be estimated as presence (cell value = 1) or absence (cell value = 0) for the species (a.k.a. Binary models) in each algorithm and dataset with pAUC ratio  $>1$ . We chose the sensitivity = specificity threshold because it is an acceptable measure that minimizes the mean positive and negative error rates (Liu et al. 2005).

This procedure produced eight binary maps (4 algorithms x 2 regions). All binary models were then overlapped, and the values of each grid cell were summed

to create a surveillance map. The surveillance map represents the agreement of the models to predict each grid cell as a potential region for the occurrence of the species. This approach was previously suggested to increase model accuracy by reducing the variability of projected models (Araújo & New 2007) and has been previously applied in different ecological situations (Carnaval & Moritz 2008; Porto et al. 2013).

Considering the context of invasive species studies, if all models predict the same grid cell as suitable for the presence of the species, then the grid cell represents an important geographical region for surveillance. Conversely, if all models predict the same grid cell as unsuitable for species presence (i.e. absence), then the grid cell represents a less important geographical region for surveillance.

We then used the quantiles of the summed values of each grid cell ( $N_{\text{sum}} = 8$ ) to assign one of four classifications for the Surveillance index: 1) Without Surveillance: less than two models predict the cell as an occurrence; 2) Lower Surveillance: two to four models predict the cells with presence; 3) Moderate Surveillance: four to six models predict the cells with presence, and 4) Great Surveillance: more than six

models predict the cells with presence. All analyzes were conducted using the R software (R Core Team 2015) dismo package (Hijmans et al. 2016).

## Results

The literature review resulted in 17 published studies between 2000 and 2016 (Table S1) and included specimens from five states covering the Southern and Southeast regions of Brazil and throughout two biomes – Pampa and Atlantic Rainforest (Figure 1). *Myocastor coypus* was recorded in five new locations from 2012 to 2017, four in the state of Paraná and one in the state of Santa Catarina.

All algorithms were considered as presenting a good model fit (Table 1). Variables presenting the highest relative importance values were 'Human Footprint,' 'Mean Temperature of the Coldest Quarter,' and 'Minimum Temperature of the Coldest Month' (Table 1). Human Footprint was positively associated with *M. coypus* suitability ( $r = 0.6$ ), while Mean Temperature of the Coldest Quarter ( $r = -0.48$ ), Min Temperature of the Coldest Month ( $r = -0.35$ ), and Annual Precipitation ( $r = -0.31$ )

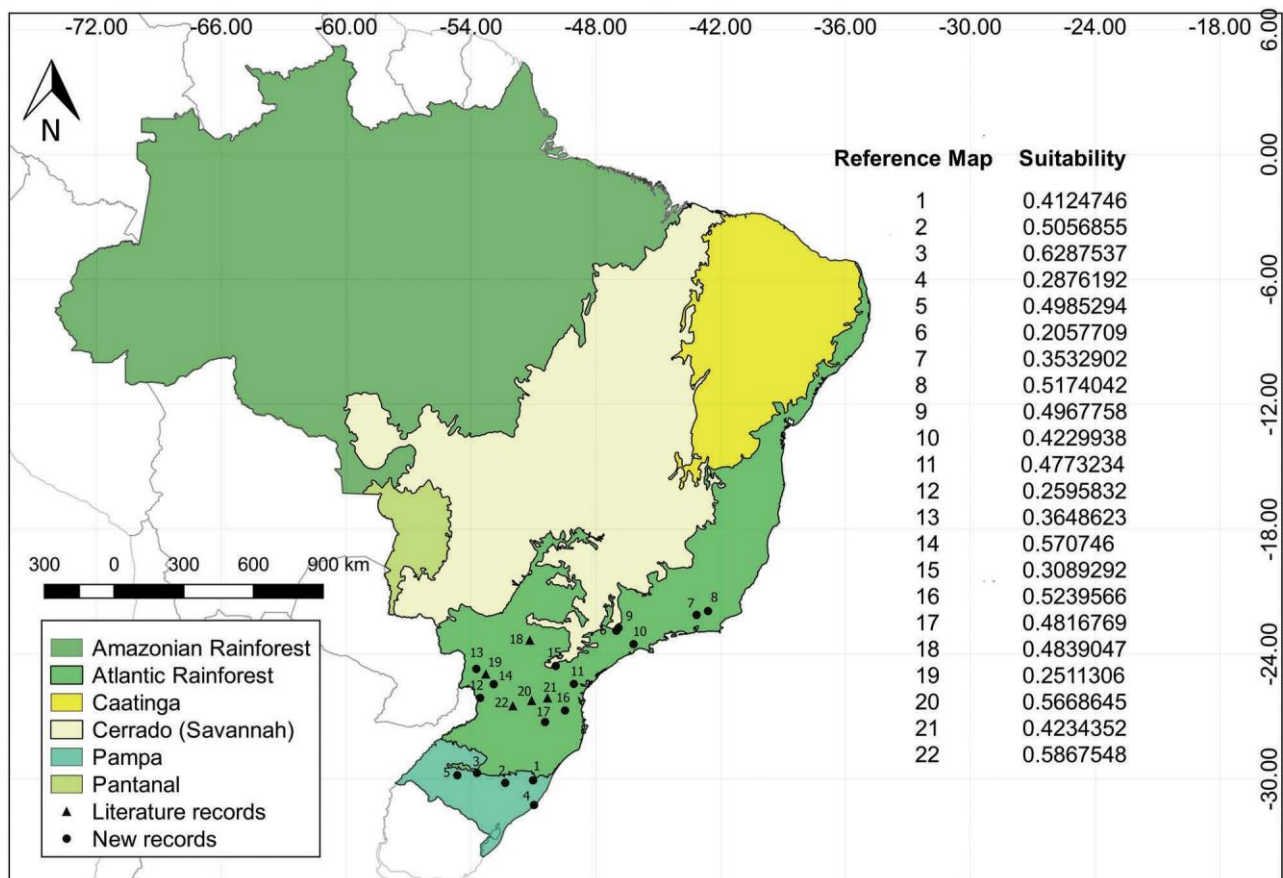


Figure 1. *Myocastor coypus* records in Brazilian biomes and the suitability values for each record.

**Table 1.** Partial area under the curve (pAUC) and threshold values (sensitivity = specificity) for the four algorithms used to model the potential distribution of *Myocastor coypus* (models were combined if pAUC > 1). The relative importance of each variable used to model the distribution of *Myocastor coypus* are displayed below the table.

Model metrics	Native data		Brazil records	
	pAUC ratio	Threshold	pAUC ratio	Threshold
Bioclim	1.745 ± 0.211	0.09636443	1.966 ± 0.000	0.1558118
Domain	1.619 ± 0.478	0.64056412	1.997 ± 0.000	0.4945468
Maxent	1.767 ± 0.283	0.34659937	1.994 ± 0.000	0.4151913
SVM	1.731 ± 0.341	0.48329812	1.999 ± 0.000	0.5336144

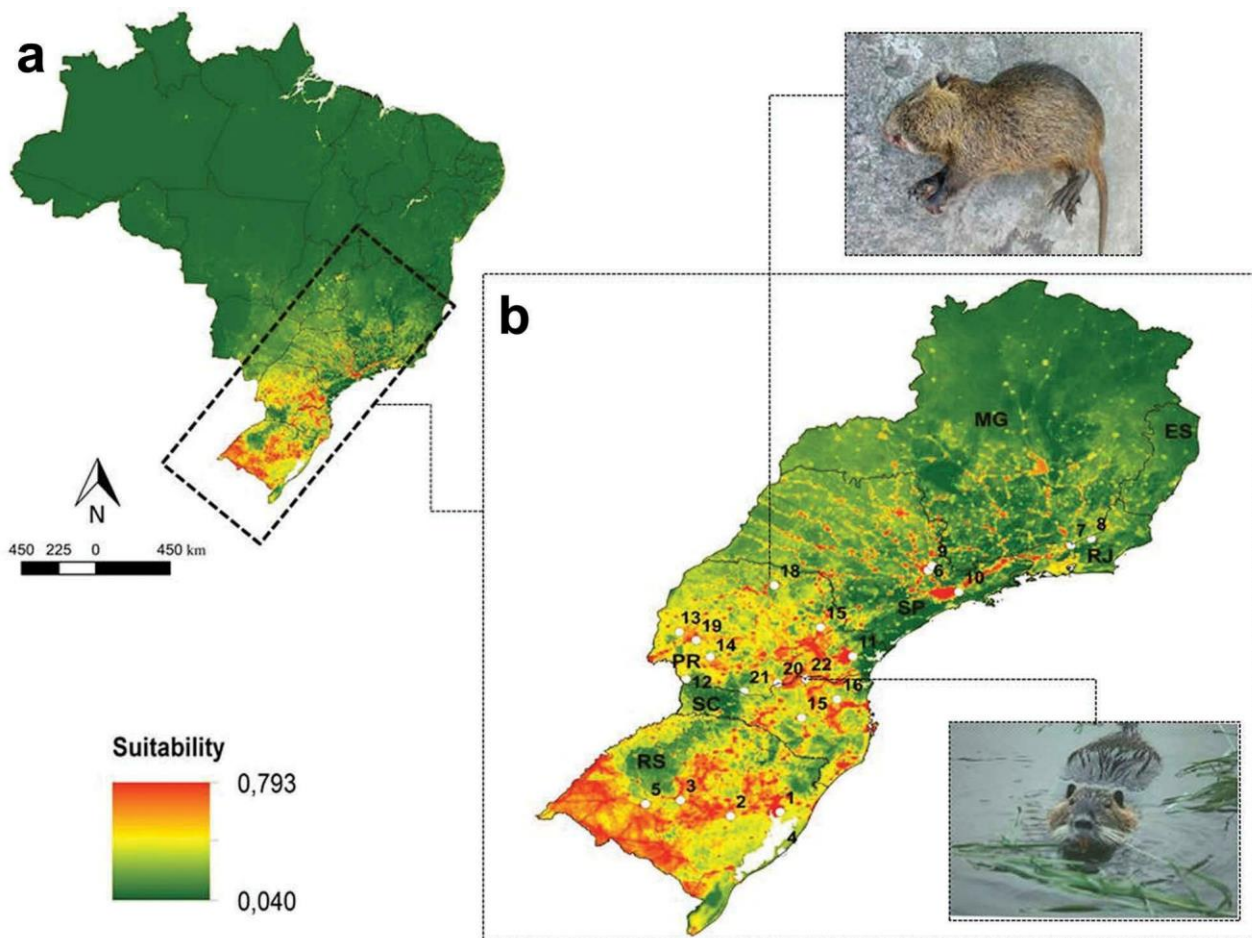
  

Combined model	
Environmental layers	Relative importance
Human Footprint	0.333
Mean Temperature of Coldest Quarter	0.208
Min Temperature of Coldest Month	0.201
Temperature Annual Range	0.116
Precipitation of Wettest Quarter	0.091
Annual Precipitation	0.051

were negatively associated with the presence of this species (see Supplementary Material 05).

Suitable regions were concentrated along the south-eastern and southern regions of Brazil (Figure 2a).

Areas exhibiting greater suitability values for the occurrence of the species are concentrated in the eastern and western mesoregions of the state of Rio Grande do Sul, the southern region of the state of Santa Catarina, and



**Figure 2.** Suitability map for *Myocastor coypus* occurrences in Brazil (a). South and Southeast Brazil, with confirmed occurrences in the published scientific literature (b). Low suitability values are represented by green and high suitability values are represented by red. Highlighted, a photographic record of *M. coypus* through opportunistic observations in northern of the state of Santa Catarina and the record of a run-over specimen on the PR-538 highway, near the Cafezal River, in the municipality of Londrina, PR.

the south and southeastern regions of the state of Paraná (Figure 2b). The highest suitability values were observed for the Pampa biome at 0.63, followed by the Atlantic Rainforest Biome, at 0.59. The lowest suitability value was found for the ecotone regions between the Atlantic rainforest and the Cerrado, at 0.24 (Figure 1 and Table S1).

The surveillance map (i.e. the combination of binary maps) (Figure 3a; for more detail see Supplementary Material 04) indicated that the prevalence observed for the South and Southern regions were classified at lower and moderate grid cell values. High-risk classification cells were concentrated in the states of Santa Catarina and the Rio Grande do Sul. Further, small high-risk patches were distributed along with the state of Paraná (Figure 3b). Of all 22 occurrences in Brazil, 50%

(N = 11) fell into grid cells classified as moderate risk, 22.7% (N = 5) as lower risk, 13.6% (N = 3) as without risk, and 9.09% (N = 2) as high risk (Figure 3c).

## Discussion

This study was the first to compile information about the current occurrence of *M. coypus* in the Brazilian territory, as well as modeling the occurrence of this species with a more accurate and updated database based on confirmed occurrences. Here, we considered this species to be native to the extreme southern Brazil only (Pampa biome), diverging from the information provided by IUCN but in accordance with studies of the species' natural history, which proposed that southern part of the state

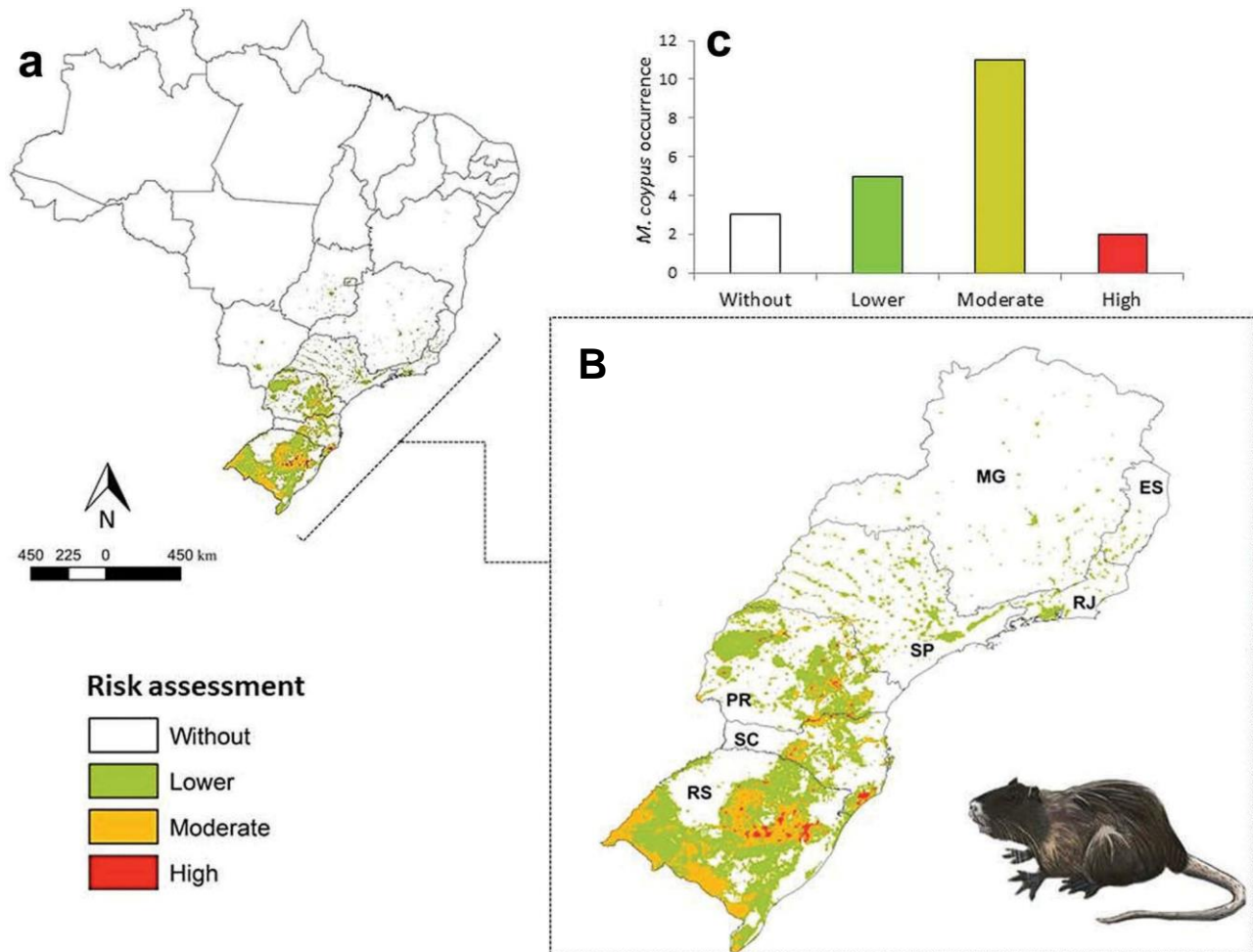


Figure 3. Surveillance map, combined binary map for the occurrence of *Myocastor coypus* in Brazil. (a) The southeastern and southern regions of Brazil are highlighted. (b) Record percentages in relation to risk assessment for Brazil areas.

of Rio Grande do Sul could be considered its native region (Woods et al. 1992). Our review of the occurrence points of *M. coypus* for Brazil indicated that its presence in southeastern Brazil is attributed to escapes from fur farms, meat production, and deliberate introductions in lagoons and rivers (Bueno 2013). Currently, this species is easily registered in flooded pastures and floodplain areas in the states of São Paulo and Rio de Janeiro (non-native region) (Rocha et al. 2004; Bueno 2013). In the state of Paraná, this species is already on the list of invasive alien species, and its transportation, creation, release or translocation, cultivation, propagation (by any means of reproduction), commercialization, donation, or intentional acquisition in any form is prohibited (IAP 2015).

The suitability model developed in the present study suggested suitable areas in Brazil were mainly found in the Atlantic Forest biome in the states of Santa Catarina, Paraná, São Paulo, and Rio de Janeiro (i.e. the Southeastern region of Brazil) (Figure 2). Our models identified that some environmental variables, such as variations in temperature, as well as the annual mean precipitation, explain the current range of *M. coypus*. We found that Annual Precipitation and Precipitation of Driest Quarter are important climatic contributors in predicting suitable areas for the *M. coypus*. These climatic variables had a negative effect on suitability of coypu, which indicate that this species can be favored in dry regions provided that they are associated with water resources (e.g. rivers and streams) as shown in previous studies (Carter & Leonard 2002; Hong et al. 2014; Farashi & Najafabadi 2015, 2017; Hilts et al. 2019).

Regarding temperature variables, according to the models developed by Gosling et al. (1983) and Jarnevich et al. (2017), *M. coypus* suffers population declines due to the adverse temperature effects in environments with temperature ranging between zero and five degrees (i.e. freezing days). However, even in its native range (i.e. Patagonia Region), this species is expected to survive low temperatures during severe winters, provided that ice sheets do not form over waterbodies for long periods of time (Ehrich 1962). Previous studies have reported that nutria densities declined 71% after river channels were frozen for 20 days (Doncaster & Micol 1989). Recently, Hilts et al. (2019) modeled the distribution of *M. coypus* based on climate change projections for 2050. As a result, the authors found that, on a broad scale, areas with  $\leq 80$  annual freezing days are more suitable for *M. coypus* establishment and prosperity. At local scales, habitat covariates, (e.g. areas with high proportions of

freshwater forested-shrub wetlands close to other wetlands) better reflect the ecological niche of this species (Hilts et al. 2019). In this context, for Neotropical regions where there are no sequential freezing days (such as Brazil), the temperature may not be a limiting factor for the occurrence of *M. coypus*. We believe that the establishment of this species in new areas is dependent only on access to new regions as well as the availability of resources in these areas.

The Human Footprint variable (i.e. landscape modification by human activities) was the most important predictor related to the occurrence of *M. coypus* in Brazil. Other researchers indicated that human disturbance represented by human population density in urban areas, distance to roads, distance to settlements and urban areas, and bare and rocky areas are important factors affecting the *M. coypus* distribution (Guichón & Cassini 2005; Bertolino & Ingegno 2009; Farashi & Najafabadi 2015). This positive correlation may be an indicator of the species' resilience in human environments (i.e. synanthropic species), a hitherto underestimated attribute for this species.

Due to widespread damage caused to ecosystems, with effects on crops and riverine vegetation by *M. coypus* (Vilà et al. 2010), several control and eradication programs have been carried out in countries where the species was introduced (Carter & Leonard 2002; Pepper et al. 2017). This species is capable of weakening dikes and irrigation structures through the grazing and undermining of riverbanks by burrowing (Sofia et al. 2017), and can, therefore, be considered an environmental engineer. According to Sofia et al. (2017), the most critical damage caused by *M. coypus* – in purely economic terms – is related to drainage structures, with direct costs for the structure management, and indirect costs connected to flooding. In recent years, Coypu-related problems have been increasing rapidly in several countries (Carter & Leonard 2002; Pepper et al. 2017). However, there is still no quantified information about the economic and environmental impact caused by this species in Brazil.

The surveillance map indicated that the Southeastern and Southern regions of Brazil could be considered more vulnerable to the establishment of *M. coypus*. Larger patches of the Santa Catarina coast and of the Rio Grande do Sul mainland were pointed out as the areas with the highest invasion risk, provided this species has access to them (see Figure 3). This could be related to the latitudinal similarity; therefore, the environmental congruence between the north region of the species' native range

and the Brazilian observed range. Conversely, the data presented herein suggest stronger environmental dissimilarity between the North region of the species' native range and Southeast of the detected Brazilian range. This can be observed by the prevalence of lower invasion risk classes in the states of São Paulo, Rio de Janeiro, Espírito Santo, and Minas Gerais. Indeed, because climate matching is an important assumption for reproduction success between environments (Holt et al. 2005).

The dispersion access of this species to new areas may easily occur in lower Brazilian latitudes, as human landscape modifications and river fragmentation by dams may facilitate its establishment. Such dams may also exhibit greater aquatic macrophyte abundances, which are an important primary food requirement for *M. coypus* (Guichón et al. 2003). We also found strong indicators that it was introduced in the northern and southern regions of Paraná in addition to documented evidence that it was introduced to the Southeast of Brazil. For this reason, further studies on the possible introduction in new areas and subsequent outcomes for *M. coypus* are essential for management measures. The model used herein presented efficient applicability and fit and can also be extended to other non-native invasive species. Our results may be an adequate basis for further studies aimed at understanding the dispersion and distribution of *M. coypus* in Brazil, as well as for management actions, if necessary.

## Acknowledgments

We thank the Postgraduate Program in Biological Sciences of the Universidade Estadual de Londrina and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES-Funding Code 1689817), for logistical and financial support.

## Disclosure statement

No potential conflict of interest was reported by the authors.


## Funding


This work was supported in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - [Proc.1689817]; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior [1689817].


## ORCID

Alan Deivid Pereira  <http://orcid.org/0000-0002-3182-2344>

José Ricardo Pires Adelino  <http://orcid.org/0000-0002-8637-2838>

Diego Azevedo Zoccal Garcia  <http://orcid.org/0000-0001-5709-6347>

Armando Cesar Rodrigues Casimiro  <http://orcid.org/0000-0001-8826-5609>

Ana Carolina Vizintim Marques  <http://orcid.org/0000-0003-4978-9260>

Ana Paula Vidotto-Magnoni  <http://orcid.org/0000-0003-1819-7019>

Sergio Bazilio  <http://orcid.org/0000-0003-3577-8931>

Mário Luís Orsi  <http://orcid.org/0000-0001-9545-4985>

## References

- Adelino JRP, Anjos L, Lima MR. 2017. Invasive potential of the pied crow (*Corvus albus*) in eastern Brazil: best to eradicate before it spreads. *Perspect Ecol Conserv.* 15 (3):227–233.
- Aiello-Lammens ME, Boria RA, Radosavljevic A, Vilela B, Anderson RP. 2015. spThin: an R package for spatial thinning of species occurrence records for use in ecological niche models. *Ecography.* 38 (5):541–545.
- Allouche O, Tsoar A, Kadmon R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *J Appl Ecol.* 43:1223–1232.
- Altman J. 1974. Observational study of behavior: sampling methods. *Behaviour.* 49(3):227–267.
- Araújo MB, New M. 2007. Ensemble forecasting of species distributions. *Trends Ecol Evol.* 22(1):42–47.
- Barve N. 2008. Tool for partial-ROC, ver. 1.0. Lawrence (KS): Biodiversity Institute.
- Bertolino S. 2009. Species account of the 100 of the most invasive alien species in Europe: *myocastor coypus* (Molina), coypu, nutria (Myocastoridae, Mammalia). In: DAISIE handbook of alien species in Europe. Invading nature—springer series in invasion ecology, v3. Dordrecht (Netherlands): Springer. p. 269–364
- Bertolino S, Ingegno B. 2009. Modelling the distribution of an introduced species: the coypu *Myocastor coypus* (Mammalia, Rodentia) in Piedmont region, NW Italy. *Ital J Zool.* 76(3):340–346.
- Booth TH, Nix HA, Busby JR, Hutchinson MF. 2014. Bioclim: the first species distribution modelling package, its early applications and relevance to most current MaxEnt studies. *Divers Distrib.* 20(1):1–9.
- Boria RA, Olson LE, Goodman SM, Anderson RP. 2014. Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. *Ecol Modell.* 275:73–77.
- Bueno C. 2013. Ocorrência de *Myocastor coypus* Molina, 1782 no Estado do Rio de Janeiro. *Bol Da Soc Bras Mastozool.* 66:9–11.
- Carnaval AC, Moritz C. 2008. Historical climate modelling predicts patterns of current biodiversity in the Brazilian Atlantic forest. *J Biogeogr.* 35:1187–1201.
- Carpenter G, Gillison AN, Winter J. 1993. Domain - a flexible modeling procedure for mapping potential distributions of plants and animals. *Biodivers Conserv.* 2 (6):667–680.

- Carter J, Leonard BP. 2002. A review of the literature on the worldwide distribution, spread of, and efforts to eradicate the coypu (*Myocastor coypus*). *Wildl Soc Bull.* 30 (1):162–175.
- Doncaster CP, Micol T. 1989. Annual cycle of a coypu (*Myocastor coypus*) population: male and female strategies. *J Zool (Lond.)*. 217:227–240.
- Drake JM, Randin C, Guisan A. 2006. Modelling ecological niches with support vector machines. *J Appl Ecol.* 43 (3):424–432.
- Ehrich S. 1962. Experiment on the adaptation of nutria to winter conditions. *J Mammal.* 43:418.
- Farashi A, Najafabadi MS. 2015. Modeling the spread of invasive nutrias (*Myocastor coypus*) over Iran. *Ecol Complexity.* 22:59–64.
- Farashi A, Najafabadi MS. 2017. A model to predict dispersion of the alien nutria, *Myocastor coypus* Molina, 1782 (Rodentia), in Northern Iran. *Acta Zool Bulg.* 69(1):65–70.
- Fick SE, Hijmans RJ. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *Int J Climatol.* 37(12):4302–4315.
- Fielding A, Bell J. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environ Conserv.* 24(1):38–49.
- Franklin J, Miller JA. 2010. *Mapping Species Distributions. Spatial Inference and Prediction.* London (UK): University Press, Cambridge.
- Gosling LM, Baker SJ, Skinner JR. 1983. A simulation approach to investigating the response of a coypu population to climatic variation. *EPPO Bull.* 13(2):183–192.
- Guichón ML, Benítez VB, Abba A, Borgnia M, Cassini MH. 2003. Foraging behaviour of coypus *Myocastor coypus*: why do coypus consume aquatic plants? *Acta Oecologica.* 24(5):241–246.
- Guichón ML, Cassini MH. 2005. Population parameters of indigenous populations of *Myocastor coypus*: the effect of hunting pressure. *Acta Theriol.* 50(1):125–132.
- Guo Q, Kelly M, Graham CH. 2005. Support vector machines for predicting distribution of sudden oak death in California. *Ecol Modell.* 182(1):75–90.
- Hijmans RJ, Phillips S, Leathwick J, Elith J. 2016. *Dismo: species distribution modeling.* R package version 1.1-1; [cited 2018 Nov 17]. Available from: <https://CRAN.R-project.org/package=dismo>
- Hilts DJ, Belitz MW, Gehring TM, Pangle KL, Uzarski DG. 2019. Climate change and nutria range expansion in the Eastern United States. *J Wildl Manag.* 83(3):591–598.
- Holt RD, Barfield M, Gomulkiewicz R. 2005. Theories of niche conservatism and evolution. In: Sax DF, Stachowicz JJ, Gaines SD, editors. *Species invasions: insights into ecology, evolution, and biogeography.* Oxford: Sinauer. p. 256–290.
- Hong S, Do Y, Kim JY, Kim DK, Joo GJ. 2014. Distribution, spread and habitat preferences of nutria (*Myocastor coypus*) invading the lower Nakdong River, South Korea. *Biol Invasions.* 17(5):1–12.
- Instituto Ambiental do Paraná: IAP. 2015. PORTARIA IAP Nº 059, DE 15 DE ABRIL DE 2015: lista Oficial de Espécies Exóticas Invasoras para o Estado do Paraná. [cited 2018 Dec 22]. Available from: [http://www.iap.pr.gov.br/arquivos/File/Lista\\_invasoras\\_PR\\_corrigida\\_set\\_2015.pdf](http://www.iap.pr.gov.br/arquivos/File/Lista_invasoras_PR_corrigida_set_2015.pdf)
- Jarnevich C, Young N, Sheffels T, Carter J, Sytsma M, Talbert C. 2017. Evaluating simplistic methods to understand current distributions and forecast distribution changes under climate change scenarios: an example with coypu (*Myocastor coypus*). *NeoBiota.* 32:107–125.
- Jiménez-Valverde A, Peterson AT, Soberón J, Overton JM, Aragón P, Lobo JM. 2011. Use of niche models in invasive species risk assessments. *Biol Invasions.* 13(12):2785–2797.
- Kadmon R, Farber O, Danin A. 2004. Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. *Ecol Appl.* 14(2):401–413.
- Legendre P, Legendre L. 1998. *Numerical ecology.* Amsterdam: Elsevier.
- Liu C, Berry PM, Dawson TP, Pearson RG. 2005. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography.* 28(3):385–393.
- Lowe SJ, Browne M, Boudjelas S, De Pooter M. 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. Auckland (NZ): Invasive Species Specialist Group (ISSG).
- Maldonado C, Molina CI, Zizka A, Persson C, Taylor CM, Albán J, Chilquillo E, Rønsted N, Antonelli A. 2015. Estimating species diversity and distribution in the era of Big Data: to what extent can we trust public databases? *Glob Ecol Biogeogr.* 24(8):973–984.
- Nix HÁ. 1986. A biogeographic analysis of Australian elapid snakes. In: Longmore R, editor. *Atlas of elapid snakes of Australia.* Australian flora and fauna series. Canberra: Australian Government Publishing Service. p. 4–15.
- Odebrecht C, Abreu PC, Bemvenuti CE, Cooling LA, Copertino M, Costa CSB, Garcia AM, Marangoni JC, Moller OO, Muelbert JH, et al. 2013. O efeito de perturbações naturais e antrópicas na ecologia do estuário da lagoa dos patos. In: Tabarelli M, Rocha CFF, Romanowski HP, Rocha O, Lacerda LD, editors. *Dez anos do Programa de Pesquisas Ecológicas de Longa Duração do Brasil: achados, lições e perspectivas.* Recife (PE): Editora Universitária da UFPE. p. 223–248.
- Pepper MA, Herrmann V, Hines JE, Nichols JD, Kendrot SR. 2017. Evaluation of nutria (*Myocastor coypus*) detection methods in Maryland, USA. *Biol Invasions.* 19:831–841.
- Peterson AT, Papes M, Soberón J. 2008. Rethinking receiver operating characteristic analysis applications in ecological niche modeling. *Ecol Modell.* 213(1):63–72.
- Peterson AT, Soberón J, Pearson RG, Anderson RP, Martínez-Meyer E, Nakamura M, Araújo MB. 2011. *Ecological niches and geographic distributions.* Princeton: Princeton University Press.
- Phillips SJ, Dudík M, Schapire RE. 2004. A maximum entropy approach to species distribution modeling. *Proceedings of the 21st International Conference on Machine Learning, ACM Press, New York.*
- Porto TJ, Carnaval AC, Rocha PLB. 2013. Evaluating forest refugial models using species distribution models, model filling and inclusion: a case study with 14 Brazilian species. *Diversity Distrib.* 19(3):330–340.
- R Core Team. 2015. *R: a language and environment for statistical computing.* R foundation for statistical computing, Vienna, Austria. [cited 2018 Nov 17]. Available from: <https://www.R-project.org>
- Rangel TF, Loyola RD. 2012. Labeling ecological niche models. *Nat Conserv.* 10(2):119–126.

- Rocha CFD, Bergallo HG, Pombal JP, Geise L, Sluys MV, Fernandes R, Caramaschi U. 2004. Fauna de anfíbios, répteis e mamíferos do Estado do Rio de Janeiro, sudeste do Brasil. *Publicações Avulsas Do Mus. Nac. Do Rio Janeiro*. 104:3–23.
- Scaravelli D. 2002. Problema *Myocastor*: considerazioni dell'esperienza ravennate. In: Petrini R, editor. *La gestione delle specie alloctone in Italia: il caso dela nutria e del gambero rosso della Louisiana*. Firenze: Proceedings of a National Congress; p. 25–28.
- Sofia G, Masin R, Tarolli P. 2017. Prospects for crowd-sourced information on the geomorphic 'engineering' by the invasive *Coypu* (*Myocastor coypus*). *Earth Surf Process Landforms*. 42:365–377.
- Venette RC, Kriticos DJ, Magarey RD, Koch FH, Baker RHA, Worner SP, Gómez Raboteaux NN, McKenney DW, Dobesberger EJ, Yemshanov D, et al. 2010. Pest risk maps for invasive alien species: a roadmap for improvement. *Bioscience*. 60(5):349–362.
- Vilà M, Basnou C, Pyšek P, Josefsson M, Genovesi P, Gollasch S, Nentwig W, Olenin S, Roques A, Roy D, Hulme PE. 2010. How well do we understand the impacts of alien species on ecosystem services? A pan-taxa assessment. *Front Ecol Environ*. 8:135–C144. doi:10.1890/080083
- West AM, Jarnevich CS, Young NE, Fuller PL. 2018. Evaluating potential distribution of high-risk aquatic invasive species in the water garden and aquarium trade at a global scale based on current established populations. *Risk Anal*. 38(11):1–23.
- Woods CA, Contreras L, Willner-Chapman G, Whidden HP. 1992. *Myocastor coypus*. *Mamm Species*. 398:1–8.

## **SUPPORT MATERIAL**

## Support Material

### **Modeling the geographic distribution of *Myocastor coypus* (Mammalia, Rodentia) in Brazil: Establishing priority areas for monitoring and an alert about the risk of invasion.**

Alan Deivid Pereira<sup>a\*</sup>, José Ricardo Pires Adelino<sup>a</sup>, Diego Azevedo Zoccal Garcia<sup>b</sup>, Armando Cesar Rodrigues Casimiro<sup>a</sup>, Ana Carolina Vizintim Marques<sup>a</sup>, Ana Paula Vidotto-Magnoni<sup>b</sup>, Sergio Bazilio<sup>c</sup>, Mário Luís Orsi<sup>b</sup>

#### **1. Spatial filter**

**Figure. S1.** Occurrence points before and after spatial filter.

#### **2. Occurrence data**

**Table S1.** *Myocastor coypus* coordinates occurrence records in Brazil.

#### **3. Selection of Bioclimatic variables**

**Table S2:** PCA loading values of GBIF thinned data set inside native range.

**Table S3:** PCA loading values from Brazilian thinned data set.

**Figure. S2:** Ordination plot of climate variables. All results were obtained only with native data according with IUCN.

**Figure. S3:** Ordination plot of climate variables. Loading values results with native and Brazil occurrences

#### **4. Ecological Niche Models and model evaluation**

**Figure. S4:** Suitability models calibrated with GBIF native occurrences and projected within Brazilian range.

**Figure. S5:** Suitability models calibrated with Brazilian occurrences (i.e. data set two) and projected within Brazilian range.

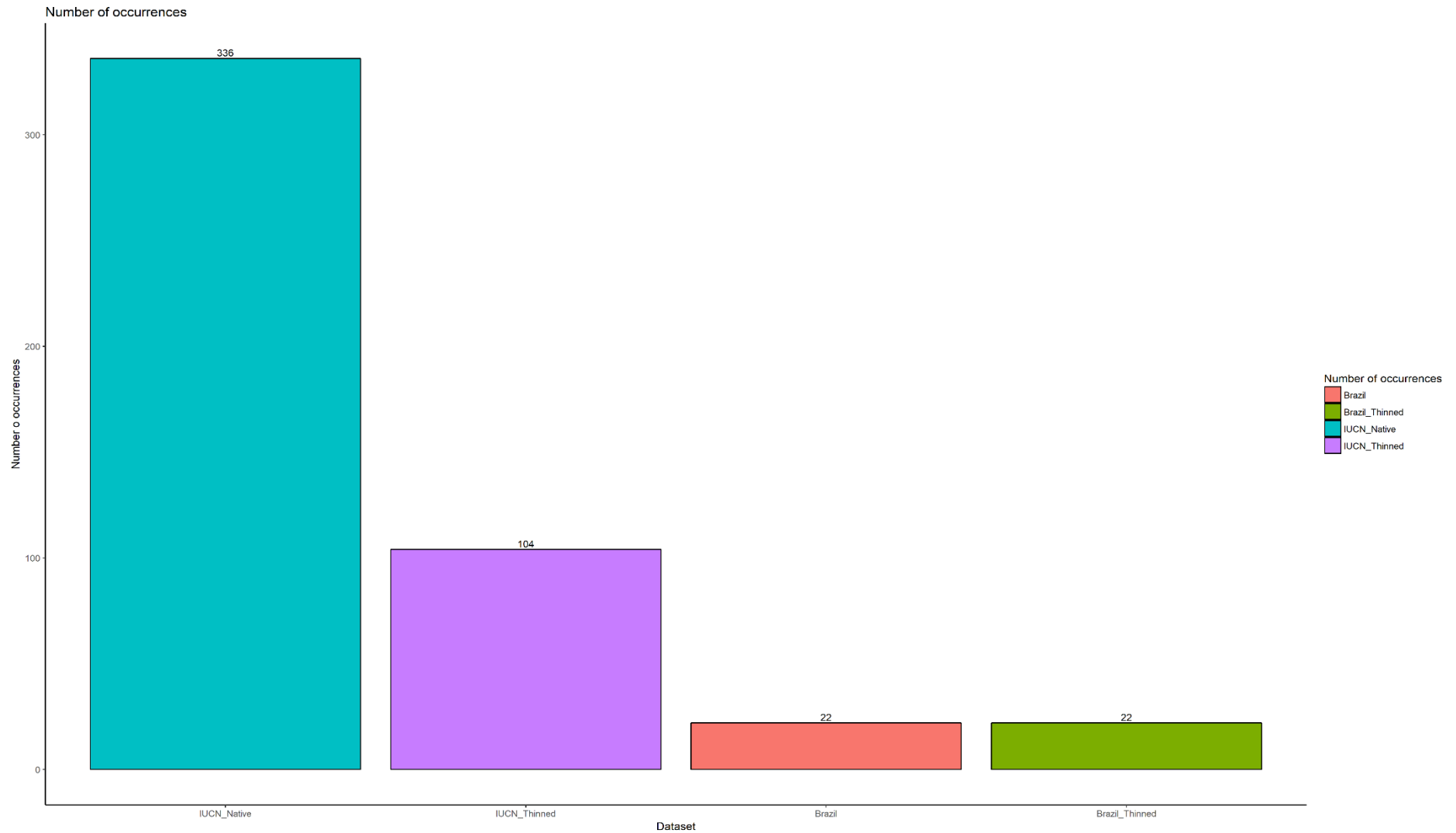
**Figure. S6.** Binary classification maps for the four different niche models used to model *M. coypus*. Each classification maps were obtained from GBIF occurrences in native range and projected within Brazilian range.

**Figure. S7.** Binary classification maps for the four different niche models used to model *M.coypus*.

#### **5. Supplementary Results**

**Figure. S8.** Correlation plot.

## 1. Spatial filter



**Fig. S1.** Occurrence points before and after spatial filter. **Blue bar** = Raw GBIF coordinate data points before spatial filter, **Purple** = Thinned GBIF coordinate data points after spatial filter, **Red** = Raw Brazil coordinate data points before spatial filter, **Green** = Thinned Brazil coordinate data points before spatial filter.

## 2. Occurrence data

**Table S1.** *Myocastor coypus* coordinates occurrence records in Brazil. **Locality:** Municipality in which each species coordinate was observed, **State:** State in which each species coordinate was observed: Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP); Rio de Janeiro (RJ), **Biome:** landscape classification in which each species coordinate was observed, **Reference:** information source in which each species coordinate was gathered, **Map ID:** point label for each occurrence in map reference (see Fig. 2 in manuscript), NR indicate *ad libitum* observations by S. Bazilio or M. L. Orsi and DR indicate dead species founded in the road. **Suitability:** suitability values for each occurrence points in Brazil.

Latitude	Longitude	Locality	State	Biome	Reference	Map ID	Suitability
30°4'8.97"S	51°1'2.70"W	Viamão	RS	Pampa	Cademartori & Machado, 2002	1	0.4124746
30°11'29"S	52°21'25"W	Pantano Grande	RS		Steil et al., 2016	2	0.5056855
29°42'59.11"S	53°42'42.25"W	Santa Maria	RS		Santos et al., 2008	3	0.6287537
31°15'17.40"S	50°58'18.01"W	Tavares	RS		Colares et al., 2000	4	0.2876192
29°49'30.00"S	54°49'30.00"W	Cacequi	RS		Pinto & Duarte, 2013	5	0.4985294
22°52'48.85"S	47°0'54.12"W	Campinas	SP	Cerrado/ Atlantic Rain Forest	Angelo et al., 2016	6	0.2057709
21°56'01"S	42°36'31"W	Rio de Janeiro	RJ	Atlantic Rain Forest	Rocha et al., 2004	7	0.3532902
22°07'09"S	43°09'22"W	Três Rios	RJ		Bueno, 2013	8	0.5174042
22°44'21"S	46°54'27"W	Pedreira	SP		Lemos et al., 2004	9	0.4967758
23°31'22"S	46°11'18"W	Mogi das Cruzes	SP		Martins et al., 2017	10	0.4229938
25°26'4.59"S	49°3'18.90"W	Piraquara	PR		Cáceres, 2004	11	0.4773234
26°06'37"S	53°33'40"W	Bom Jesus do Sul	PR		Wolfart et al., 2013	12	0.2595832
24°42'49"S	53°44'35"W	Toledo	PR		Junior & Silva, 2015	13	0.3648623
25°26'59"S	52°54'29"W	Quedas do Iguaçu	PR		Juraszek et al., 2014	14	0.570746
24°34'22"S	49°55'35"W	Piraí do Sul	PR		Grazzini et al., 2015	15	0.3089292
27°16'00"S	50°26'26"W	São Cristóvão do Sul	SC		Cherem et al., 2007	16	0.5239566
26°42'44.98"S	49°28'51.39"W	Doutor Pedrinho	SC		Tortato et al., 2014	17	0.4816769
23°19'37.12"S	51°10'32.54"W	Londrina	PR		<i>Present study (DR)</i>	18	0.4839047
24°57'21"S	53°27'19"W	Cascavel	PR		<i>Present study (NR)</i>	19	0.2511306
26°13'48"S	51°05'11"W	União da Vitória	PR		<i>Present study (NR)</i>	20	0.5668645
26°29'03"S	51°59'26"W	Palmas	PR		<i>Present study (NR)</i>	21	0.4234352
26°06'23"S	50°19'20"W	Três Barras	SC		<i>Present study (NR)</i>	22	0.5867548

### 3. Selection of Bioclimatic variables

Climate data were obtained from the WorldClim database version 2.0 (Fick and Hijmans, 2017). The WorldClim database has 19 bioclimatic variables. Because few number of studies focused in species environmental relationship we choose to no previously select the variables used in the model. However, because the negative effects of collinearity variables in environmental niche models we selected the variables using multivariate approach. To do this, we extracted the environmental values from each thinned data set (850 occurrences for the dataset one and 22 for the dataset two) and submit both datasets to a PCA analyses. We used highest loading values for the two principal components to identify correlated variables (i.e., had similar vector directions) (Table S2 and table S3).

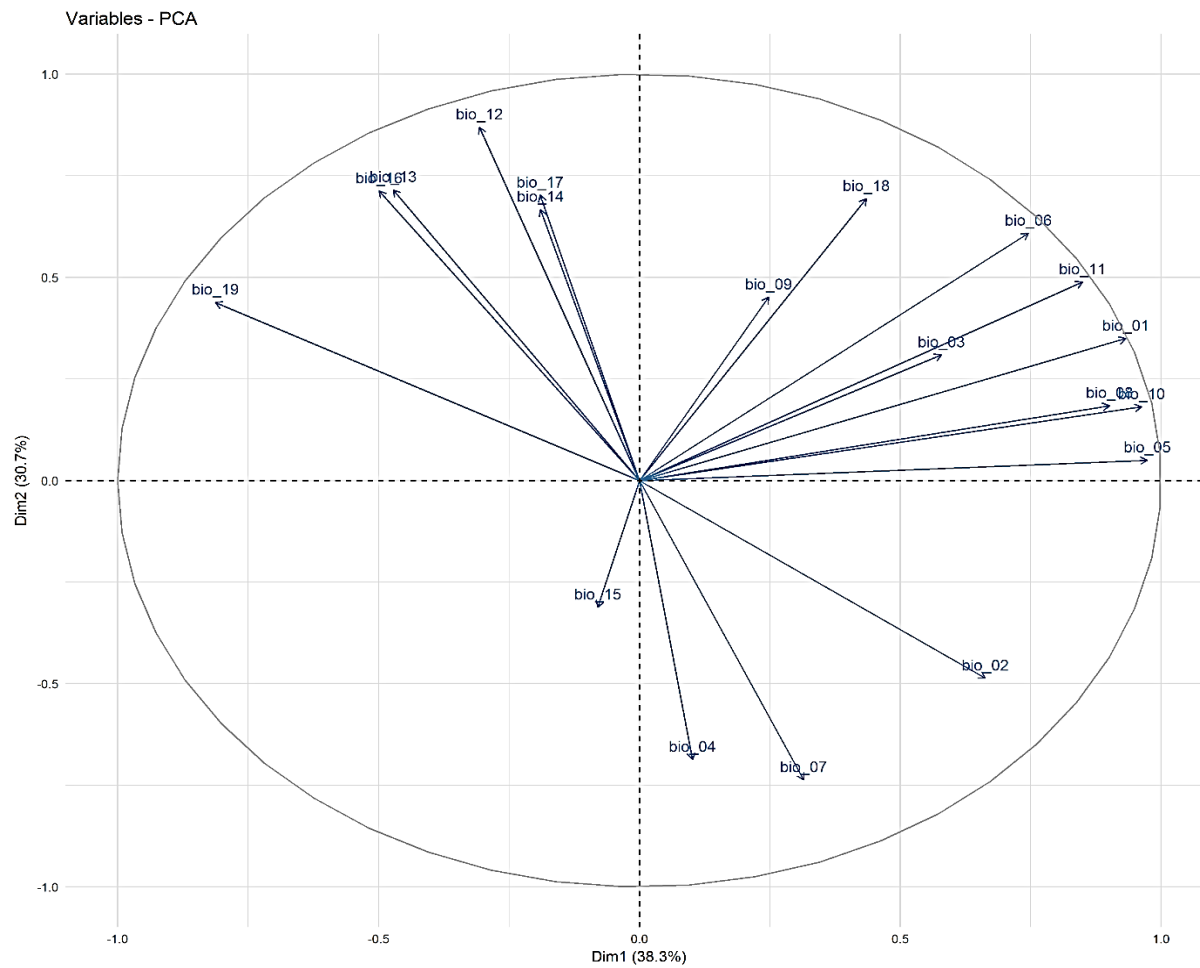
**Table S2:** PCA loading values of GBIF thinned data set inside native range. In bold, selected bioclimatic variables names and values of retained variables. PC1 = first component of PCA, PC2 = second component of PCA.

Variable	Bioclimatic Variable Names	PC1	PC2
bio_01	Temperature Annual Range	0.346	0.145
bio_02	Mean Diurnal Range (mean of monthly (max temp – min temp))	0.246	-0.201
bio_03	Isothermality ((BIO2/BIO7)* 100)	0.215	0.128
bio_04	Temperature Seasonality (standard deviation *100)	0.038	-0.284
<b>bio_05</b>	<b>Max Temperature of Warmest Month</b>	<b>0.361</b>	0.021
bio_06	Min Temperature of Coldest Month	0.277	0.252
<b>bio_07</b>	<b>Temperature Annual Range</b>	0.117	<b>-0.305</b>
bio_08	Mean Temperature of Wettest Quarter	0.334	0.076
bio_09	Mean Temperature of Driest Quarter	0.092	0.187
bio_10	Mean Temperature of Warmest Quarter	0.357	0.075
bio_11	Mean Temperature of Coldest Quarter	0.315	0.202
<b>bio_12</b>	<b>Annual Precipitation</b>	-0.114	<b>0.36</b>
bio_13	Precipitation of Wettest Month	-0.175	0.296
bio_14	Precipitation of Driest Month	-0.07	0.276
bio_15	Precipitation Seasonality (coefficient of variation)	-0.03	-0.129
bio_16	Precipitation of Wettest Quarter	-0.185	0.295
bio_17	Precipitation of Driest Quarter	-0.071	0.291
bio_18	Precipitation of Warmest Quarter	0.161	0.287
<b>bio_19</b>	<b>Precipitation of Coldest Quarter</b>	<b>-0.302</b>	0.181

**Table S3:** PCA loading values from Brazilian thinned data set. In bold, loading bioclimatic variables names and values of retained variables. PC1 = first component of PCA, PC2 = second component of PCA.

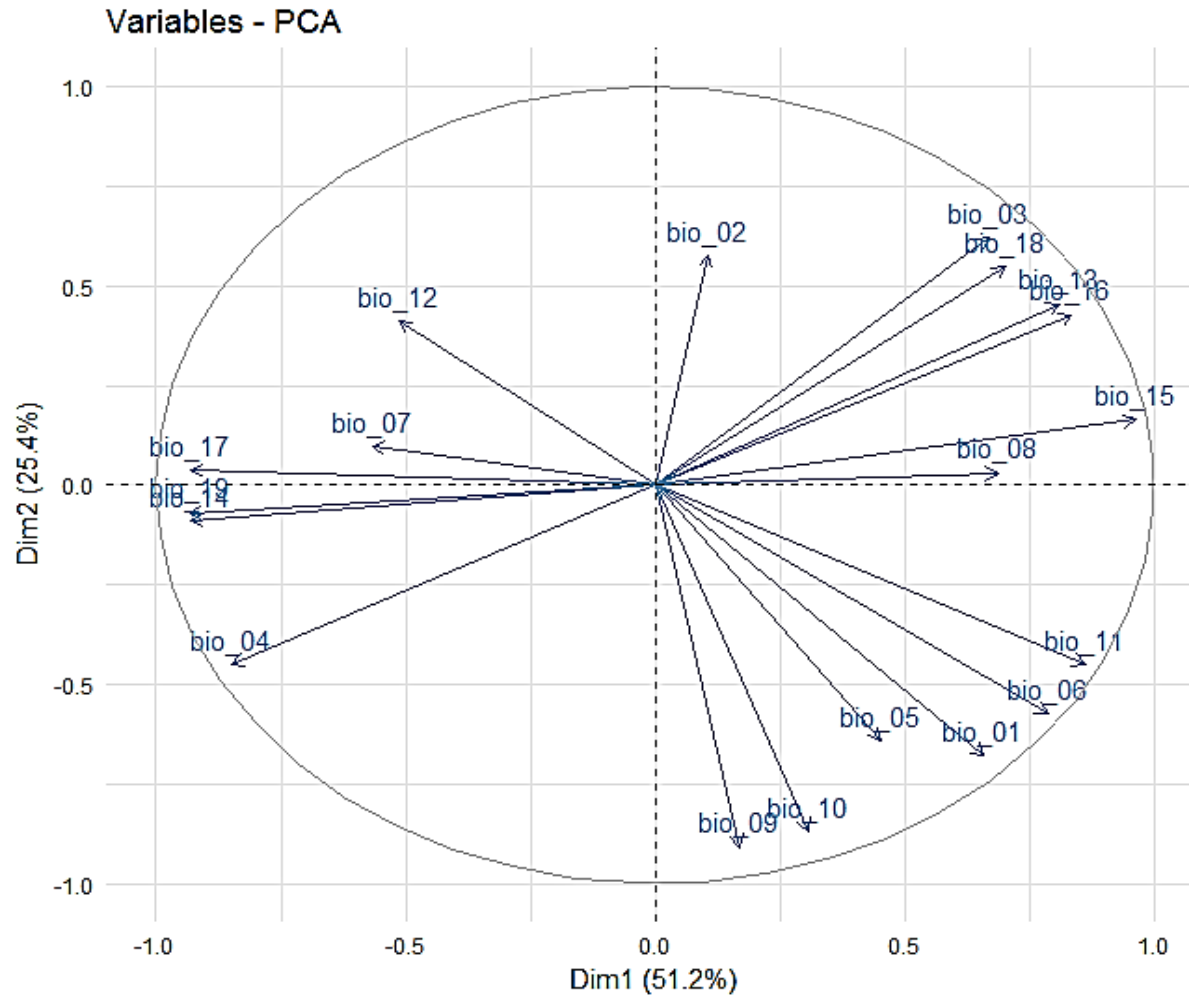
Variable	Bioclimatic Variable Names	PC1	PC2
<b>bio_01</b>	Temperature Annual Range	0.211	<b>-0.309</b>
bio_02	Mean Diurnal Range (mean of monthly (max temp – min temp))	0.034	0.262
<b>bio_03</b>	<b>Isothermality ((BIO2/BIO7)* 100)</b>	<b>0.215</b>	<b>0.283</b>
<b>bio_04</b>	<b>Temperature Seasonality (standard deviation *100)</b>	<b>-0.272</b>	<b>-0.205</b>
bio_05	Max Temperature of Warmest Month	0.145	-0.292
<b>bio_06</b>	Min Temperature of Coldest Month	<b>0.253</b>	<b>-0.261</b>
bio_07	Temperature Annual Range	-0.181	0.044
bio_08	Mean Temperature of Wettest Quarter	0.220	0.014
<b>bio_09</b>	Mean Temperature of Driest Quarter	<b>0.054</b>	<b>-0.414</b>
bio_10	Mean Temperature of Warmest Quarter	0.098	-0.396
<b>bio_11</b>	Mean Temperature of Coldest Quarter	<b>0.276</b>	<b>-0.206</b>
<b>bio_12</b>	Annual Precipitation	<b>-0.164</b>	<b>0.187</b>
bio_13	Precipitation of Wettest Month	0.259	0.208
<b>bio_14</b>	Precipitation of Driest Month	<b>-0.299</b>	<b>-0.041</b>
<b>bio_15</b>	<b>Precipitation Seasonality (coefficient of variation)</b>	<b>0.309</b>	<b>0.075</b>
<b>bio_16</b>	Precipitation of Wettest Quarter	<b>0.267</b>	<b>0.195</b>
bio_17	Precipitation of Driest Quarter	-0.298	0.017
bio_18	Precipitation of Warmest Quarter	0.225	0.250
bio_19	Precipitation of Coldest Quarter	-0.299	-0.032

The vector directions (Fig S2 and Fig S3) indicate the correlation of variable with the component axes and therefore allow us to choose the variable that more contribute with the variable explanation from each axis.



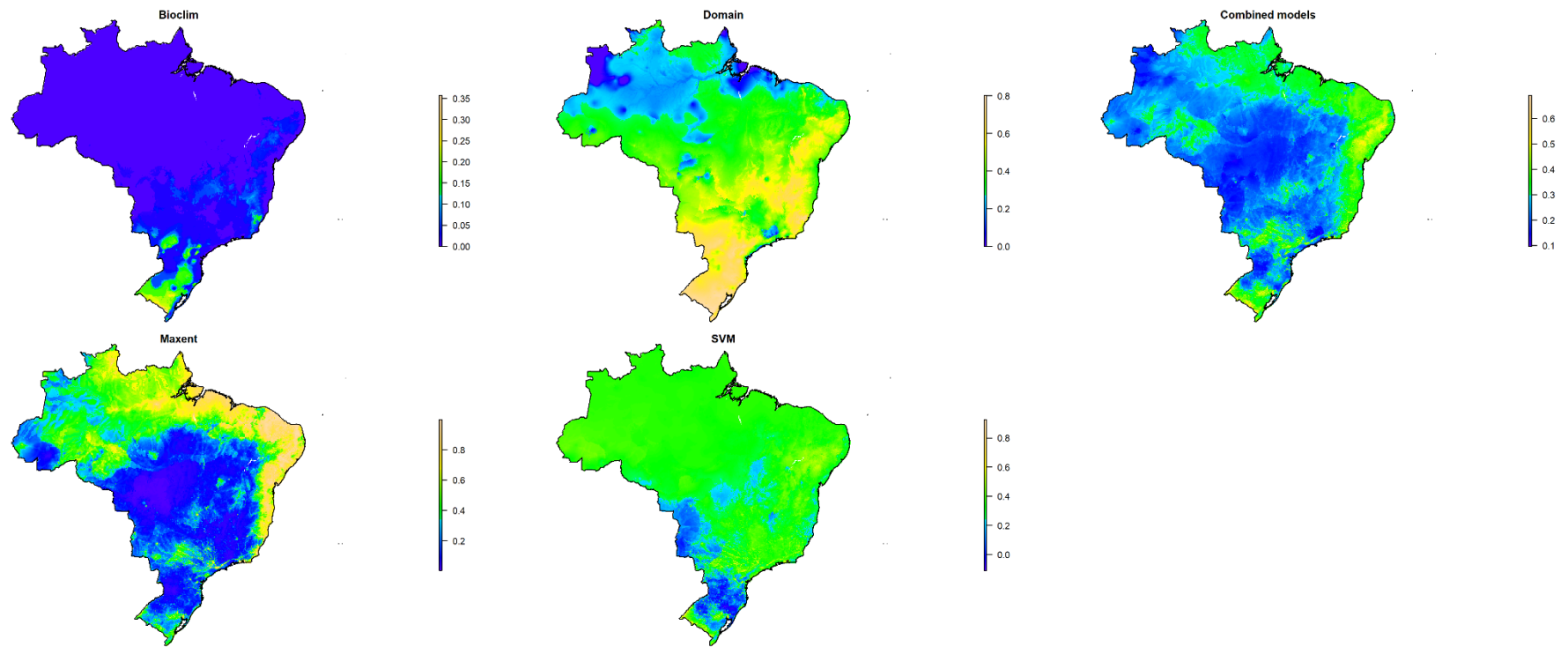
**Fig. S2:** Ordination plot of climate variables. All results were obtained only with native data according with IUCN.

**Fig. S3:** Ordination plot of climate variables. Loading values results with native and Brazil occurrences.

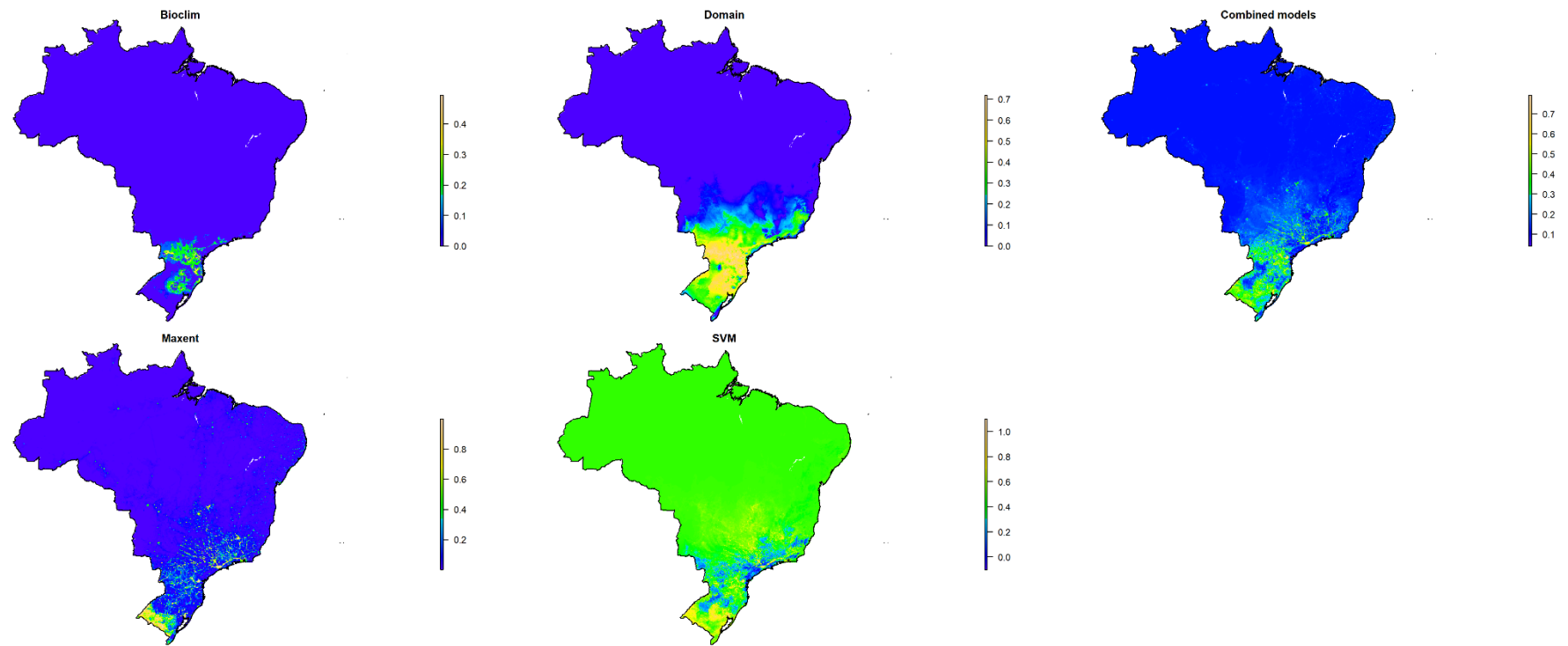


#### 4. Ecological Niche Models and model evaluation

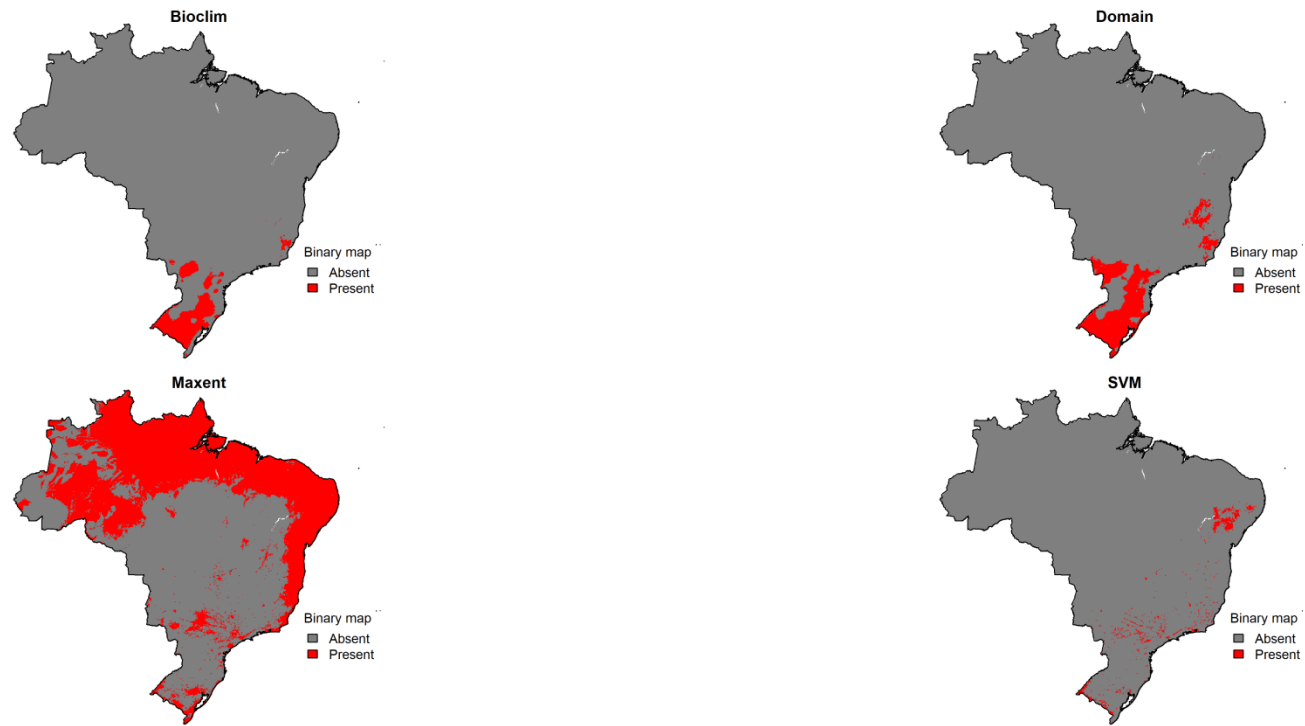
Environmental niche models are computational approach to execute a sequence of mathematical functions that allows correlate species occurrence with environmental data (here called algorithm). This results in the suitability environmental maps which that can be projected among space and time (Peterson, 2003). However, different algorithms result in different ecological dissimilarities and therefore influencing the precision, accuracy and reality of the models (Rangel & Loyola, 2012). Further, a large number of algorithms can be used to model species environmental relationship and are classified in: 1) Distance measures model, 2) Regression methods models and 3) Machine learning methods (Franklin, 2010). Hence, because each environmental niche models are fitted with different mathematical parameters, usually different algorithms result in different predictive models. Although, due to higher variation in model performance (Diniz-Filho et al., 2009), combine multiple models (i.e. ensemble approach) is pointed out as a better alternative to reduce methodological dissimilarity between (Araújo and New, 2007). Therefore, the ensemble approach increases the predictivity capacity of the final model. In this study, we analyzed *M.coypus* occurrence with the following environmental niche models: Bioclim (Nix, 1986; Booth et al., 2014), Domain (Carpenter et al., 1993), Support Vector Machine (Guo et al., 2005; Drake et al., 2006), and Maxent (Phillips et al., 2004). We choose these distribution models due to the capacity to model species environment relation with presence only data (Franklin, 2010). Each environmental niche model was built using 100 iterations and the mean suitability values were used to generate a final distribution model for each of the four algorithms (Fig S4 and S5). All models presented mean pROC values larger than one. Hence, we combined all models to produce a single final model. To do this, we used the mean suitability per grid cell among all environmental niche models. We then, used the sensitivity = specificity threshold to create a binary map for each data set, resulting in eight predictive models (i.e. four calibrated from Native range projected to Brazil and four calibrated in Brazilian range and projected to Brazil) (Fig.S6 and Fig S7). As a final step, we overlapped all binary maps by summing the values in each grid cell, which resulted in four possible values for the predicted presence. This allows to classify the cells in four classes of risk assessment: (i) Without, when the maximum of two models predict the cell as occurrence; (ii) Lower, when more than two to four models predict the cells with presence; (iii) Moderate, when more than four to six models predict the cells with presence; (iv) Great, when more than six models predict the cells with presence.



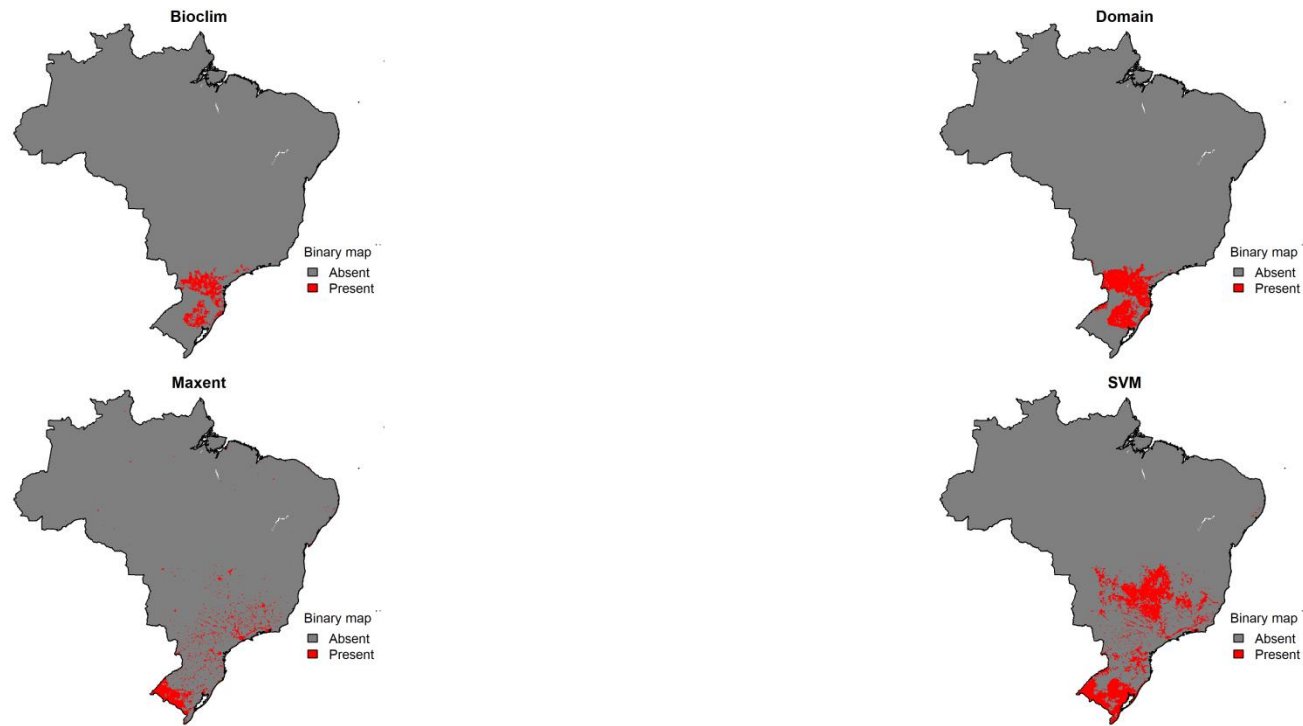
**Fig. S4:** Suitability models calibrated with GBIF native occurrences and projected within Brazilian range. Color gradient shows suitability values from blue (i.e. low suitability) to yellow (i.e. Highest values).



**Fig. S5:** Suitability models calibrated with Brazilian occurrences (i.e. data set two) and projected within Brazilian range. Color gradient shows suitability values from blue (i.e. low suitability) to yellow (i.e. Highest values).

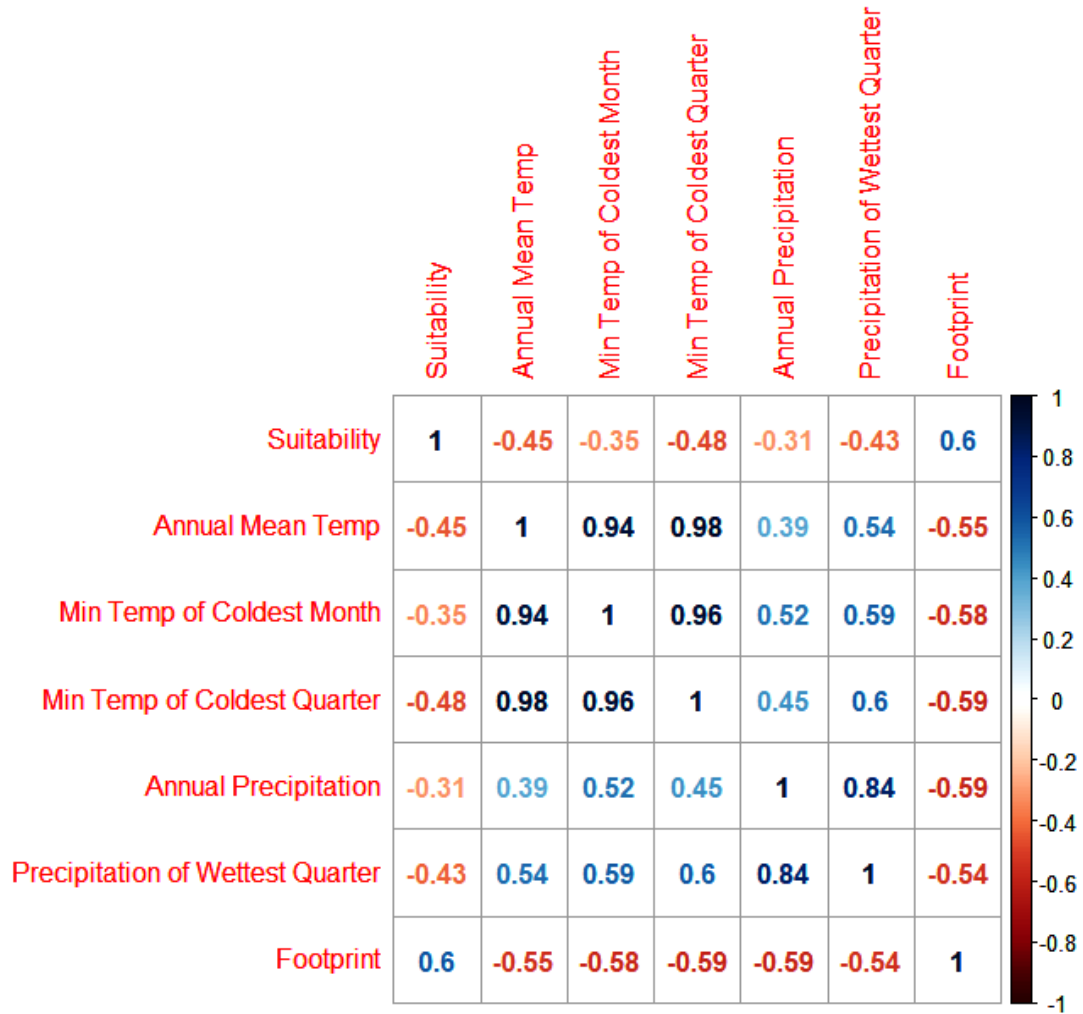


**Fig S6.** Binary classification maps for the four different niche models used to model *M. coypus*. Each classification maps were obtained from GBIF occurrences in native range and projected within Brazilian range. Binary models use threshold values (i.e. here sensitivity = specificity) to classify grid cells in presence and absence class. Grey color indicate cell predicted as absence and red indicate cell predicted as presence.



**Fig S7.** Binary classification maps for the four different niche models used to model *M.coypus*. Each classification maps were obtained from Brazilian occurrences and projected within Brazilian range. Binary models use threshold values (i.e. here sensitivity = specificity) to classify grid cells in presence and absence class. Grey color indicate cell predicted as absence and red indicate cell predicted as presence.

## 5. Supplementary results



**Fig. S8.** Pairwise correlation values of suitability values obtained by the ensemble approach and the environmental variables used in the modeling procedures for *Myocastor coypus* in Brazil.

## References

- Angelo, G.B., Nagai, M.E., Sazima, I., 2016. Relações alimentares de aves com capivaras (*Hydrochoerus hydrochaeris*) em parque urbano no Sudeste do Brasil. Pap. Avulsos Zool. 56, 33–43. <http://dx.doi.org/10.11606/0031-1049.2016.56.04>.
- Araújo, M.B., New, M., 2007. Ensemble forecasting of species distributions. Trends Ecol. Evol. 22, 42–47. <https://doi.org/10.1016/j.tree.2006.09.010>
- Bertolino, S., Ingegno, B., 2009. Modelling the distribution of an introduced species: The coypu *Myocastor coypus* (Mammalia, Rodentia) in Piedmont region, NW Italy. Ital. J. Zool. 76, 340–346. <https://doi.org/10.1080/11250000903155483>
- Booth, T.H., Nix, H.A., Busby, J.R., Hutchinson, M.F., 2014. Bioclim: The first species distribution modelling package, its early applications and relevance to most current MaxEnt studies. Divers. Distrib. 20, 1–9. <https://doi.org/10.1111/ddi.12144>
- Bueno, C., 2013. Ocorrência de *Myocastor coypus* Molina, 1782 no Estado do Rio de Janeiro. Bol. da Soc. Bras. Mastozool. 66, 9–11.
- Cáceres N, 2004. Occurrence of *Conepatus chinga* (Molina) (Mammalia, Carnivora, Mustelidae) and other terrestrial mammals in the Serra do Mar, Paraná, Brazil. Rev. Bras. Zool. 21, 577–579. <https://doi.org/10.1590/S0101-81752004000300020>
- Carpenter, G., Gillison, A.N., Winter, J., 1993. Domain - a Flexible Modeling Procedure for Mapping Potential Distributions of Plants and Animals. Biodivers. Conserv. 2, 667–680. <https://doi.org/10.1007/BF00051966>
- Cademartori, C.V., Machado, M., 2002. A fauna de vertebrados de um banhado costeiro em área periurbana no sul do Brasil. Rev. Bras. Zool. 4, 31–43.
- Cherem, J.J., Kammers, M., Ghizoni-Jr, I.R., Martins, A., 2007. Mamíferos de médio e grande porte atropelados em rodovias do Estado de Santa Catarina, sul do Brasil. Biotemas 20, 81–96.
- Colares, E.P., Waldemarin, H.F., 2000. Feeding of the neotropical river otter (*Lontra longicaudis*) in the coastal region of the Rio Grande do Sul state, southern Brazil. IUCN Otter Spec. Gr. Bull. 17, 6–13.
- Diniz-Filho, J.A.F., Mauricio Bini, L., Fernando Rangel, T., Loyola, R.D., Hof, C., Nogués-Bravo, D., Araújo, M.B., 2009. Partitioning and mapping uncertainties in ensembles of forecasts of species turnover under climate change. Ecography (Cop.). 32, 897–906. <https://doi.org/10.1111/j.1600-0587.2009.06196.x>
- Drake, J.M., Randin, C., Guisan, A., 2006. Modelling ecological niches with support vector

- machines. *J. Appl. Ecol.* 43, 424–432. <https://doi.org/10.1111/j.1365-2664.2006.01141.x>
- Farashi, A., Najafabadi, M.S., 2015. Modeling the spread of invasive nutrias (*Myocastor coypus*) over Iran. *Ecol. Complex.* 22, 59–64. <https://doi.org/10.1016/j.ecocom.2015.02.003>
- Farashi, A., Najafabadi, M.S., 2017. A Model to Predict Dispersion of the Alien Nutria , *Myocastor coypus* Molina , 1782 ( Rodentia ), in Northern Iran 69, 65–70.
- Fick, S.E., Hijmans, R.J., 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* 37, 4302–4315. <https://doi.org/10.1002/joc.5086>
- Grazzini, G., Mochi-Junior, C.M., Oliveira, H., Pontes, J.S., Almeida, F.G., Tiepolo, L.M., 2015. Inventário da mastofauna de pequeno porte de área de Floresta com Araucária no Paraná. *Pap. Avulsos Zool.* 55, 217–230. <http://dx.doi.org/10.1590/0031-1049.2015.55.15>
- Guo, Q., Kelly, M., Graham, C.H., 2005. Support vector machines for predicting distribution of Sudden Oak Death in California. *Ecol. Modell.* 182, 75–90. <https://doi.org/10.1016/j.ecolmodel.2004.07.012>
- Fernandes, A., Junior, N., 2015. A construção de um modelo para o ensino de ecologia em unidades de conservação: o caso do parque ecológico diva Paim Barth, município de Toledo, Paraná. *Periódico Eletrônico "Fórum Ambient. da Alta Paul.* 4, 219–231. <http://dx.doi.org/10.17271/1980082711420151286>
- Franklin, J., 2010. Mapping Species Distributions. *Spatial Inference and Prediction.* University Press, Cambridge.
- Juraszek, A., Bazilio, S., Golec, C., 2014. Levantamento de mamíferos de médio e grande porte na RPPN Federal Corredor do Iguaçu na região Centro-oeste do Paraná. *Acta Iguazu* 3, 113–123.
- Legendre, P., Legendre, L., 1998. *Numerical ecology.* Elsevier, Amsterdam.
- Lemos, E.R.S. De, D'Andrea, P.S., Bonvicino, C.R., Famadas, K.M., Padula, P., Cavalcanti, A.A., Schatzmayr, H.G., 2004. Evidence of hantavirus infection in wild rodents captured in a rural area of the state of São Paulo, Brazil. *Pesqui. Veterinária Bras.* 24, 71–73. <https://doi.org/10.1590/S0100-736X2004000200004>
- Martins, T.F., Milanelo, L., Krawczak, F. da S., Furuya, H.R., Fitorra, L.S., Dores, F.T. das, Pedro, V. da S., Hippolito, A.G., Labruna, M.B., 2017. Diversity of ticks in the wildlife screening center of São Paulo city, Brazil. *Ciência Rural* 47, 1–6. <https://doi.org/10.1590/0103-8478cr20161052>.

- Nix, H.A., A Biogeographic Analysis of Australian Elapid snakes. In: Longmore, R., Ed., Atlas of Elapid Snakes of Australia. Australian Flora and Fauna Series No. 7, 1986, Australian Government Publishing Service, Canberra, 4-15.
- O'Donnell, M.S., Ignizio, D.A., 2012. Bioclimatic Predictors for Supporting Ecological Applications in the Conterminous United States. Geological Survey, United States
- Peterson, A.T., 2003. Predicting the geography of species' invasions via ecological niche modeling, 419–433.
- Pinto, L.C., Duarte, M.M., 2013. Occurrence (new recOrd) Of maned wOlf *Chrysocyon brachyurus* (Illiger, 1815) (carnIvOra,. *Ciência Florest.* 23, 253–259.
- Rangel, T.F., Loyola, R.D., 2012. Labeling Ecological Niche Models. *Nat. Conserv.* 10, 119–126. <https://doi.org/10.4322/natcon.2012.030>
- Rocha, C.F.D., Bergallo, H.G., Pombal Jr, J.P., Geise, L., Sluys, M. Van, Fernandes, R., Caramaschi, U., 2004. Fauna de anfíbios, répteis e mamíferos do Estado do Rio de Janeiro, sudeste do Brasil. *Publicações Avulsas do Mus. Nac. do Rio Janeiro* 104, 3–23.
- Santos, T.G. dos, Spies, M.R., Kopp, K., Trevisan, R., Cechin, S.Z., 2008. Mamíferos do campus da Universidade Federal de Santa Maria , Rio Grande do Sul , Brasil *Introdução. Biota Neotrop.* 8, 125–131. <http://dx.doi.org/10.17058/cp.v28i1.7855>
- Steil, L., Düpont, A., Lobo, E.A., 2016. Levantamento da fauna silvestre atropelada na BR 290 (km 210 a 214), município de Pantano Grande, RS, Brasil. *Cad. Pesqui. Série Biol.* 28, 13–23. <http://dx.doi.org/10.17058/cp.v28i1.7855>
- Tortato, F.R., Konder, B.V., Catarina, S., 2007. Carnívora , Mustelidae ) da Reserva Biológica Estadual do Sassafrás , Santa Catarina , sul do Brasil *Material e métodos. Biota Neotrop.* 7, 365–367. <https://doi.org/10.5007/2175-7925.2014v27n3p123>
- Wolfart, M.R., Fré, M. Da, Miranda, G.B. de, Lucas, E.M., 2013. Mamíferos terrestres em um remanescente de Mata Atlântica , O estudo foi desenvolvido em um remanescente. *Biote* 26, 111–119. <https://doi.org/10.5007/2175-7925.2013v26n4p111>

## CAPÍTULO 4

### **Mammalian defaunation in Devonian kniferidges and meridional plateaus of the Brazilian Atlantic Rainforest**

Alan Deivid Pereira, Juliano André Bogoni, Sergio Bazilio, Mário Luís Orsi

Capítulo redigido segundo as normas do periódico *Biological Conservation*, disponível em:  
<https://www.elsevier.com/journals/biological-conservation/0006-3207/guide-for-authors>

1 **Mammalian defaunation in Devonian kniferidges and meridional plateaus of the**  
2 **Brazilian Atlantic Rainforest**

3  
4 Alan Deivid Pereira<sup>a</sup>; Juliano André Bogoni<sup>b,c</sup>; Sergio Bazilio<sup>d</sup>; Mário Luís Orsi<sup>e</sup>

5  
6 <sup>a</sup> Programa de Pós-Graduação em Ciências Biológicas, Centro de Ciências Biológicas,  
7 Departamento de Biologia Animal e Vegetal, Universidade Estadual de Londrina,  
8 Londrina, PR, Brazil, Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 –  
9 Londrina, Paraná, Brazil.

10 <sup>b</sup> Universidade de São Paulo, Escola Superior de Agricultura “Luiz de Queiroz”,  
11 Laboratório de Ecologia, Manejo e Conservação de Fauna Silvestre (LEMaC),  
12 Piracicaba, São Paulo, Brazil.

13 <sup>c</sup> School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ,  
14 Norwich, United Kingdom.

15 <sup>d</sup> Universidade Estadual do Paraná – UNESPAR, Campus de União da Vitória. Caixa  
16 Postal 241, CEP 84600-970, União da Vitória, PR, Brazil.

17 <sup>e</sup> Laboratório de Ecologia de Peixes e Invasões Biológicas. Universidade Estadual de  
18 Londrina, Centro de Ciências Biológicas, Departamento de Biologia Animal e Vegetal,  
19 Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 – Londrina, Paraná,  
20 Brazil.

21  
22 **Corresponding author:** [alandeivid\\_bio@live.com](mailto:alandeivid_bio@live.com)

23  
24  
25  
26 **ABSTRACT**

27 Defaunation of mammals may be triggered by commercial hunting, habitat degradation,  
28 or the synergic combination of both. Although the population decrease of the mammal  
29 community in the Brazilian Atlantic Rainforest has been discussed in past studies, there  
30 is scanty information on the southern section of the biome about the defaunation level of  
31 remnant forest fragments. The current paper evaluates habitat conversion regarding the  
32 decrease of medium and large mammals of the South Atlantic Rainforest through a  
33 defaunation index. Results showed a high defaunation degree for the southern Brazilian  
34 Atlantic Rainforest, with more than 50% of analyzed fragments revealing higher  
35 medium defaunation rates than expected medium ones. Areas with a higher percentage  
36 of soil cover for silviculture and agriculture have greater defaunation rates when  
37 compared to areas with natural forest cover. Further, protected areas proved to be more  
38 balanced functionally and less defaunized than non-protected ones. Big herbivores and  
39 carnivores lie within the more defaunation-affected functional categories and loss may  
40 cause unstable functional fragments with low resilience rates.

41  
42 **Keywords:** Deforestation; forest fragmentation; land use; mammalian communities;  
43 protected areas; tropical rainforest.

## 51 INTRODUCTION

52  
53 Forest fragmentation, conversion of habitat and overhunting are the main causes  
54 for global biodiversity decrease (Fahrig, 2003; Gardner et al., 2009; Wilson et al.,  
55 2016). Deforestation and habitat conversion are historically more pronounced in littoral  
56 regions and the interior plateaus of the Atlantic Rainforest (Dean, 1996; Ribeiro et al.,  
57 2009), featuring one of the 25 hotspots in world biodiversity (Myers et al., 2000). The  
58 Atlantic Rainforest biome has a relevant good percentage of mammal diversity within  
59 South America, comprising 321 species, of which 89 (27.7%) are endemic (Paglia et al.  
60 2012; Graipel et al., 2017).

61 Due to fragmentation and drastic decrease in the forest coverage in the Atlantic  
62 Rainforest, mammal assemblages live in native forest remnants smaller than 100 hectares  
63 and immersed within anthropogenic matrixes (Ribeiro et al., 2009). Mammal populations  
64 in tropical forests have the highest decrease rates worldwide (Dirzo et al., 2014; Bogoni  
65 et al. 2018), with chronic and repeated defaunation events (i.e., local extinctions) (Canale  
66 et al., 2012). Defaunation may occur directly by subsistence and commercial hunting and  
67 indirectly by fauna decrease due to human activities not specifically aimed at the animals,  
68 such as habitat destruction, extractive activities, soil, and water pollution (Redford, 1992).

69 Defaunation may be defined as the decrease in abundance and occurrence of  
70 animals in a given community (Terborgh 1988; Peres 1990; Redford 1992), and which  
71 may affect in a disproportional way bigger animal with low reproduction rates,  
72 especially large mammals (Cardillo et al., 2005). The negative effects of local mammal  
73 defaunation may occur at different ecological scales and affect seed dispersal and  
74 predation (Stoner et al., 2007; Markl et al., 2012), with the substitution of large  
75 predators by medium-sized ones (Taylor et al., 2016) and cause the decrease of other  
76 taxonomic groups (Galetti and Dirzo, 2013; Kurten, 2013; Bogoni et al., 2019).

77 It has been calculated that 96% of the Atlantic Rainforest biome is subjected to  
78 the effects of trophic cascades due to defaunation of mammals (Jorge et al., 2013). The  
79 main defaunation boosters in the Atlantic Rainforest include a long and persistent history  
80 of overhunting, conversion, and fragmentation of habitats, or a synergic combination of  
81 both (Bogoni et al., 2018). Therefore, the establishment of protected areas (PAs) is one  
82 of the most relevant policies run by the government for the preservation of biodiversity  
83 (Jenkins and Joppa, 2009).

84 The Devonian Escarpment's Environmental Protection Area is one of the most  
85 relevant regions for conservation in southern Brazil (Ribeiro et al 2009). With over 324  
86 thousand hectares, it spreads over a great part of the Campos Gerais in Southern Brazil  
87 and forms a specific landscape that alternates pine tree forests, savannas, and rocky  
88 outcrops. It is a transition zone between Mixed Ombrophilous Forest, Savanna, and  
89 localized Natural Fields (Maack, 2012), and some sites are highly valued for touristic  
90 visitation, such as canyons, and archeological and pre-historical ruins (Takeda et al.,  
91 2001). However, the conversion of natural areas in monocultures, mainly *Eucalyptus*  
92 spp. and *Pinus* spp. together with agriculture areas threaten the stability of the region's  
93 biodiversity (Almeida and Moro, 2007).

94 Studies on the Brazilian Atlantic Rainforest, at regional scales, have shown high  
95 levels of defaunation in mammal assemblages (Galetti et al., 2006; Canalle et al., 2012;  
96 Bogoni et al., 2016; Galetti et al., 2017). Most studies on defaunation in the Atlantic  
97 Rainforest are concentrated in South-Eastern and Northeastern Brazil (e.g., Galetti et al.,  
98 2006, 2017; Canale et al., 2012). A biome-scale study, however, showed a larger  
99 defaunation in the biome but remains several spatial gaps in terms of defaunation in the  
100 high-modified plateaus of the Atlantic Rainforest only accessed via spatial interpolation

101 (Bogoni et al., 2018).

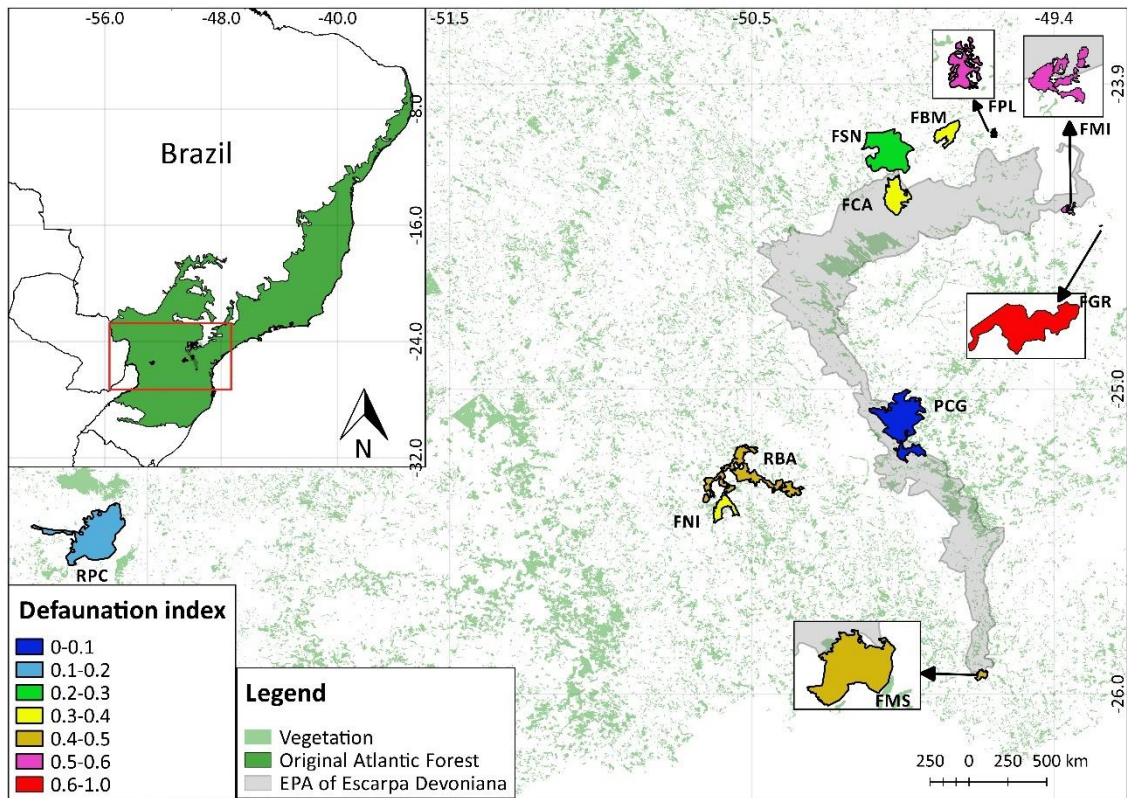
102 Consequently, there is very scanty information on the effects of conservation of  
103 habitats in the decrease of large- and medium-sized mammals within the southern  
104 section of the biome. Data are retrieved from 65 camera traps installed during five  
105 years, with a total effort of 29.788 camera-trap-days, in four protected areas and seven  
106 forest fragments in Devonian knife ridges and surroundings areas in Southern Brazil,  
107 aiming at quantifying defaunation in remnant forests of the southern region of the  
108 Atlantic Rainforest to analyze the effects of fragmentation and forest conversion on the  
109 structure of assemblages of large- and medium-sized mammals between the current  
110 structure of assemblages compared with a historical baseline. We hypothesized that: (1)  
111 in areas with a high percentage of natural environment conversion, mainly those  
112 employed for agriculture and silviculture, defaunation rates are higher when compared  
113 to areas with a greater percentage of natural forests; (2) all areas reveal a historical  
114 erosion of local richness, averaging 70% of species (based on Bogoni et al. 2018).

## 115 **MATERIAL AND METHODS**

### 116 *Study area*

117  
118  
119 The current study sampled mammal fauna across 91 distribution places in 11  
120 sampling sites of the Atlantic Rainforest of Southern Brazil (Fig. 1). Four are Protected  
121 Areas (PAs), namely, Parque Nacional dos Campos Gerais (PCG), Reserva Biológica  
122 das Araucárias (RBA), Reserva Particular do Patrimônio Natural Corredor do Iguaçu  
123 (RPC) and Floresta Nacional de Irati (FNI). The other seven sites are non-protected  
124 forest remnants, namely, Fragmento São Nicolau (FSN), Fragmento Portão Lajeado  
125 (FPL), Fragmento Mirante (FMI), Fragmento Monte Selete (FMS), Fragmento  
126 Caxambu (FCA), Fragmento Barra Mansa (FBM) and Fragmento da Gruta (FGR) (Fig.  
127 1, Table 1). Although sites RBA, RPC and FNI are not included within Environmental  
128 Protection Area (EPA) limits of the Devonian Escarpment, they are taken into account  
129 in current analysis due to their similar characteristics with regard to their phyto-  
130 physiology and the use of soil of the other sampling sites sharing the surroundings and  
131 comprising the meta-region of the Devonian Escarpment.

132 Sampling sites have vegetation composed of phyto-physiologies Mixed  
133 Ombrophilous Forest (FOM) for sites RBA, FNI, RPC and FPL, and Height/Natural  
134 Fields for PCG and FCA, coupled to transition zones between Height Fields and FOM  
135 for sampling units FSN, FMI, FMS, FBM and FGR (Figure 1). According to Köppen's  
136 classification, the region's climate is Cfa (humid temperate climate with hot summers)  
137 for the sampling site RPC and Cfb (humid temperate climate with moderately hot  
138 summers) for the other sampling units. Both are oceanic climates without a defined dry  
139 season (Peel et al., 2007).



148  
149  
150  
151  
152  
153  
154  
155

**Figure 1.** Map of the areas analyzed of the Atlantic Rainforest in southern Brazil, with special reference to EPA of the Devonian Escarpment. PCG: Parque Nacional dos Campos Gerais; RBA: Reversa Biológica das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN Corredor do Iguaçu; FSN: Fragmento São Nicolau; FPL: Fragmento Portão lajeado; FMS: Fragmento Monte Seletto; FCA: Fragmento Caxambu; FMI: Fragmento Mirante; FBM: Fragmento Barra Mansa; FGR: Fragmento da Gruta.

### ***Mammal sampling and functional groups***

156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170

Sampling sites were monitored at different times between 2011 and 2017. Sixty-five camera traps (Bushnell HD) were employed, with at least two devices in each sampling unit, according to the size of each sampling area (Table 1). Camera traps were distributed in the fragments, near water sprouts, on the treks and pathways, taking into account the commonest trails used by species. Cameras were kept at an average distance of 1,801 ( $\pm$  792.7) and placed 50 cm above the ground on tree trunks and without baits. Camera traps were active during at least 365 days of sampling ( $\sim$ 8,760 h) at each site, with a monthly change of memory cards and batteries during the study period. Sampling effort was equal to the number of camera traps multiplied by the number of sampling days (with 24 hours), resulting in a total effort of 29,788 trap-days (Table 1). An event was independent when there were (a) consecutive photographs by the same camera with an interval of at least 60 minutes or (b) nonconsecutive photographs by the same camera (Srbek-Araujo and Chiarello, 2013)

171  
172  
173  
174  
175

The species *Sus scroffa* Linnaeus, 1758, *Myocastor coypus* (Molina, 1782) (see. Pereira et al. 2020) and *Lepus europaeus* (Pallas, 1778), which are exotic and invasive species in the region, were excluded. The species *Sapajus nigrinus* (Goldfuss, 1809) and *Alouatta guariba clamitans* Cabrera, 1940 (tree-dwelling species), rarely detected with camera traps, were also excluded.

176

The alpha taxonomic nomenclature followed Paglia et al. (2012), following

177 recent taxonomic changes (e.g., *Leopardus guttulus* (Hensel, 1872), based on Trigo et  
 178 al. (2013)) and *Sapajus* genera, based on Lynch-Alfaro -Alfaro et al. (2012). In the case  
 179 of the orders Pilosa and Rodentia, Patton et al. (2015) were consulted for precise  
 180 identification. All those species with an adult body mass  $\geq 1$  kg were considered  
 181 medium- to large-bodied mammals (Paglia et al., 2012).

182 The species were classified into nine functional groups according to their  
 183 morpho-ecological traits which were not necessarily exclusive. Classification followed  
 184 suggestions on groups by Bogoni et al. (2018), or rather, species were classified  
 185 according to the following functional groups: (1) frugivores; (2) large grazers or  
 186 browsers: e.g., genus *Mazama*, *Ozotoceros* and *Tapirus*; (3) mesocarnivores (body mass  
 187  $< 13$ kg); (4) apex predator ( $> 13$ kg). Following the previous classification, the proportion  
 188 of each main trophic category of each species was taken into account (sourced from  
 189 Wilman et al., 2004) to establish its energetic level (e.g. if a *Tapirus* population  
 190 consumes 70% leaves and 30% fruits, its trophic level will be 1.3 (i.e.  $(0.7 \times 1) + (0.3 \times$   
 191  $2)$ ), grouping them according to the following functional groups: (5) high trophic level;  
 192 (6) intermediate trophic level and (7) low trophic level. Finally, the species were  
 193 grouped according to total biomass, included in the functional groups (8) small-bodied  
 194 species ( $< 10$ kg) and (9) large-bodied species ( $\geq 10$ kg). Body mass thresholds and broad  
 195 trophic classes are based on Wilman et al. (2004) and Paglia et al. (2012).

196  
 197 **Table 1.** Description of sampling effort employed on all study areas in the Atlantic  
 198 Rainforest, Brazil. PCG: Parque Nacional dos Campos Gerais; RBA: Reversa Biológica  
 199 das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN Corredor do Iguaçu; FSN:  
 200 Fragmento São Nicolau; FPL: Fragmento Portão lajeado; FMS: Fragmento Monte  
 201 Selete; FCA: Fragmento Caxambu; FMI: Fragmento Mirante; FBM: Fragmento Barra  
 202 Mansa; FGR: Fragmento da Gruta.

203

204 *Landscape characterization*

205

Areas	Total Traps	Limit size (ha)	Traps/ha (political size) (n)	Linear distance ( $\pm$ SD) between traps (meters)	Monitoring days	Total Traps-Days	Years sampling
PCG	10	21.299	0.469	1.104 $\pm$ 551.9	730	7.300	2013-2014 2016-2017
RBA	13	14.930	0.870	892 $\pm$ 1.216	707	9.191	2012-2014
FNI	4	3.495	1.149	1.209 $\pm$ 473.7	240	960	2012-2013
RPC	10	5.115	1.955	2.068 $\pm$ 1.309	324	3.240	2011-2012
FSN	6	18.426	0.434	2.649 $\pm$ 891	350	2.100	2015-2016
FPL	6	325	0.018	1438.5 $\pm$ 1350.3	352	2.112	2015-2016
FMS	2	958	0.002	1.180 $\pm$ 0	352	704	2015-2016
FCA	4	7.729	0.517	1.404 $\pm$ 648.5	350	1.400	2015-2016
FMI	4	992	0.004	1.865 $\pm$ 196.6	347	1.388	2015-2016
FBM	2	4.542	0.440	3.668 $\pm$ 0	350	700	2015-2016
FGR	2	50	0.040	2.343 $\pm$ 0	347	694	2015-2016
<b>Total</b>	<b>65</b>	-	-	-	-	<b>29.788</b>	-
<b>Average</b>	<b>12</b> ( $\pm 6.5$ )	<b>0.536</b> ( $\pm 0.57$ )	<b>0.1563</b> ( $\pm 0.38$ )	<b>1,801</b> ( $\pm 792.7$ )	<b>111</b> ( $\pm 107$ )	<b>4099</b> ( $\pm 1.577$ )	-

206 Data retrieved from Brazilian ground charts, provided by the Instituto Brasileiro  
207 de Geografia e Estatísticas (IBGE, 2018), were employed. Data include the  
208 characterization of the landscape from OLI/Landsat-8 satellite images (spatial resolution  
209 30 m) for the 2011-2016 period, on a 450x450 km grid (IBGE, 2018).

210 Each landscape was drawn as an area of 20 km<sup>2</sup>, including the extent of each  
211 area, combining surrounding lands and covering 22,000 ha. The prevailing land cover  
212 class was verified for each pixel (Hoskins et al., 2016). Cover classes and ground use  
213 were defined as follows: Artificial areas (areas with predominant non-agricultural  
214 anthropic surfaces); Silviculture (areas characterized by forest plantations of exotic or  
215 native species as a monoculture); Agricultural areas (area characterized by temporal,  
216 semi-perennial and permanent fields, irrigated or non-irrigated, with land used for the  
217 production of food crops, fibers, and agribusiness commodities); Managed Pasture  
218 (areas for the pasture of cattle and other animals, with cultivated vegetation (brachiaria,  
219 ryegrass, and others) or grassland (natural), with intense anthropic interference); Forest  
220 Vegetation (area with forests, except for monoculture of exotic vegetation) and  
221 continental water bodies (including backland waters, such as rivers, streams, canals, and  
222 other surface water bodies) (Table A1). Sampling sites were also categorized according  
223 to the Human Development Index (HDI) and Demographic Density in the case of  
224 municipalities in which they occur (Bogoni et al., 2018).

## 225 226 *Data analysis*

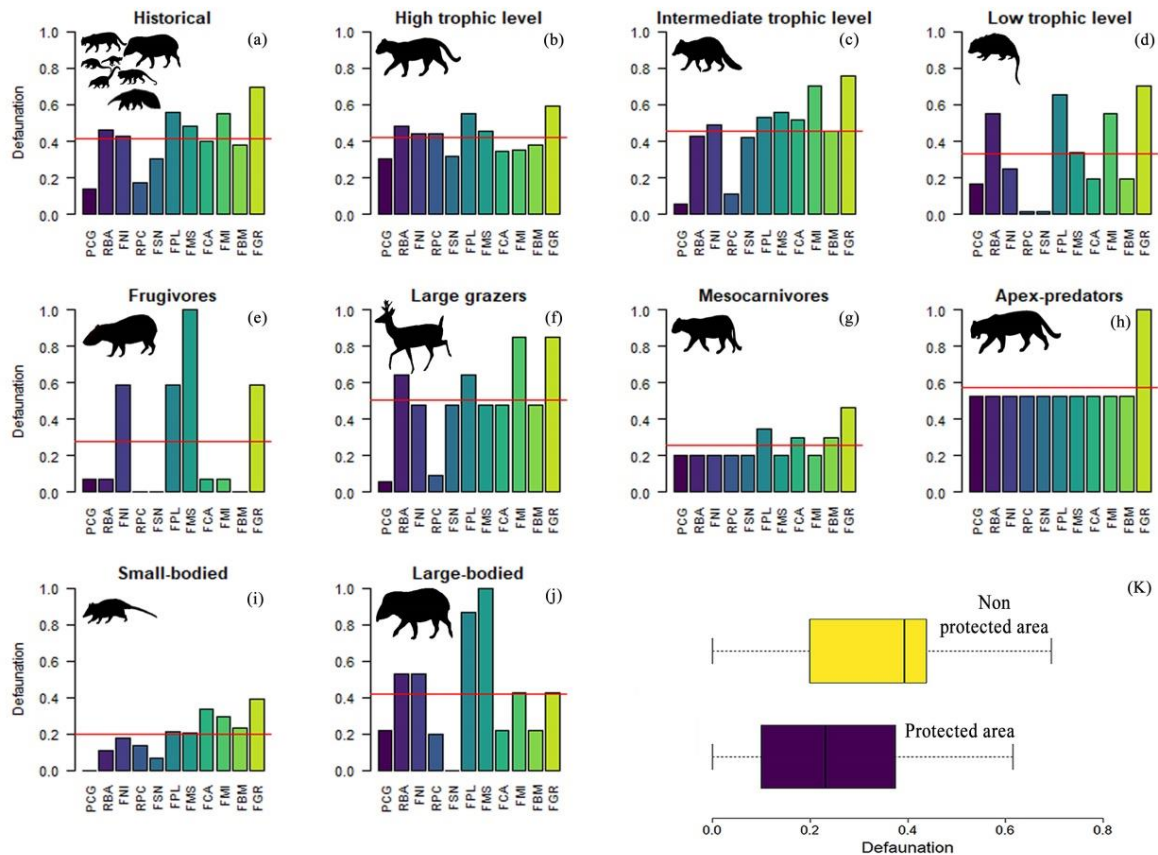
227  
228 The defaunation index (Giacomini and Galetti, 2013) was used to assess the  
229 degree of total mammal defaunation and for each forest remnant analyzed. The  
230 defaunation index is a weighted measure of dissimilarity between focal assemblies and a  
231 reference assembly (e.g., historical baseline). The index ranges between 0 (completely  
232 intact) to 1 (completely defaunated) and is based on the Bray-Curtis dissimilarity index  
233 with an importance weight species. In this case, all species have the same importance  
234 rate ( $\omega = 1$ ) (see Giacomini and Galetti, 2013). The defaunation index was calculated  
235 for the entire mammal assemblage (total defaunation) and each functional group  
236 (assemblage-level) for each sampling unit through a matrix of presence and absence,  
237 compared to the historical baseline. Baseline assemblage of current sampling sites was  
238 employed to calculate the index, assuming probable occurrences based on known  
239 geographic range polygons obtained from the IUCN (2019) to determine the historical  
240 presence of each species at each sampling site (Bogoni et al., 2018).

241 We assessed whether landscape features (i.e., land use) and social variables (e.g.,  
242 IDH) affected observed total defaunation with Poisson generalized linear modeling  
243 (GLM) and analysis of deviance based on the  $\chi^2$  distribution (or quasi-Poisson GLM  
244 and F-tests to account for over-dispersion; Zuur et al., 2009). The likelihood ratio test  
245 was applied to select the model that best explained defaunation in relation to viable soil  
246 use. The likelihood value is used to define the measure of fit, while the number of  
247 parameters measures complexity (Zuur et al., 2009). Variables were removed one by  
248 one, using the top-down strategy recommended by Diggle et al. (2002). Non-significant  
249 variables ( $P > 0.05$ ) were tested with a more straightforward form (that is, with fewer  
250 degrees of freedom) and, if the effect was non-significant, they were excluded from the  
251 model (Zuur et al., 2009).

## 252 253 **RESULTS**

254  
255 Thirty-nine mammal species were reported, retrieved from 7,755 independent

256 registers, ranging between 14 and 31 species per area, including discarded species  
 257 (Table A2). Baseline historical dataset revealed average ( $D_{bs} = 0.42$ ) in defauna-  
 258 tion index for all sampling areas, with greatest defauna-  
 259 tion index for FGR, with ( $D_{bs} = 0.69$ ),  
 260 followed by FPL ( $D_{bs} = 0.56$ ) and FMI ( $D_{bs} = 0.55$ ). PNC had the lowest defauna-  
 261 tion rates ( $D_{bs} = 0.14$ ) (Fig. 2A). Protected areas had the lowest defauna-  
 262 tion rates when compared to non-protected ones ( $W = 861.5$ ;  $P < 0.05$ ) (Fig 2K.)



263  
 264 **Fig 2.** Defauna- tion index for medium- and large-bodied mammals on study sites in the  
 265 southern portion of the Brazilian Atlantic Forest biome: (a) all medium- and large-  
 266 bodied mammal species; (b) high trophic level; (c) intermediate trophic level; (d) low  
 267 trophic level; (e) frugivores; (f) large grazers; (g) mesocarnivores; (h) apex-predators;  
 268 (i) small-bodied; (j) large-bodied; (k) boxplot illustrating the difference in defauna-  
 269 tion index between non-protected and protected areas.

270  
 271

272 In the case of functional groups, FGR had the highest defauna- tion rates for high  
 273 trophic level ( $D_{bs} = 0.60$ ), intermediate trophic level ( $D_{bs} = 0.76$ ), low trophic level ( $D_{bs}$   
 274  $= 0.70$ ), mesocarnivores ( $D_{bs} = 0.46$ ), apex-predators ( $D_{bs} = 1$ ) and small-bodied ( $D_{bs} =$   
 275  $0.39$ ). In the case of large grazers, FMI and FGR had the highest defauna- tion rates ( $D_{bs}$   
 276  $= 0.85$ ) in both areas. FMS revealed the highest defauna- tion rate for Frugivores ( $D_{bs} =$   
 277  $1$ ), whilst defauna- tion for large-bodied mammals was highest at FMS ( $D_{bs} = 0.87$ ) (Fig.  
 278 2, Table A3)

279 Within the context of the six land-use types and two socioeconomic variables  
 280 tested in the GLM, only silviculture, agriculture and vegetation better explained the total  
 281 defauna- tion rates in the sample units investigated (Table 2). GLM analysis explained

282 16% of total variation in mammal defaunation when only landscape variables were  
 283 taken into account.

284

285 **Table 2.** Results of GLM with a quasi-Poisson distribution of the best model for  
 286 defaunation according to the covered-land use variables.

287

	Estimate	SE	<i>t</i> value	<i>P</i>
(Intercept)	-0466795	0.189144	-2.468	<0.002
Silviculture	0.009585	0.001914	5.008	<0.001
Agriculture	0.007302	0.001913	3.818	<0.001
Forest	0.012127	0.003260	3.720	<0.001
Vegetation				

Dispersion parameter for quasi-Poisson Family taken to be 0.12464

Null deviance: 17.748 on 109 degrees of freedom

288

289

## 290 **DISCUSSION**

291

292 Our results showed a high defaunation degree within the Southern section of the  
 293 Brazilian Atlantic Rainforest, with more than 50% in all fragments analyzed. They  
 294 reveal defaunation means higher than the mean historical rate of 0.42 for the southern  
 295 section of the biome. Previous results indicated that the estimated defaunation rate for  
 296 the entire Atlantic Rainforest is even higher at 0.71 (See fig. 2 of Bogoni et al., 2018).  
 297 One of the main consequences of defaunation of large mammals at the local, regional  
 298 and global level is the loss of ecosystem services (Galetti and Dirzo, 2013; Dirzo et al.,  
 299 2014; Galetti et al., 2015). Current results show that all sampled fragments are  
 300 undergoing consequences caused by defaunation in the composition of medium- and  
 301 large-sized functional mammal groups. Such a loss may result in unstable functional  
 302 fragments, with low potential resilience (Galetti and Dirzo, 2013; Kurten et al., 2015).

303 Within the functional groups analyzed, the Apex-predator species had the  
 304 greatest defaunation-caused decline. The species have essential ecosystem functions and  
 305 regulate and control the population of big herbivores, such as capybaras, deer and wild  
 306 pigs, and mesopredators such as opossum, tayra, coati, jaguarondi (Jorge et al., 2013).  
 307 Their absence will probably interrupt the predator-prey relationships with unforeseen  
 308 effects in the ecosystemic functions (Weckel et al., 2006; Jorge et al., 2013). The big  
 309 jaguar is the biggest predator (50-160 kg) at the top of the neotropical region and its diet  
 310 is not superior to that of the puma (22-70 kg), the second biggest predator (Di Bitetti et  
 311 al., 2010). Although big jaguars have been historically distributed throughout the entire  
 312 Atlantic Rainforest biome (Beisiegel et al., 2012), it has been estimated that less than  
 313 300 adult specimens inhabit the biome, distributed in eight isolated populations  
 314 (Beisiegel et al., 2012; Paviolo et al., 2016). Despite the great sampling effort (29.788  
 315 camera-trap-days), with different search methodologies, the jaguar has not been  
 316 reported in any fragment under analysis. This indicates the local extinction of the  
 317 species. The leading causes for the population decrease of jaguars in the Brazilian  
 318 Southern Atlantic Rainforest, including the current region, is associated with habitat  
 319 loss, hunting and killing by ranchers who kill jaguars and pumas to retaliate loss in  
 320 stock herds (Paviolo et al., 2016; Srbek-Araujo and Chiarello, 2017).

321 The second most affected functional group by defaunation comprises the large  
 322 herbivores. Large grazers have a significant impact on ecosystemic processes and are

323 known to change the composition of vegetation (Elschot et al., 2015). Decrease or local  
324 extinction of large grazers may trigger cascade events that alter the dynamics and  
325 structure of local communities. Several studies have shown that grazing not only  
326 reduces ground biomass but that grazer species function as ecosystem engineers. Due to  
327 trampling, they increase the density in soil layers (Elschot et al., 2015, Nolte et al.  
328 2013), causing anoxic conditions (*i.e.*, lack of oxygen) and changes in the nitrogen cycle  
329 of the soil (Schrama et al., 2013).

330 The third most affected functional group by defaunation lies at the intermediate  
331 trophic level (Fig. 2). The group comprises peccaries, deer and tapirs, which have  
332 unique ecological roles within the environment, such as the efficient removal of fruits,  
333 long-distance dispersion and plant dispersion with large-sized seeds (Beck, 2006; Gayot  
334 et al., 2004; O’Farrill et al., 2013). The southern section of the Atlantic Rainforest  
335 experienced a severe collapse in mammal biomass, especially primary consumers  
336 (Bogoni et al., 2018). Species such as *Tayassu pecari* and *Tapirus terrestris* (large  
337 dispersers) showed low abundance in current inventory and demonstrated the rareness  
338 of these species within the Environmental Protection Area (EPA) of the Devonian  
339 Escarpment, indicating functional extinction or reduced activities. Both species are  
340 classified as Critically Endangered in the state of Paraná, where the fragments under  
341 analysis occur (MMA, 2014). They were intensely hunted in the past while they require  
342 large areas for the maintenance of the population (Altrichter et al., 2012; Jorge et al.,  
343 2013). The local extinction of big frugivores has serious impacts on forest composition  
344 and dynamics since seed dispersal is a key-step within the cycle of plant life, with  
345 profound implications for succession, regeneration, carbon stock and conservation of  
346 biodiversity (Bello et al., 2016; Peres et al., 2016).

347 After the analysis of variables related to soil use, the areas with the highest  
348 percentage of soil cover for silviculture and agriculture proved to have the highest  
349 defaunation levels when compared with areas with more forests and protected areas. As  
350 conservation units, fragments had functionally balanced assemblies, with lower mean  
351 rates of defaunation when compared to non-protected areas (Fig. 2K). Within the  
352 remnants analyzed, the fragment Gruta (FGR), with the smallest area (23 ha) had the  
353 highest defaunation rates. Although small fragments (<50 ha) may be viable stepping-  
354 stones between bigger fragments, and change landscape connectivity (Magioli et al.,  
355 2016), these fragments are incapable of sustaining viable mammal populations due to  
356 size, quality and hunting pressure restrictions in the areas (Galetti et al., 2009; Canale et  
357 al., 2012).

358 The Atlantic Rainforest is one of the most disturbed and fragmented ecosystems  
359 in the Americas (Ribeiro et al., 2009). Its pristine area amounted to 1.5 million km<sup>2</sup>, but  
360 at present has a mere 11.7% of the original forest coverage, most of which are remnants  
361 with less than 100 hectares surrounded by different types of agrosystem and silviculture  
362 matrixes (Ribeiro et al., 2009). Effects of habitat fragmentation and natural forest  
363 replacement by reforestation with exotic species on the community of large mammals  
364 have already been investigated in studies at the local level (e.g., Bogoni et al., 2013;  
365 2016; Wilson et al., 2016). Results indicate that matrix serves as a functional filter.  
366 Most species are not able to obtain resources in such environments and remain confined  
367 to smaller fragments (Chiarello, 2000).

368 Previous studies indicated that local extinctions are more pronounced at the  
369 eastern sections of the Atlantic Rainforest (Northeastern and Eastern Atlantic  
370 provinces), ranging between the states of Pernambuco and northern Minas Gerais, with  
371 great repercussions on large mammals and species, appreciated by hunters past and  
372 present (*i.e.*, wild pig, jaguar, spider monkey, armadillo and anteater) (Canale et al.,

2012; Mendes-Pontes et al., 2016; Bogoni et al., 2018). Current results show a similar pattern for the southern section of the biome and indicate strong trends that the structure for mammal assemblies is already compromised, due to large herbivore and carnivores profoundly affected by defaunation. Further, even if hunting pressure and running down of mammals in the region analyzed have not been evaluated, it may be inferred that in this section of the Atlantic Rainforest, important changes in the functional composition of the species are associated with landscape characteristics.

The conservation of biodiversity through the delimitation of new protected areas in current political conditions in Brazil does not integrate state or federal management and planning (Thomé and Haddad, 2019). New resources are thus highly necessary, coupled to existing ones, for the promotion of activities foreseen in management of existing conservation units that have not been fulfilled. These activities foresee the management and control of exotic species within reserve areas and the units' biological restoration programs. If such measures are not taken, as large-sized mammals are locally brought to extinction, pressures caused by anthropic changes will also affect medium-sized animals and consequently influence abundance rates, with forest remnants of the Atlantic Rainforest changing into empty and homogenous forests.

390

## 391 **ACKNOWLEDGMENTS**

392

393 The authors would like to thank the Postgraduate Program in Biological Sciences of the  
394 Universidade Estadual de Londrina and the Coordination for the Upgrading of Higher  
395 Education Personnel (CAPES-Funding Code 1689817), for logistical and financial  
396 support. JAB is supported by postdoctoral fellowships grants 2018-05970-1 and 2019-  
397 11901-5, São Paulo Research Foundation (FAPESP).

398

399

## 400 **REFERENCES**

401

402 Ahumada, J.A., Silva, C.E.F., Gajapersad, K., Hallam, C., Hurtado, J., Martin, E.,  
403 McWilliam, A., Mugerwa, B., O'Brien, T., Rovero, F., Sheil, D., Spironello, W.R.,  
404 Winarni, N., Andelman, S.J., 2011. Community structure and diversity of tropical  
405 forest mammals: Data from a global camera trap network. *Philos. Trans. R. Soc. B*  
406 *Biol. Sci.* 366, 2703–2711. <https://doi.org/10.1098/rstb.2011.0115>

407 Alfaro, J.W.L., Matthews, L., Boyette, A.H., MacFarlan, S.J., Phillips, K.A., Falótico,  
408 T., Ottoni, E., Verderane, M., Izar, P., Schulte, M., Melin, A., Fedigan, L., Janson,  
409 C., Alfaro, M.E., 2012. Anointing variation across wild capuchin populations: A  
410 review of material preferences, bout frequency and anointing sociality in *Cebus*  
411 and *Sapajus*. *Am. J. Primatol.* 74, 299–314. <https://doi.org/10.1002/ajp.20971>

412 Almeida, C.G., Moro, R.S., 2007. Análise da cobertura florestal no Parque Nacional dos  
413 Campos Gerais, Paraná, como subsídio ao seu plano de manejo. *Terra Plur.* 1, 115–  
414 122.

415 Altrichter, M., Taber, A., Beck, H., Reyna-Hurtado, R., Lizarraga, L., Keuroghlian, A.,  
416 Sanderson, E.W., 2012. Range-wide declines of a key Neotropical ecosystem  
417 architect, the Near Threatened white-lipped peccary *Tayassu pecari*. *Oryx* 46, 87–  
418 98. <https://doi.org/10.1017/S0030605311000421>

419 Beck, H., 2006. a Review of Peccary–Palm Interactions and Their Ecological  
420 Ramifications Across the Neotropics. *J. Mammal.* 87, 519–530.  
421 <https://doi.org/10.1644/05-mamm-a-174r1.1>

- 422 Beisiegel, B., Sana, D., Moranes, E., 2012. The jaguar in the Atlantic Forest. CAT  
423 News 14–18.
- 424 Bello, C., Galetti, M., Pizo, M.A., Magnago, L.F.S., Rocha, M.F., Lima, R.A.F., Peres,  
425 C.A., Ovaskainen, O., Jordano, P., 2015. Defaunation affects carbon storage in  
426 tropical forests. *Sci. Adv.* 1, 1DUMMY. <https://doi.org/10.1126/sciadv.1501105>
- 427 Bogoni, J.A., Bogoni, T.C., Graipel, M.E., Marinho, J.R., 2013. The Influence of  
428 Landscape and Microhabitat on the Diversity of Large- and Medium-Sized  
429 Mammals in Atlantic Forest Remnants in a Matrix of Agroecosystem and  
430 Silviculture. *ISRN For.* 2013, 1–13. <https://doi.org/10.1155/2013/282413>
- 431 Bogoni, J.A., Cherem, J.J., Hettwer Giehl, E.L., Oliveira-Santos, L.G., De Castilho,  
432 P.V., Picinatto Filho, V., Fantacini, F.M., Tortato, M.A., Luiz, M.R., Rizzaro, R.,  
433 Graipel, M.E., 2016. Landscape features lead to shifts in communities of medium-  
434 to large-bodied mammals in subtropical Atlantic Forest. *J. Mammal.* 97, 713–725.  
435 <https://doi.org/10.1093/jmammal/gyv215>
- 436 Bogoni, J.A., Pires, J.S.R., Graipel, M.E., Peroni, N., Peres, C.A., 2018. Wish you were  
437 here: How defaunated is the Atlantic Forest biome of its medium- to largebodied  
438 mammal fauna? *PLoS One* 13, 1–23. <https://doi.org/10.1371/journal.pone.0204515>
- 439 Bogoni, J.A., da Silva, P.G., Peres, C.A., 2019. Co-declining mammal–dung beetle  
440 faunas throughout the Atlantic Forest biome of South America. *Ecography (Cop.)*.  
441 42, 1803–1818. <https://doi.org/10.1111/ecog.04670>
- 442 Canale, G.R., Peres, C.A., Guidorizzi, C.E., Gatto, C.A.F., Kierulff, M.C.M., 2012.  
443 Pervasive defaunation of forest remnants in a tropical biodiversity hotspot. *PLoS*  
444 *One* 7. <https://doi.org/10.1371/journal.pone.0041671>
- 445 Cardillo, M., Mace, G.M., Jones, K.E., Bielby, J., Bininda-Emonds, O.R.P., Sechrest,  
446 W., Orme, C.D.L., Purvis, A., 2005. Evolution: Multiple causes of high extinction  
447 risk in large mammal species. *Science (80)*. 309, 1239–1241.  
448 <https://doi.org/10.1126/science.1116030>
- 449 Chiarello, A.G., 2000. Conservation value of a native forest fragment in a region of  
450 extensive agriculture. *Rev. Bras. Biol.* 60, 237–247. <https://doi.org/10.1590/s0034-71082000000200007>
- 451
- 452 Dean, W., 1996. *A ferro e fogo: a história e a devastação da mata atlântica brasileira,*  
453 *Companhia das Letras, São Paulo, Brasil.*
- 454 Di Bitetti, M.S., De Angelo, C.D., Di Blanco, Y.E., Paviolo, A., 2010. Niche  
455 partitioning and species coexistence in a Neotropical felid assemblage. *Acta*  
456 *Oecologica* 36, 403–412. <https://doi.org/10.1016/j.actao.2010.04.001>
- 457 Diggle, P. J., Heagerty, P., Liang, K.Y., Zeger, S.L., 2002. *The Analysis of Longitudinal Data.*  
458 *Second Edition. Oxford University Press, Oxford, England.*
- 459 Dirzo, R., Young, H.S., Galetti, M., Ceballos, G., Isaac, N.J.B., Collen, B., 2014.  
460 Defaunation in the Anthropocene. *Science (80- )*.  
461 <https://doi.org/10.1126/science.1251817>
- 462 Elschot, K., Bakker, J.P., Temmerman, S., Van De Koppel, J., Bouma, T.J., 2015.  
463 Ecosystem engineering by large grazers enhances carbon stocks in a tidal salt  
464 marsh. *Mar. Ecol. Prog. Ser.* 537, 9–21. <https://doi.org/10.3354/meps11447>
- 465 Fahrig, L., 2003. Effects of Habitat Fragmentation on Biodiversity. *Annu. Rev. Ecol.*  
466 *Evol. Syst.* 34, 487–515.  
467 <https://doi.org/10.1146/annurev.ecolsys.34.011802.132419>
- 468 Galetti, M., Brocardo, C.R., Begotti, R.A., Hortenci, L., Rocha-Mendes, F., Bernardo,  
469 C.S.S., Bueno, R.S., Nobre, R., Bovendorp, R.S., Marques, R.M., Meirelles, F.,  
470 Gobbo, S.K., Beca, G., Schmaedecke, G., Siqueira, T., 2017. Defaunation and  
471 biomass collapse of mammals in the largest Atlantic forest remnant. *Anim.*  
472 *Conserv.* 20, 270–281. <https://doi.org/10.1111/acv.12311>

- 473 Galetti, M., Dirzo, R., 2013. Ecological and evolutionary consequences of living in a  
474 defaunated world. *Biol. Conserv.* 163, 1–6.  
475 <https://doi.org/10.1016/j.biocon.2013.04.020>
- 476 Galetti, M., Donatti, C.I., Pires, A.S., Guimarães, P.R., Jordano, P., 2006. Seed survival  
477 and dispersal of an endemic Atlantic forest palm: The combined effects of  
478 defaunation and forest fragmentation, in: *Botanical Journal of the Linnean Society*.  
479 Elsevier Ltd, pp. 141–149. <https://doi.org/10.1111/j.1095-8339.2006.00529.x>
- 480 Galetti, M., Giacomini, H.C., Bueno, R.S., Bernardo, C.S.S., Marques, R.M.,  
481 Bovendorp, R.S., Steffler, C.E., Rubim, P., Gobbo, S.K., Donatti, C.I., Begotti,  
482 R.A., Meirelles, F., Nobre, R.D.A., Chiarello, A.G., Peres, C.A., 2009. Priority  
483 areas for the conservation of Atlantic forest large mammals. *Biol. Conserv.* 142,  
484 1229–1241. <https://doi.org/10.1016/j.biocon.2009.01.023>
- 485 Galetti, M., Guevara, R., Neves, C.L., Rodarte, R.R., Bovendorp, R.S., 2015.  
486 Defaunation affects the populations and diets of rodents in Neotropical rainforests  
487 Defaunation affects the populations and diets of rodents in Neotropical rainforests.  
488 *Biol. Conserv.* 190, 2–7. <https://doi.org/10.1016/j.biocon.2015.04.032>
- 489 Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A., Sodhi,  
490 N.S., 2009. Prospects for tropical forest biodiversity in a human-modified world.  
491 *Ecol. Lett.* 12, 561–582. <https://doi.org/10.1111/j.1461-0248.2009.01294.x>
- 492 Gayot, M., Henry, O., Dubost, G., Sabatier, D., 2004. Comparative diet of the two forest  
493 cervids of the genus *Mazama* in French Guiana. *J. Trop. Ecol.* 20, 31–43.  
494 <https://doi.org/10.1017/S0266467404006157>
- 495 Giacomini, H.C., Galetti, M., 2013. An index for defaunation. *Biol. Conserv.* 163, 33–  
496 41. <https://doi.org/10.1016/j.biocon.2013.04.007>
- 497 Graipel, M.E., Cherem, J.J., Monteiro-Filho, E.L.A., Carmignotto, A.P. 2017.  
498 Mamíferos da Mata Atlântica, in: Monteiro-Filho, E.L.A., Conte, C.E. (Eds.),  
499 Revisões em Zoologia: Mata Atlântica. Ed. UFPR, Curitiba, pp. 391–482.
- 500 IBGE, 2018. Instituto Brasileiro de Geografia e Estatística. Cobertura e uso da terra.  
501 URL. <https://www.ibge.gov.br/geociencias/downloads-geociencias.html>
- 502 IUCN, 2019. The IUCN Red List of Threatened Species. Version 2019-2. URL.  
503 <https://www.iucnredlist.org>
- 504 Jenkins, C.N., Joppa, L., 2009. Expansion of the global terrestrial protected area system.  
505 *Biol. Conserv.* 142, 2166–2174. <https://doi.org/10.1016/j.biocon.2009.04.016>
- 506 Jorge, M.L.S.P., Galetti, M., Ribeiro, M.C., Ferraz, K.M.P.M.B., 2013. Mammal  
507 defaunation as surrogate of trophic cascades in a biodiversity hotspot. *Biol.*  
508 *Conserv.* 163, 49–57. <https://doi.org/10.1016/j.biocon.2013.04.018>
- 509 Hoskins, A.J., Bush, A., Gilmore, J., Harwood, T., Hudson, L.N., Ware, C., Williams,  
510 K.J., Ferrier, S., 2016. Downscaling land-use data to provide global 30" estimates  
511 of five land-use classes. *Ecol. Evol.* 6, 3040–3055.  
512 <https://doi.org/10.1002/ece3.2104>
- 513 Kurten, E.L., 2013. Cascading effects of contemporaneous defaunation on tropical  
514 forest communities. *Biol. Conserv.* 163, 22–32.  
515 <https://doi.org/10.1016/j.biocon.2013.04.025>
- 516 Kurten, E.L., Wright, S.J., Carson, W.P., Palmer, T.M., 2015. Hunting alters seedling  
517 functional trait composition in a Neotropical forest. *Ecology* 96, 1923–1932.  
518 <https://doi.org/10.1890/14-1735.1>
- 519 Lynch-Alfaro, J.W.L., Matthews, L., Boyette, A.H., MacFarlan, S.J., Phillips, K.A.,  
520 Falótico, T., Ottoni, E., Verderane, M., Izar, P., Schulte, M., Melin, A., Fedigan,  
521 L., Janson, C., Alfaro, M.E., 2012. Anointing variation across wild capuchin  
522 populations: A review of material preferences, bout frequency and anointing

523 sociality in *Cebus* and *Sapajus*. *Am. J. Primatol.* 74, 299–314.  
524 <https://doi.org/10.1002/ajp.20971>

525 Magioli, M., Ferraz, K.M.P.M. de B., Setz, E.Z.F., Percequillo, A.R., Rondon, M.V. de  
526 S.S., Kuhnen, V.V., Canhoto, M.C. da S., dos Santos, K.E.A., Kanda, C.Z.,  
527 Fregonezi, G. de L., do Prado, H.A., Ferreira, M.K., Ribeiro, M.C., Villela, P.M.S.,  
528 Coutinho, L.L., Rodrigues, M.G., 2016. Connectivity maintain mammal  
529 assemblages functional diversity within agricultural and fragmented landscapes.  
530 *Eur. J. Wildl. Res.* 62, 431–446. <https://doi.org/10.1007/s10344-016-1017-x>

531 Markl, J.S., Schleunig, M., Forget, P.M., Jordano, P., Lambert, J.E., Traveset, A.,  
532 Wright, S.J., Böhning-Gaese, K., 2012. Meta-Analysis of the Effects of Human  
533 Disturbance on Seed Dispersal by Animals. *Conserv. Biol.* 26, 1072–1081.  
534 <https://doi.org/10.1111/j.1523-1739.2012.01927.x>

535 Mendes Pontes, A.R., Beltrão, A.C.M., Normande, I.C., Malta, A.D.J.R., Da Silva,  
536 A.P., Santos, A.M.M., 2016. Mass extinction and the disappearance of unknown  
537 mammal species: Scenario and perspectives of a biodiversity hotspot's hotspot.  
538 *PLoS One* 11, 1–26. <https://doi.org/10.1371/journal.pone.0150887>

539 Myers, N., Mittermeier, R.A., Kent, C.G.M.G.A.B. da F.J., \*, 2000. Biodiversity  
540 hotspots for conservation priorities. *Nature* 403, 853–858.  
541 <https://doi.org/10.1038/35002501>

542 Nolte, S., Müller, F., Schuerch, M., Wanner, A., Esselink, P., Bakker, J.P., Jensen, K.,  
543 2013. Does livestock grazing affect sediment deposition and accretion rates in salt  
544 marshes? *Estuar. Coast. Shelf Sci.* 135, 296–305.  
545 <https://doi.org/10.1016/j.ecss.2013.10.026>

546 O'Farrill, G., Galetti, M., Campos-Arceiz, A., 2013. Frugivory and seed dispersal by  
547 tapirs: An insight on their ecological role. *Integr. Zool.*  
548 <https://doi.org/10.1111/j.1749-4877.2012.00316.x>

549 Paglia, A.P., Fonseca, G.A.B. da, Rylands, A.B., Herrmann, G., Aguiar, L.M.S.,  
550 Chiarello, A.G., Leite, Y.L.R., Costa, L.P., Siciliano, S., Kierulff, M.C.M.,  
551 Mendes, S.L., Mittermeier, R.A., Patton, J.L., 2012. Annotated checklist of  
552 Brazilian mammals 2<sup>o</sup> Edição, Occasional Papers in Conservation Biology.

553 Patton, J.L., Pardiñas, U.F., D'Elía, G., 2015. *Mammals of South America.*  
554 Volume 2. Rodents. University of Chicago Press, Chicago.

555 Paviolo, A., De Angelo, C., Ferraz, K.M.P.M.B., Morato, R.G., Martinez Pardo, J.,  
556 Srbek-Araujo, A.C., Beisiegel, B.D.M., Lima, F., Sana, D., Xavier Da Silva, M.,  
557 Velázquez, M.C., Cullen, L., Crawshaw, P., Jorge, M.L.S.P., Galetti, P.M., Di  
558 Bitetti, M.S., De Paula, R.C., Eizirik, E., Aide, T.M., Cruz, P., Perilli, M.L.L.,  
559 Souza, A.S.M.C., Quiroga, V., Nakano, E., Ramírez Pinto, F., Fernández, S.,  
560 Costa, S., Moraes, E.A., Azevedo, F., 2016. A biodiversity hotspot losing its top  
561 predator: The challenge of jaguar conservation in the Atlantic Forest of South  
562 America. *Sci. Rep.* 6, 1–16. <https://doi.org/10.1038/srep37147>

563 Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Koppen-  
564 Geiger climate classificatio. *Hydrol. Earth Syst. Sci.* 11, 1643–1644.  
565 <https://doi.org/10.1002/ppp.421>

566 Peres, C.A., Emilio, T., Schiatti, J., Desmoulière, S.J.M., Levi, T., 2016. Dispersal  
567 limitation induces long-term biomass collapse in overhunted Amazonian forests.  
568 *Proc. Natl. Acad. Sci. U. S. A.* 113, 892–897.  
569 <https://doi.org/10.1073/pnas.1516525113>

570 Redford, K.H., 1992. The Empty of neotropical forest where the vegetation still appears  
571 intact. *BioScience* 42, 412–422.

- 572 Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M., 2009. The  
573 Brazilian Atlantic Forest: How much is left, and how is the remaining forest  
574 distributed? Implications for conservation. *Biol. Conserv.* 142, 1141–1153.  
575 <https://doi.org/10.1016/j.biocon.2009.02.021>
- 576 Schrama, M., Heijning, P., Bakker, J.P., van Wijnen, H.J., Berg, M.P., Olff, H., 2013.  
577 Herbivore trampling as an alternative pathway for explaining differences in  
578 nitrogen mineralization in moist grasslands. *Oecologia* 172, 231–243.  
579 <https://doi.org/10.1007/s00442-012-2484-8>
- 580 Srbek-Araujo, A.C., Chiarello, A.G., 2013. Influence of camera-trap sampling design on  
581 mammal species capture rates and community structures in southeastern Brazil.  
582 *Biota Neotrop.* 13, 51–62. <https://doi.org/10.1590/s1676-06032013000200005>
- 583 Srbek-Araujo, A.C., Chiarello, A.G., 2017. Population status of the jaguar *Panthera*  
584 *onca* in one of its last strongholds in the Atlantic Forest. *Oryx* 51, 246–253.  
585 <https://doi.org/10.1017/S0030605315001222>
- 586 Stoner, C., Caro, T., Mduma, S., Mlingwa, C., Sabuni, G., Borner, M., Schelten, C.,  
587 2007. Changes in large herbivore populations across large areas of Tanzania. *Afr.*  
588 *J. Ecol.* 45, 202–215. <https://doi.org/10.1111/j.1365-2028.2006.00705.x>
- 589 Takeda, A.C., Takeda, I.J.M., Farago, P.V., 2001. Unidades de conservação da região  
590 dos campos gerais, Paraná. *Publ. UEPG – Biol. Heal. Sci.* 7, 57–78.
- 591 Taylor, R.A., Ryan, S.J., Brashares, J.S., Johnson, L.R., 2016. Hunting, food subsidies,  
592 and mesopredator release: the dynamics of crop-raiding baboons in a managed  
593 landscape. *Ecology* 97, 951–960. <https://doi.org/10.1890/15-0885.1>
- 594 Thomé, M.T.C., Haddad, C.F.B., 2019. Brazil’s biodiversity researchers need help.  
595 *Science* (80-. ). 364, 1144 LP – 1145. <https://doi.org/10.1126/science.aax9478>
- 596 Trigo, T.C., Schneider, A., De Oliveira, T.G., Lehugeur, L.M., Silveira, L., Freitas,  
597 T.R.O., Eizirik, E., 2013. Molecular data reveal complex hybridization and a  
598 cryptic species of Neotropical wild cat. *Curr. Biol.* 23, 2528–2533.  
599 <https://doi.org/10.1016/j.cub.2013.10.046>
- 600 Weckel, M., Giuliano, W., Silver, S., 2006. Jaguar (*Panthera onca*) feeding ecology:  
601 Distribution of predator and prey through time and space. *J. Zool.* 270, 25–30.  
602 <https://doi.org/10.1111/j.1469-7998.2006.00106.x>
- 603 Wilman, H., J., B., J., S., C., de L.R., M., R., W, J., 2014. EltonTraits 1.0: Species-  
604 level foraging attributes of the world’s birds and mammals. *Ecology* 95, 2027.
- 605 Wilson, M.C., Chen, X.Y., Corlett, R.T., Didham, R.K., Ding, P., Holt, R.D., Holyoak,  
606 M., Hu, G., Hughes, A.C., Jiang, L., Laurance, W.F., Liu, J., Pimm, S.L.,  
607 Robinson, S.K., Russo, S.E., Si, X., Wilcove, D.S., Wu, J., Yu, M., 2016. Habitat  
608 fragmentation and biodiversity conservation: key findings and future challenges.  
609 *Landsc. Ecol.* 31, 219–227. <https://doi.org/10.1007/s10980-015-0312-3>
- 610 Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G., 2009. *Mixed Effects*  
611 *Models and Extensions in Ecology with R.* Springer, New York.

612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630

## **SUPPORT MATERIAL**

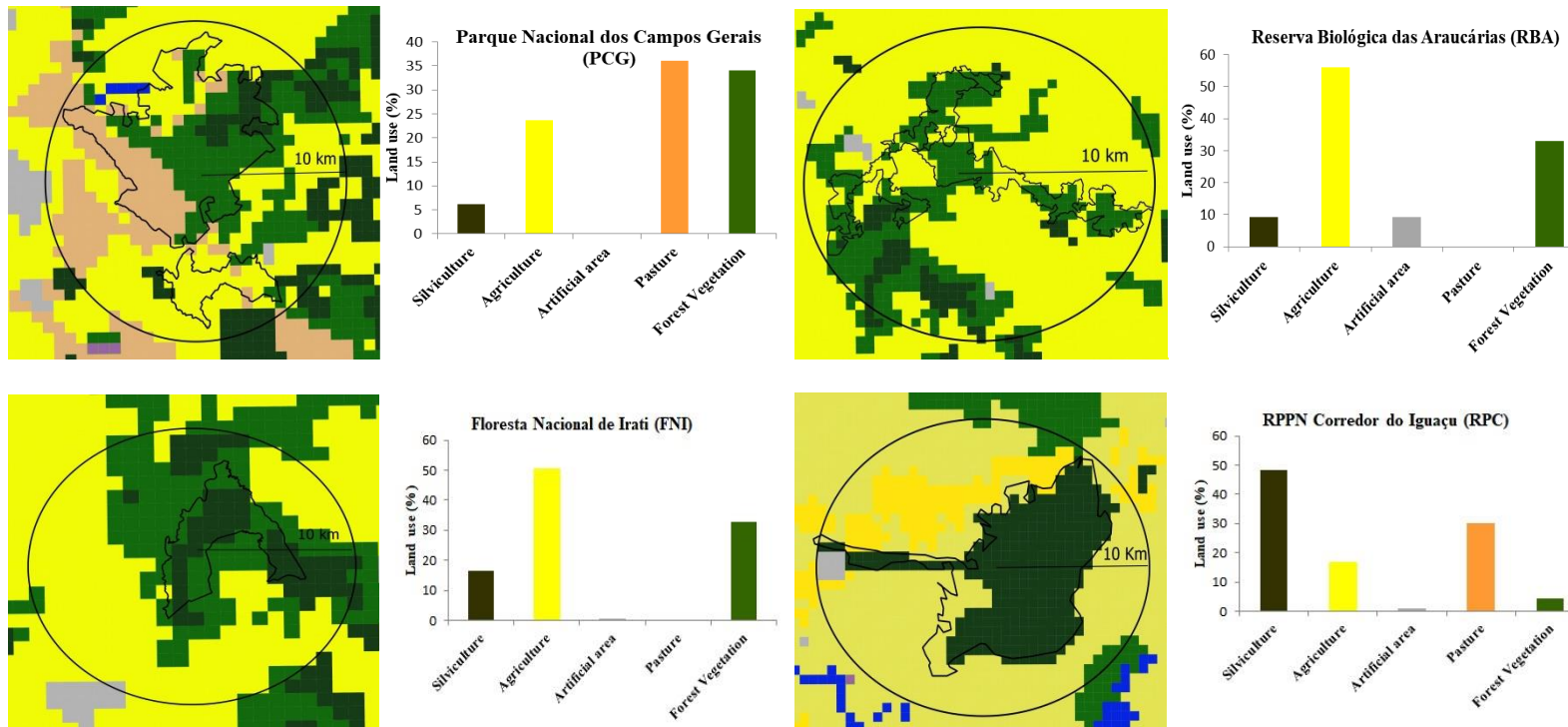
## Supporting Information S1

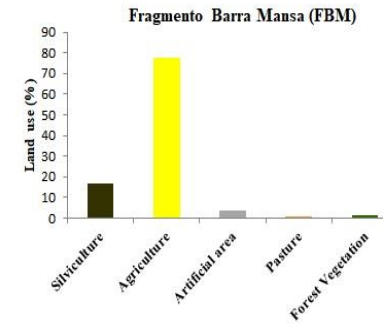
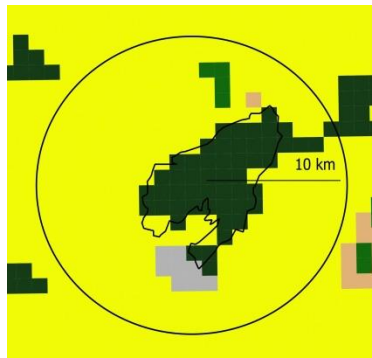
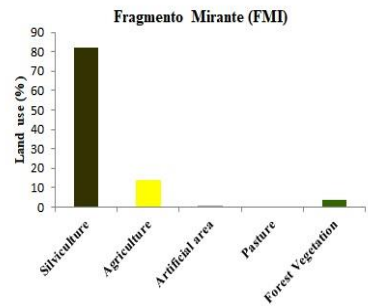
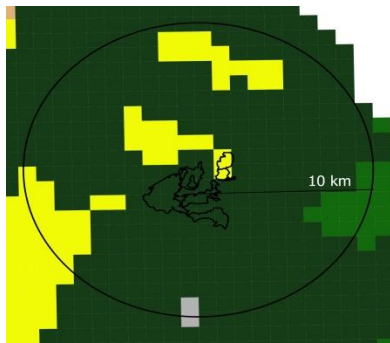
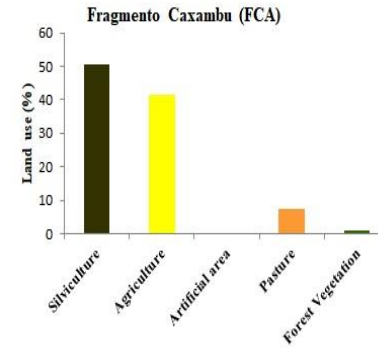
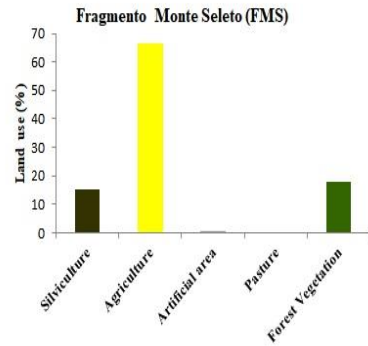
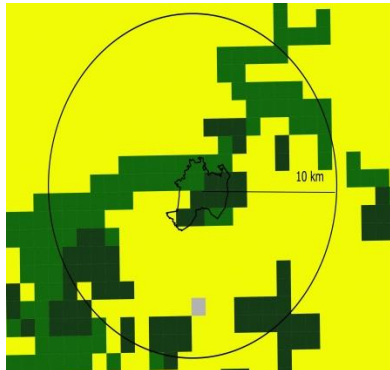
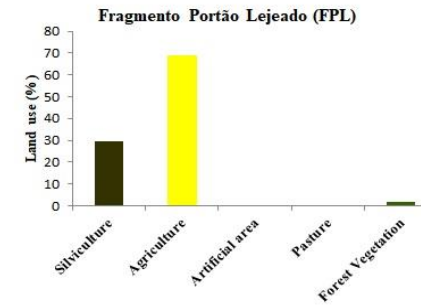
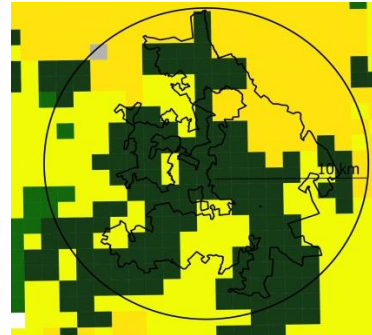
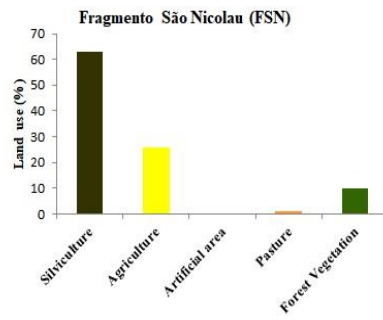
Landscape characterization of the analyzed areas. **Areas:** PCG: Parque Nacional dos Campos Gerais; RBA: Reversa Biológica das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN Corredor do Iguaçu; FSN: Fragmento São Nicolau; FPL: Fragmento Portão lajeado; FMS: Fragmento Monte Selete; FCA: Fragmento Caxambu; FMI: Fragmento Mirante; FBM: Fragmento Barra Mansa; FGR: Fragmento da Gruta; HB: Historical baseline.

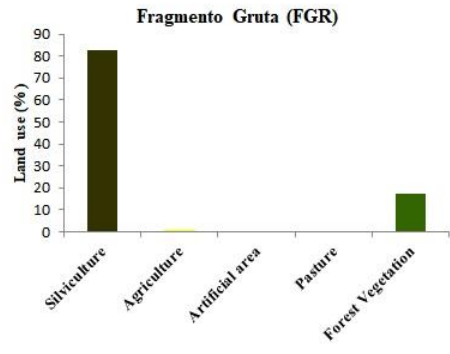
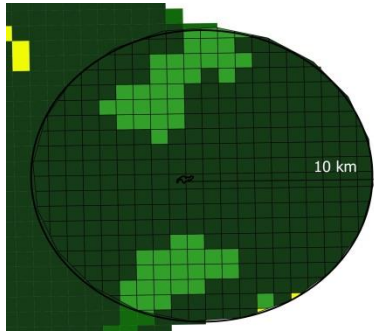
Areas	Coordinates		Silviculture	Agriculture	Artificial area	Pasture	Forest Vegetation	Size area (ha)	Demographic density	Human Development Index
	Longitude	Latitude								
PCG	-50.0275	-25.0403	6.22	23.65	0	36.02	34,11	21.299	171.81	0.763
RBA	-50.6146	-25.3005	9.16	55.95	9.16	0	32.86	14.930	42.43	0.66
FNI	-50.5848	-25.3807	16.61	50.6	0.02	0	32.77	3.495	13.99	0.645
RPC	-52.7147	-25.5158	48.1	16.75	1	30	4.15	5.115	19.39	0.629
FSN	-50.0023	-24.1342	63.27	26.67	0	0	10.06	18.426	18.74	0.723
FPL	-49.5609	-26.0214	29.53	68.71	0	0	1.76	325	25.94	0.686
FMS	-49.6927	-25.9306	15.07	66.63	0.34	0	17.96	958	25.94	0.686
FCA	-49.9792	-24.2835	50.58	41.29	0	7.2	0.93	7.729	18.74	0.708
FMI	-49.3853	-24.3345	82	13.86	0.43	0	3.71	992	13.43	0.663
FBM	-49.8177	-24.09	16.94	77.75	3.42	0.55	1.34	4.542	20.5	0.723
FGR	-49.2693	-24.4006	82.45	0.09	0	0	17.46	50	13.43	0.663

## Supporting Information S3

Land use cover found in forest remnants of the South Atlantic Forest in Brazil.







## **Supporting Information S2**

List of medium-sized and large mammal species in the 11 areas analyzed along with the IUCN historical baseline. **Trophic Guild:** Ca: Carnivore; Fr: Frugivore; Fo: Folivore; Gr: Gumivore; Hb: Herbivore grazer; In: Insectivore; Myr: Myrmecophage; On: Omnivore; Os: Piscivore. **Areas:** PCG: Parque Nacional dos Campos Gerais; RBA: Reversa Biológica das Araucárias; RPC: FNI: Floresta Nacional de Irati; RPPN **Corredor do Iguaçu**; FSN: **Fragmento São Nicolau**; FPL: **Fragmento Portão lajeado**; FMS: **Fragmento Monte Seletto**; FCA: **Fragmento Caxambu**; FMI: **Fragmento Mirante**; FBM: **Fragmento Barra Mansa**; FGR: **Fragmento da Gruta**; **HB:** Historical baseline.

Taxon	Considered	Trophic Guild	Areas											HB	Status IUCN	
			PCG	RBA	FNI	RPC	FSN	FPL	FMS	FCA	FMI	FBM	FGR			
<b>Didelphimorphia</b>																
<b>Didelphidae</b>																
<i>Didelphis albiventris</i> Lund, 1840	Yes	Fr/On	X	X	X	X	X	X	X	X		X	X		X	LC
<i>Didelphis aurita</i> (Wied-Neuwied, 1826)	Yes	Fr/On	X	X	X	X	X			X	X			X	X	LC
<b>Pilosa</b>																
<b>Mymercophagidae</b>																
<i>Myrmecophaga tridactyla</i> Linnaeus, 1758	Yes	Myr	X					X			X	X	X	X	X	VU
<i>Tamandua tetradactyla</i> (Linnaeus, 1758)	Yes	Myr	X	X	X	X	X	X	X	X	X				X	LC
<b>Cingulata</b>																
<b>Dasypodidae</b>																
<i>Cabassous tatouay</i> (Desmarest, 1804)	Yes	Myr		X				X	X			X	X		X	LC
<i>Dasypus novemcinctus</i> Linnaeus, 1758	Yes	In/On	X	X	X	X	X	X	X	X	X	X	X	X	X	LC
<i>Dasypus septemcinctus</i> Linnaeus, 1758	Yes	In/On		X					X						X	LC
<i>Euphractus sexcinctus</i> (Linnaeus, 1758)	Yes	In/On	X	X		X	X								X	LC
<b>Perissodactyla</b>																
<b>Tapiridae</b>																
<i>Tapirus terrestris</i> (Linnaeus, 1758)	Yes	Hb/Fr					X								X	VU
<b>Cetartiodactyla</b>																
<b>Cervidae</b>																
<i>Mazama americana</i> (Erxleben, 1777)	Yes	Fr/Hb	X	X	X	X	X	X	X	X	X		X		X	DD
<i>Mazama gouazoubira</i> (G. Fischer, 1814)	Yes	Fr/Hb	X	X	X	X	X	X	X	X	X	X	X	X	X	LC
<i>Mazama nana</i> (Hensel, 1872)	Yes	Fr/Hb	X												X	VU
<i>Ozotoceros bezoarticus</i> (Linnaeus, 1758)	Yes	Fr/Hb													X	NT
<b>Tayassuidae</b>																
<i>Pecari tajacu</i> (Linnaeus, 1758)	Yes	Fr/Hb	X	X	X	X	X	X			X		X		X	LC
<i>Tayassu pecari</i> (Link, 1795)	Yes	Fr/Hb					X	X							X	VU

**Suidae***Sus scrofa* Linnaeus, 1758 \*

No On X X

**Primates****Atelidae***Alouatta guariba clamitans* Cabrera, 1940

No Fo/Fr X X X X X X X X X X

**Cebidae***Sapajus nigritus* (Goldfuss, 1809)

No Fr/On X X X X X X X X X X

**Carnivora****Canidae***Cerdocyon thous* (Linnaeus, 1766)

Yes In/On X X X X X X X X X X X X X LC

*Chrysocyon brachyurus* (Illiger, 1815)

Yes Ca/On X X X X X X X X X X X X X NT

*Speothos venaticus* (Lund, 1842)

Yes Ca X X X X X X X X X X X X X NT

**Felidae***Leopardus guttulus* (Hensel, 1872)

Yes Ca X X X X X X X X X X X X X VU

*Leopardus pardalis* (Linnaeus, 1758)

Yes Ca X X X X X X X X X X X X X LC

*Leopardus wiedii* (Schinz, 1821)

Yes Ca X X X X X X X X X X X X X NT

*Panthera onca* (Linnaeus, 1758)

Yes Ca X X X X X X X X X X X X X NT

*Puma concolor* (Linnaeus, 1771)

Yes Ca X X X X X X X X X X X X X LC

*Herpailurus yagouaroundi* (É. Geoffroy Saint-Hilaire, 1803)

Yes Ca X X X X X X X X X X X X X LC

**Mustelidae***Eira barbara* (Linnaeus, 1758)

Yes Fr/On X X X X X X X X X X X X X LC

*Galictis cuja* (Molina, 1782)

Yes Ca X X X X X X X X X X X X X LC

*Lontra longicaudis* (Olfers, 1818)

No Ps X X X X X X X X X X X X X NT

**Procyonidae***Nasua nasua* (Linnaeus, 1766)

Yes Fr/On X X X X X X X X X X X X X VU

*Procyon cancrivorus* (G. Cuvier, 1798)

Yes Fr/On X X X X X X X X X X X X X LC

**Lagomorpha****Leporidae**

<i>Sylvilagus brasiliensis</i> (Linnaeus, 1758)	Yes	Hb		X		X	X					X		X	EN	
<i>Lepus europaeus</i> Pallas, 1778*	No	Hb	X	X	X	X	X			X	X	X	X			
<b>Rodentia</b>																
<b>Caviidae</b>																
<i>Hydrochoerus hydrochaeris</i> (Linnaeus, 1766)	No	Hb														LC
			X	X	X		X			X	X	X		X		
<b>Cuniculidae</b>																
<i>Cuniculus paca</i> (Linnaeus, 1766)	Yes	Fr/Hb	X	X		X	X			X	X	X		X	LC	
<b>Dasyproctidae</b>																
<i>Dasyprocta azarae</i> Lichtenstein, 1823	Yes	Fr/Gr	X	X	X	X	X	X	X	X	X	X	X	X	DD	
<b>Echimyidae</b>																
<i>Myocastor coypus</i> (Molina, 1782)	No				X		X									
<b>Erethizontidae</b>																
<i>Coendou spinosus</i> (F. Cuvier, 1823)	Yes	Fr/Fo	X	X	X	X		X	X					X	LC	

### Supporting Information S3

Defaunation values found in forest remnants of the South Atlantic Forest in Brazil.

Areas	DEFAUNATION									
	Historical	High trophic level	Intermediate trophic level	Low trophic level	Frugivores	Large grazers	Mesocarnivores	Apex predator	Small-bodied species	Large-bodied species
PCG	0.14	0.30	0.05	0.17	0.07	0.06	0.21	0.53	0.00	0.22
RBA	0.46	0.48	0.43	0.55	0.07	0.65	0.21	0.53	0.11	0.53
FNI	0.43	0.44	0.49	0.25	0.59	0.48	0.21	0.53	0.18	0.53
RPC	0.18	0.44	0.11	0.02	0.00	0.10	0.21	0.53	0.14	0.20
FSN	0.30	0.32	0.42	0.02	0.00	0.48	0.21	0.53	0.07	0.00
FPL	0.56	0.55	0.53	0.66	0.59	0.65	0.21	0.53	0.21	0.87
FMS	0.56	0.46	0.56	0.34	1.00	0.48	0.35	0.53	0.21	1.00
FCA	0.40	0.34	0.52	0.19	0.07	0.48	0.30	0.53	0.33	0.22
FMI	0.55	0.35	0.71	0.55	0.07	0.85	0.21	0.53	0.29	0.42
FBM	0.38	0.38	0.45	0.19	0.00	0.48	0.30	0.53	0.23	0.22
FGR	0.69	0.60	0.76	0.70	0.59	0.85	0.46	1.00	0.39	0.42

## CONCLUSÃO GERAL

O presente estudo foi o primeiro a avaliar o grau de defaunação em remanescentes de Mata Atlântica Sul *in loco*, localizados no estado do Paraná. Mais especificamente o foco de nosso interesse foi a região da Área de Proteção Ambiental da Escarpa Devoniana. Esta importante área de conservação da biodiversidade brasileira, vem sofrendo intensas pressões nas esferas legislativas e do setor agropecuário para a redução de sua área de extensão geográfica. Alguns desses setores alegam que a atual demarcação já contempla áreas com atividades agrícolas entre outras e a sua redução não implicaria em danos à conservação das espécies dos remanescentes.

Nós concluímos que os remanescentes de Mata Atlântica sul enfrentam diretamente questões indicadas como precursoras da defaunação em todo o globo. A primeira é o desconhecimento básico sobre distribuição geográfica das espécies em remanescentes florestais. Este problema é ainda mais grave ao consideramos que existem unidades de conservação que não contam sequer com inventários básicos da diversidade, dificultando assim qualquer plano de conservação, manejo ou estratégias de restauração. A segunda questão é a mortalidade de animais em pequenas rodovias que cortam remanescentes florestais. Nossos dados sugerem que este é um fator que deve ser considerado como causa direta para o declínio de algumas espécies, sendo necessário a implementação de medidas de mitigação básicas que constam na legislação do Brasil e do Estado do Paraná. A terceira questão é a introdução de espécies não nativas tendo como consequência eventos de invasões biológicas. Já está bem relatado os impactos ambientais e econômicos do javali (*Sus scrofa*) no território brasileiro. Porém pouco se sabe do impacto aos ecossistemas que o rato-do-banhado (*Mycastor coypus*) pode causar nos diferentes sistemas biológicos do Brasil. Nossos dados indicam que a espécie pode aumentar seu limite de ocorrência vindo a se tornar uma “espécie problema” se medidas de controle não forem adotadas em curto espaço de tempo. Por fim nossos dados indicam que o longo histórico de conversão de florestas naturais em pastagens e monoculturas de espécies não nativas, reflete diretamente o grau de defaunação no remanescentes restantes.

Mesmo em áreas densamente fragmentadas os mamíferos de médio e grande porte persistem na região da APA da Escarpa Devoniana bem como em regiões do segundo planalto meridional paranaense. Contudo é possível observar em todos os remanescentes florestais analisados eventos de defaunação local. Podemos denotar que em áreas protegidas a defaunação é menor se comparadas a remanescentes sem qualquer status de

proteção. Ainda assim, salientamos que desenho experimental pode ser melhorado, através da inclusão de mais remancentes de Mata Atlântica em diferentes estados de conservação e com matrizes diversificadas. O declínio e ausência de espécies-chaves em determinadas regiões com interesse conservacionista, indicam que as florestas estão sob risco de instabilidade funcional, acarretando na perda direta de serviços necessários para a sua manutenção e resiliência.

## **ANEXO A**

### **Normas técnicas – Revista Papeis Avulsos de Zoologia**

[Register](#)[Login](#)[CURRENT](#)[ARCHIVES](#)[ANNOUNCEMENTS](#)[ABOUT](#) ▾[HOME](#) / [Submissions](#)

[Login](#) or [Register](#) to make a submission.

## Submission Preparation Checklist

As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

<input checked="" type="checkbox"/>	The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).
<input checked="" type="checkbox"/>	The manuscript is in ENGLISH.
<input checked="" type="checkbox"/>	The submission file is in OpenOffice, Microsoft Word, or RTF document file format.
<input checked="" type="checkbox"/>	All authors' ORCID ID were included.
<input checked="" type="checkbox"/>	Where available, URLs for the references have been provided.
<input checked="" type="checkbox"/>	The text is double-spaced between lines, justified text, and Calibri font, body 11 (eleven) (except for special symbols not included in this font).
<input type="checkbox"/>	

✓	Pictures, graphics and illustrations even inserted in the text <b>must necessarily</b> be sent in separate files, in the original format in which they were created.
✓	The text adheres to the stylistic and bibliographic requirements outlined in the <a href="#">Author Guidelines</a> .
✓	Authors declare that there is no conflict of interest; otherwise, it must be specified in “Comments to the Editor”.
✓	An authors’ contributions statement must be included in a section at the end of the article for works written by more than 4 (four) authors. The statement has to include the individual contribution of each author.

## Author Guidelines

### SUBMISSION OF MANUSCRIPTS

**IMPORTANT:** You **must** correctly complete all fields **for each AUTHOR:** Name, Middle Name, Last Name, Email, ORCID, URL (if there is), Institution/Affiliation, Country, and Biography Summary.

From 2019 on, the inclusion of the **ORCID ID** for each author is mandatory.

The fields **for the manuscript** should also be filled with the information: Title, Abstract, Area and Sub-Area of Knowledge, Keywords, Language and Funding/Support Agencies.

- The manuscript must be sent only in ENGLISH.
- Manuscripts should be sent in the format “.DOCX” or “.RTF” to the journal submission system, along with a submission letter explaining the importance and originality of the study.
- All submissions are performed through the “[Portal de Revistas da USP](#)”.
- Pictures, graphics, and illustrations even inserted in the text **must necessarily** be sent in separate files, in the original format in which they were created.
- The files must be sent in separate files formats: “.PSD”, “.TIF”, “.JPG”, “.PCX”, “.GIF” or “.BMP” for figures; “.EPS”, “.CDR”, “.WMF”, “.AI”, “.PPTX” or “.XLSX” for graphics; and “.MOV”, “.AVI”, “.MPG”, “.MP4” or “.M4V” for videos.
- Tables should be placed at the end of the manuscript.
- Always keep updated the email and the address of the author(s) or corresponding.
- The authors may suggest potential reviewers.

**AUTHORS WHOSE NATIVE LANGUAGE IS NOT ENGLISH ARE ENCOURAGED TO HAVE THEIR MANUSCRIPTS REVISED BY A NATIVE ENGLISH-SPEAKING BEFORE SUBMISSION.**

### MANUSCRIPT FORMAT

- The manuscripts must be double-spaced between lines, justified text, and Calibri font, body 11 (eleven) (except for special symbols not included in this font).
- The text should be organized in the following sections, each started on a new page, in the order, and numbered consecutively: **Title Page, Abstract with Keywords, Body Text, Acknowledgments, References, Appendices, Tables, and Figure Legends.**
- Scientific names of species and genera, and other Latin terms, must be *italicized* in all sections of the manuscript.

**(1) TITLE PAGE:** Should include the **Title, Running Title, Author(s) Name(s), ORCID numbers(s), Institution(s), and Address(es).** The title should be concise and, where appropriate, should include particulars about families and/or taxa of higher categories. New taxa names should not be included in the titles.

**(2) ABSTRACT WITH KEYWORDS:** All papers should have an abstract and keywords in **English.** The quality of the abstract is of great importance since it can be reproduced in other vehicles. Therefore, must be written in an intelligible form as it may be published separately, and should summarize the main facts, ideas, and conclusions of the article. Telegraphic abstracts are unacceptable. Finally, the abstract should include all new taxonomic names for reference purposes. Abbreviations should be avoided. It should not include bibliographical references. Abstracts and keywords must not exceed 350 (three hundred and fifty) and 5 (five) words, respectively.

**(3) BODY TEXT:** The main body text varies with different types of papers, but should usually include the following sections: **Introduction, Material and Methods, Results, Discussion, Conclusion, Acknowledgments, and References.** The main headings of each section of the body of the text should be written in capital letters, bold and centered. Secondary headings should have only the first letter capitalized, bolded, and centered. Tertiary headings should be the first letter capitalized, in bold and indented left. In all cases, the text should start on the next line.

**(4) REFERENCES:** Citations in the text should be given as follows: Martins (1959) *or* (Martins, 1959) *or* (Martins, 1959, 1968, 2015) *or* Martins (1959a, b) *or* Martins (1959: 14-20) *or* Martins (1959: figs. 1, 2) *or* Martins & Reichardt (1964) *or* (Lane, 1940; Martins & Chemsak, 1966a, b) *or* Martins *et al.* (1966) *or* (Martins *et al.*, 1966), the latter when the article contains 3 (three) or more authors. There is no need to provide a full reference when authors and date are presented only as an authority of taxa.

**(5) REFERENCES MODELS:** References should be arranged alphabetically and according to the following format, respecting the titles in *italics*. Journal titles must be written in full (not abbreviated):

- **Journal Article** - Author(s). Year. Article title. *Journal name*, volume: initial page-final page.
- **Journal Article (print and online version with different dates, for instance: ahead-of-print, online first, etc.)** - Author(s). Year online. Article title. *Journal name*, volume: initial page-final page, Year on print.
- **Books** - Author(s). Year. *Book title*. Publisher, Place of publication.

- **Books Chapters** - Author(s). Year. Chapter title or part. *In*: Author(s) or Editor(s), *Book title*. Publisher, Place of publication, volume or part, initial page-final page.
- **Dissertations and Theses** - Author(s). Year. *Title of dissertation or thesis*. (Masters Dissertation or Doctoral Thesis). University, Place of publication.
- **Electronic Publications** - Author(s). Year. *Document title*. Available at: electronic address. Accessed: DD/MM/AAAA.
- **Datasets** - Author(s). Year. *Title*. Version. Publisher. [dataset]. Available at: (preferably the DOI number as url). Accessed: DD/MM/AAAA. - See more in the **Research Data** section.

## TABLES

- All tables should be numbered in the same sequence in which they are cited in the text.
- Legends should be self-explanatory, without the need to resort to text.
- Tables should be formatted preferentially towards portrait, remaining the sense landscape for exceptional cases.
- In the text, tables should be referred as Table 1, Tables 2 and 4, Tables 2-6.
- Use “TABLE” in the table(s) heading(s).

## FIGURES

- All figures should be numbered in the same sequence in which they are cited in the text.
- Each illustration of a composite figure should be identified by a capital letter and referred to in the text as, for example: Fig. 1A, Fig. 1B.
- When possible, the letters must be positioned in the lower-left corner of each illustration of a composite figure.
- Photographs in black and white or color must be sending at high resolution (300 DPI minimum).
- Use “Fig(s).” for referring to figures in the text, and “fig(s).” when referring to figures in another paper.
- Use “FIGURE” in the figure(s) heading(s).
- The figures will be printed in black and white but maintained in color in the final PDF file.

## PROOFS

- Page-proofs with the revised version will be sent by email to the corresponding author.
- Page-proofs must be returned to the Editor, preferentially within 48 (forty-eight) hours.
- Only necessary corrections in proof will be permitted.
- The omission of return the proof will mean automatic approval of version with no changes and may result in a delay in publication.

## ARTICLE PROCESSING CHARGE (APC)

- There is no publication fee to submit or publish in **Papéis Avulsos de Zoologia**.

## THIRD-PARTY CONTENT

- Previously published content as figures, tables, illustrations, etc. must be accompanied by written permission from the copyright holder to reproduce.

## RESPONSIBILITY

- The scientific content and opinions expressed in this publication are sole responsibility of the respective authors.

## **AUTHORSHIP AND AUTHORS' CONTRIBUTIONS STATEMENT:**

All Authors must meet the two minimum criteria:

- Actively participate of the results discussion.
- Review and approve the final version of the paper.

An authors' contributions statement must be included in a section at the end of the article for works written by more than 4 (four) authors.

The statement has to include the individual contribution of each author.

Acknowledgments section may contain a declaration of other kinds of contributions.

## **COPYRIGHTS**

- A Term of Assent and Cession of Copyright ([attached template](#)) should be signed and sent to the Editor, prior to publication of the manuscript.
- Papéis Avulsos de Zoologia adopts for publication the Creative Commons License – CC-BY (<https://creativecommons.org/licenses/by/4.0>).

## **CONFLICT OF INTEREST**

- Author must declare if there is any conflict of interest at the submission of the manuscript.
- If there is no conflict of interest, the authors should select in the submission form the option: “Authors declare that there is no conflict of interest”; otherwise, it must be specified in “Comments to the Editor”.
- Coeditors, Associated Editors, and Reviewers must declare to the Editor any conflict of interest before starting the review process.
- For further information on Conflict of Interest refer to Council of Science Editors White Paper on Publication Ethics ([English](#) or [Portuguese](#) versions).

## **FUNDING INFORMATION**

- Research grants from funding agencies (please inform the research funder and the grant number) or any financial support must be declared.

## **RESEARCH DATA**

- Papéis Avulsos de Zoologia recommends the deposit of scientific data in appropriate repositories and its citation in accordance with [FAIR principles](#) (Findable, Accessible, Interoperable and Re-usable).
- As described in the “General Information” section of this Instructions to Authors, all nucleotide sequence data (aligned as well as unaligned) should be submitted to [GenBank](#) or [European Molecular Biology Laboratory](#) (EMBL). All articles that contain nomenclatural acts

are registered in [Zoobank](#) by the journal staff and the Life Science Identifier (LSID) of the article is included in the published version.

- Authors are encouraged to deposit their data in a repository that is best suited to their dataset. Some examples of repositories are the [Global Biodiversity Information Facility](#) (GBIF), [Environmental Data Initiative](#) (EDI), [Dryad](#), [Figshare](#), [Zenodo](#), etc.
- The data repository used must guarantee the preservation of the data and provide a persistent identifier such as a DOI so it can be accessible and citable.
- Journal will make exceptions for sensitive information as the location of endangered species.
- Datasets used in the research, deposited in a scientific research data repository, should be cited in the “Materials and method section” and its reference (with the DOI number) should be included in the reference list.

### Datasets References Examples:

- Dataset deposited in a scientific research data repository:

Botham, M.; Roy, D.; Brereton, T.; Middlebrook, I.; Randle, Z. 2013. *United Kingdom Butterfly Monitoring Scheme: species trends 2012*. NERC Environmental Information Data Centre. [dataset]. Available at: <https://doi.org/10.5285/5afbbd36-2c63-4aa1-8177-695bed98d7a9> . Accessed: 13/04/2019.

United States Department of Health and Human Services. Substance Abuse and Mental Health Services Administration. Office of Applied Studies. 2015. *Treatment Episode Data Set - Discharges (TEDS-D) -- Concatenated, 2006 to 2011*. Version V5. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 23 Nov. 2015. Available at: <https://doi.org/10.3886/ICPSR30122.v5> . Accessed: 30/09/2019.

- Article supplementary information deposited in a scientific research data repository:

Yoon, J; Sofaer, H.R, Sillet, T. S, Morrison, S.A., Ghalambor, C.K. 2017. Data from: The relationship between female brooding and male nestling provisioning: does climate underlie geographic variation in sex roles?. *Journal of Avian Biology*, 48(2):220-228. Available at: <https://doi.org/10.5285/5afbbd36-2c63-4aa1-8177-695bed98d7a9> . Accessed: 07/07/2019.

- Dataset published as data paper:

Bovendorp, R. S., Villar, N., de Abreu-Junior, E. F., Bello, C., Regolin, A. L., Percequillo, A. R., & Galetti, M. 2017. Atlantic small-mammal: a dataset of communities of rodents and marsupials of the Atlantic forests of South America. *Ecology*, 98(8):2226–2226. [data paper]. Available at: <http://dx.doi.org/10.1002/ecy.1893>. Accessed: 07/10/2019.

### AUTHOR SELF-ARCHIVING

- Authors can share the **accepted manuscript**<sup>1</sup> or the **published version**<sup>2</sup> of the manuscript with their colleagues and post them on personal websites or institutional repositories for academic purposes while providing bibliographic details that credit, if applicable, its publication in this journal.

<sup>1</sup> Accepted manuscript - sometimes called post-print version, is the final draft author manuscript including the referees’ suggestions, before the copyediting process.

<sup>2</sup> Published version - is the article published in PDF format available at the Papéis Avulsos de Zoologia website.

## PUBLICATION ETHICS

- Research or publication misconduct (plagiarism, self-plagiarism, fabrication or falsification of data and results, etc.) will be treated in accordance with the [Commission on Publication Ethics](#) (COPE) guidelines.
- Allegations, corrections, and doubts must be sent to the Editor ([contact information](#)). All allegations/cases will be evaluated and, when necessary, retractions, corrections or expressions of concern will be published.

## CONTENT

For more details of the manuscript preparation format, see [CBE Style Manual](#), available at the electronic address of the Council of Science Editors.

**Papéis Avulsos de Zoologia** is a publication of the [Museu de Zoologia](#) da Universidade de São Paulo.

Always consult the instructions to authors updated on the electronic pages: [www.scielo.br/paz](http://www.scielo.br/paz) or [www.revistas.usp.br/paz](http://www.revistas.usp.br/paz).

## Copyright Notice

**Responsibility:** The scientific content and the opinions expressed in the manuscript are the sole responsibility of the author(s).

**Copyrights:** Papéis Avulsos de Zoologia. The journal is licensed under CC-BY [Creative Commons](#) license.

## Privacy Statement

The names and email addresses entered in this journal site will be used exclusively for the stated purposes of this journal and will not be made available for any other purpose or to any other party.

**MAKE A SUBMISSION**

## KEYWORDS

---

## **ANEXO B**

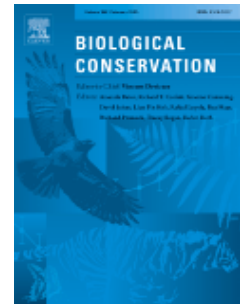
### **Normas técnicas – Revista Biological Conservation**



### TABLE OF CONTENTS

---

●	<b>Description</b>	<b>p.1</b>
●	<b>Audience</b>	<b>p.1</b>
●	<b>Impact Factor</b>	<b>p.1</b>
●	<b>Abstracting and Indexing</b>	<b>p.2</b>
●	<b>Editorial Board</b>	<b>p.2</b>
●	<b>Guide for Authors</b>	<b>p.4</b>



ISSN: 0006-3207

### DESCRIPTION

---

*Biological Conservation* is a leading international journal in the discipline of **conservation science**. The journal publishes articles spanning a diverse range of fields that contribute to the biological, sociological, ethical and economic dimensions of **conservation**. The primary aim of *Biological Conservation* is the publication of high-quality papers that advance the science and practice of conservation, or which demonstrate the application of conservation principles and policy. *Biological Conservation* invites the [submission](#) of research articles, reviews (including systematic reviews and perspectives), short communications, policy perspectives, and letters to the [editor](#) dealing with all aspects of conservation science, including theoretical and empirical investigations into the consequences of human actions for the diversity, structure and function of terrestrial, aquatic or marine ecosystems. Such papers may include quantitative assessments of extinction risk, fragmentation effects, spread of invasive organisms, conservation genetics, conservation management, global change effects on biodiversity, landscape or reserve design and management, restoration ecology, or resource economics. We also welcome papers coming from social sciences including those reporting on advances in conservation politics, ethics, policy, human social structure and biodiversity, and political culture among other subjects. *Biological Conservation* covers interdisciplinary topics within conservation biology and also provides practical applications of conservation research for land/resource managers and policy makers. We publish articles and thematic special issues that have a global relevance in terms of the topics or issues addressed, and thus demonstrate applications of conservation science and management beyond the specific system or species studied. *Biological Conservation* is an affiliate publication of the Society for Conservation Biology (SCB). SCB members can obtain a [personal subscription](#) to this journal through the Society.

### AUDIENCE

---

Environmentalists, conservationists, botanists, marine scientists, ecologists, biologists, zoologists.

### IMPACT FACTOR

---

2018: 4.451 © Clarivate Analytics Journal Citation Reports 2019

## ABSTRACTING AND INDEXING

---

Environmental Periodicals Bibliography  
Current Advances in Ecological Sciences  
AGRICOLA  
Embase  
Engineering Village - GEOBASE  
Current Contents - Agriculture, Biology & Environmental Sciences  
Energy Information Abstracts  
Biological and Agricultural Index  
Science Citation Index  
Cambridge Scientific Abstracts  
Elsevier BIOBASE  
Scopus

## EDITORIAL BOARD

---

### *Editor-in-Chief*

**Vincent Devictor**, UMR CNRS-UM2 5554 cc065, Institut des Sciences de l'Evolution de Montpellier

### *Editors*

**Amanda Bates**, Memorial University of Newfoundland, St John's, Newfoundland and Labrador, Canada

**Richard Corlett**, Chinese Academy of Sciences, Menglun, Yunnan, China

**Graeme Cumming**, ARC Centre of Excellence for Coral Reef Studies, Townsville, Queensland, Australia

**Varun R. Goswami**, Conservation Initiatives, Guwahati, India

**Lian Pin Koh**, Betty and Gordon Moore Center for Science Conservation International, Arlington, Virginia, United States

**Rafael Loyola**, Federal University of Goias, Brazil

**Bea Maas**, University of Vienna, Wien, Austria

**Anna Pidgeon**, University of Wisconsin-Madison Department of Forest and Wildlife Ecology, Madison, Wisconsin, United States

**Richard B. Primack**, Boston University, Boston, Massachusetts, United States

**Tracey Regan**, Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria, Australia

**Robin Roth**, University of Guelph, Guelph, Ontario, Canada

### *Book Review Editor*

**David Johns**, PO Box 725, McMinneville, Oregon, OR 97218

### *Editorial Board*

**Barry Brook**, The University of Adelaide, Adelaide, South Australia, Australia

**Zuzana Burivalova**, Princeton University, Princeton, New Jersey, United States

**Regis Cereghino**, Toulouse 1 University Capitole, Toulouse, France

**Jin Chen**, Xishuangbanna Tropical Botanical Garden, Mengla, China

**Enrico Di Minin**, University of Helsinki, Helsinki, Finland

**Johan Ekroos**, Lund University, Lund, Sweden

**Markus Fischer**, University of Bern, Bern, Switzerland

**Travis Gallo**, George Mason University, Fairfax, Virginia, United States

**Kevin Gaston**, University of Exeter Environment and Sustainability Institute, Penryn, United Kingdom

**Laurent Godet**, Coast Environment Remote Sensing Geomatics Nantes, Nantes, France

**Radim Hédli**, Institute of Botany Czech Academy of Sciences Department of Vegetation Ecology, Brno, Czech Republic

**Zhigang Jiang**, Chinese Academy of Sciences, Beijing, China

**Janice Ser Huay Lee**, Nanyang Technological University, Singapore, Singapore

**Pia Lentini**, University of Melbourne School of BioSciences, University Of Melbourne, Australia

**David Lindenmayer**, Australian National University, Canberra, Australia

**Hong Liu**, Florida International University, Miami, Florida, United States

**Tessa Mazon**, University of Queensland, Brisbane, Queensland, Australia

**Abraham Miller-Rushing**, Acadia National Park, Bar Harbor, Maine, United States

**Peter Moyle**, University of California Davis, Davis, California, United States

**Javier Nori**, National University of Cordoba, Cordoba, Argentina

**Daniel Oro**, Mediterranean Institute for Advanced Studies, Esporles, Spain

**Ludmila Rattis**, Woods Hole Research Center, Falmouth, Massachusetts, United States

**Denis Allan Saunders**, CSIRO Land and Water Floreat, Floreat, Australia

**Christian H. Schulze**, University of Vienna Faculty of Life Sciences, Vienna, Austria

**Anna Sher**, University of Denver, Denver, Colorado, United States

**Assaf Shwartz**, Technion Israel Institute of Technology, Haifa, Israel

**Steve Sinclair**, Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria, Australia

**Fernanda Thiesen Brum**, Federal University of Parana - Polytechnic Centre Campus, Curitiba, Paraná, Brazil

**Anne Toomey**, Pace University, New York, New York, United States

**Serge Wich**, Liverpool John Moores University, Liverpool, United Kingdom

## GUIDE FOR AUTHORS

---

### *Your Paper Your Way*

We now differentiate between the requirements for new and revised submissions. You may choose to submit your manuscript as a single Word or PDF file to be used in the refereeing process. Only when your paper is at the revision stage, will you be requested to put your paper in to a 'correct format' for acceptance and provide the items required for the publication of your article.

**To find out more, please visit the Preparation section below.**

### INTRODUCTION

**Please read all information carefully and follow the instructions in detail when preparing your manuscript.**

Manuscripts that are not prepared according to our guidelines will be sent back to authors without review.

*Biological Conservation* encourages the submission of high-quality manuscripts that advance the science and practice of conservation, or which demonstrate the application of conservation principles and policy. **Conservation implications should be clearly emphasized and discussed.** Given the broad international readership of the journal, published articles should have global relevance in terms of the topics or issues addressed, and thus demonstrate applications for conservation beyond the specific system or species studied.

### *Types of paper*

Word counts include text, references, figures and tables. Each figure or table should be considered equal to 300 words.

#### **1. Full length articles (Research papers)**

Research papers report the results of original research. The material must not have been previously published elsewhere. Full length articles are up to 8,000 words.

#### **2. Review articles**

Reviews summarize the status of research in a field of current interest. They may be submitted or invited. Review articles are up to 12,000 words and must include a methods section explaining how the literature for review was selected. We also consider Systematic Reviews, which apply a methodology to synthesize and appraise the scientific evidence on a specific question or hypothesis. More about systematic reviews can be found here: <http://www.environmentalevidence.org/information-for-authors>.

#### **3. Perspectives:**

These articles provide an opportunity for authors to present a novel, distinctive viewpoint on any subject within the journal's scope. The article should be well grounded in evidence and adequately supported by citations but may focus on a stimulating and thought-provoking line of argument that represents a significant advance in thinking about conservation problems and solutions. Perspectives articles should not exceed 8000 words.

#### **4. Short communications**

Short communications highlight both novel research and replication studies that report preliminary findings that are particularly compelling and highly relevant to conservation science and practice. If submitting a replication study, please include in your cover letter the rationale for undertaking the study. Short communications should not exceed 4,000 words.

#### **5. Policy Analysis**

These are short commentary pieces on contemporary, internationally relevant conservation or conservation-related policy issues that enable researchers, policy makers, and practitioners to make timely contributions to policy debates and actions. Contributions are based on research, expert analysis, literature review, or practitioner reflections regarding specific policy issues. Pure opinion pieces will not be considered for this paper type. Forum articles should be written in an accessible style and supported by real world examples and/or referenced scientific evidence and should not exceed 4,000 words.

## 6. Fast-Tracked Papers

Fast-Tracked Papers may be any of the above paper types, but are to be submitted only upon invitation from the editors. These papers will be fast-tracked by having reviewers lined up by the handling editor in advance, and upon publication these papers will be showcased in an ongoing special issue.

## 7. Book Reviews

Book reviews will be included in the journal on a range of relevant titles that are not more than two years old. These are usually less than 2,000 words. Please submit your requests/ideas to David Johns at [johnsd@embarqmail.com](mailto:johnsd@embarqmail.com).

## 8. Editorials

Opinion pieces by experts on a topic, usually invited by the Editor. The topic is usually timely and offers important insights into the field.

## 9. Correspondence

Letters to the Editor (Correspondence) papers are responses to recently published papers. Letters must be short (a maximum 800 words) and include only key references (5 maximum) and one figure if necessary. The content must be constructive, discuss significant issues, and respectful in tone. Provided the editors agree that publication of the letter is warranted, it will generally also receive a response from the authors of the original article, and both letter and response will be published in the same issue.

### **Submission checklist**

You can use this list to carry out a final check of your submission before you send it to the journal for review. Please check the relevant section in this Guide for Authors for more details.

#### **Ensure that the following items are present:**

One author has been designated as the corresponding author with contact details:

- E-mail address
- Full postal address

All necessary files have been uploaded:

*Manuscript:*

- Include keywords
- All figures (include relevant captions)
- All tables (including titles, description, footnotes)
- Ensure all figure and table citations in the text match the files provided
- Indicate clearly if color should be used for any figures in print

*Graphical Abstracts / Highlights files* (where applicable)

*Supplemental files* (where applicable)

Further considerations

- Manuscript has been 'spell checked' and 'grammar checked'
- All references mentioned in the Reference List are cited in the text, and vice versa
- Permission has been obtained for use of copyrighted material from other sources (including the Internet)
- A competing interests statement is provided, even if the authors have no competing interests to declare
- Journal policies detailed in this guide have been reviewed
- Referee suggestions and contact details provided, based on journal requirements
- We strongly encourage authors to check the existing evidences for their case at [Conservation Evidence](#). The introduction of the paper should include a sentence highlighting whether any evidence is already available or not with corresponding references.

For further information, visit our [Support Center](#).

## **BEFORE YOU BEGIN**

### **Ethics in publishing**

Please see our information pages on [Ethics in publishing](#) and [Ethical guidelines for journal publication](#).

## **Policy and Ethics**

All appropriate ethics and other approvals were obtained for the research. Where appropriate, authors should state that their research protocols have been approved by an authorized animal care or ethics committee, and include a reference to the code of practice adopted for the reported experimentation or methodology. The Editor will take account of animal welfare issues and reserves the right not to publish, especially if the research involves protocols that are inconsistent with commonly accepted norms of animal research.

## **Declaration of interest**

All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. Authors should complete the declaration of interest statement using [this template](#) and upload to the submission system at the Attach/Upload Files step. If there are no interests to declare, please choose: 'Declarations of interest: none' in the template. This statement will be published within the article if accepted. [More information](#).

## **Submission declaration and verification**

Submission of an article implies that the work described has not been published previously (except in the form of an abstract, a published lecture or academic thesis, see '[Multiple, redundant or concurrent publication](#)' for more information), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. To verify originality, your article may be checked by the originality detection service [Crossref Similarity Check](#).

## **Use of inclusive language**

Inclusive language acknowledges diversity, conveys respect to all people, is sensitive to differences, and promotes equal opportunities. Articles should make no assumptions about the beliefs or commitments of any reader, should contain nothing which might imply that one individual is superior to another on the grounds of race, sex, culture or any other characteristic, and should use inclusive language throughout. Authors should ensure that writing is free from bias, for instance by using 'he or she', 'his/her' instead of 'he' or 'his', and by making use of job titles that are free of stereotyping (e.g. 'chairperson' instead of 'chairman' and 'flight attendant' instead of 'stewardess').

## **Author contributions**

For transparency, we encourage authors to submit an author statement file outlining their individual contributions to the paper using the relevant CRediT roles: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing. Authorship statements should be formatted with the names of authors first and CRediT role(s) following. [More details and an example](#)

## **Changes to authorship**

Authors are expected to consider carefully the list and order of authors **before** submitting their manuscript and provide the definitive list of authors at the time of the original submission. Any addition, deletion or rearrangement of author names in the authorship list should be made only **before** the manuscript has been accepted and only if approved by the journal Editor. To request such a change, the Editor must receive the following from the **corresponding author**: (a) the reason for the change in author list and (b) written confirmation (e-mail, letter) from all authors that they agree with the addition, removal or rearrangement. In the case of addition or removal of authors, this includes confirmation from the author being added or removed.

Only in exceptional circumstances will the Editor consider the addition, deletion or rearrangement of authors **after** the manuscript has been accepted. While the Editor considers the request, publication of the manuscript will be suspended. If the manuscript has already been published in an online issue, any requests approved by the Editor will result in a corrigendum.

### *Article transfer service*

This journal is part of our Article Transfer Service. This means that if the Editor feels your article is more suitable in one of our other participating journals, then you may be asked to consider transferring the article to one of those. If you agree, your article will be transferred automatically on your behalf with no need to reformat. Please note that your article will be reviewed again by the new journal. [More information](#).

### **Copyright**

Upon acceptance of an article, authors will be asked to complete a 'Journal Publishing Agreement' (see [more information](#) on this). An e-mail will be sent to the corresponding author confirming receipt of the manuscript together with a 'Journal Publishing Agreement' form or a link to the online version of this agreement.

Subscribers may reproduce tables of contents or prepare lists of articles including abstracts for internal circulation within their institutions. [Permission](#) of the Publisher is required for resale or distribution outside the institution and for all other derivative works, including compilations and translations. If excerpts from other copyrighted works are included, the author(s) must obtain written permission from the copyright owners and credit the source(s) in the article. Elsevier has [preprinted forms](#) for use by authors in these cases.

For gold open access articles: Upon acceptance of an article, authors will be asked to complete an 'Exclusive License Agreement' ([more information](#)). Permitted third party reuse of gold open access articles is determined by the author's choice of [user license](#).

### **Author rights**

As an author you (or your employer or institution) have certain rights to reuse your work. [More information](#).

### *Elsevier supports responsible sharing*

Find out how you can [share your research](#) published in Elsevier journals.

### **Role of the funding source**

You are requested to identify who provided financial support for the conduct of the research and/or preparation of the article and to briefly describe the role of the sponsor(s), if any, in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. If the funding source(s) had no such involvement then this should be stated.

### **Open access**

Please visit our Open Access page from the Journal Homepage for more information.

### *Elsevier Researcher Academy*

[Researcher Academy](#) is a free e-learning platform designed to support early and mid-career researchers throughout their research journey. The "Learn" environment at Researcher Academy offers several interactive modules, webinars, downloadable guides and resources to guide you through the process of writing for research and going through peer review. Feel free to use these free resources to improve your submission and navigate the publication process with ease.

### *Language (usage and editing services)*

Please write your text in good English (American or British usage is accepted, but not a mixture of these). Authors who feel their English language manuscript may require editing to eliminate possible grammatical or spelling errors and to conform to correct scientific English may wish to use the [English Language Editing service](#) available from Elsevier's Author Services.

### **Submission**

Our online submission system guides you stepwise through the process of entering your article details and uploading your files. The system converts your article files to a single PDF file used in the peer-review process. Editable files (e.g., Word, LaTeX) are required to typeset your article for final publication. All correspondence, including notification of the Editor's decision and requests for revision, is sent by e-mail.

## Referees

Authors are at liberty to suggest the names of up to three potential reviewers (with full contact details). Potential reviewers should not include anyone with whom the authors have collaborated during the research being submitted.

## Additional Information

### Editorial Process

Publishing space in the journal is limited, such that many manuscripts must be rejected. To expedite the processing of manuscripts, the journal has adopted a two-tier review process. During the first stage of review, the handling editor evaluates the manuscript for appropriateness and scientific content, taking advice where appropriate from members of the editorial board. Criteria for rejection at this stage include: **Manuscript lacks a strong conservation focus or theme, or management implications not well-developed.** Please note that research on a rare or endangered species or ecosystem is not sufficient justification to merit publication in *Biological Conservation*. Published research must also advance the science and practice of conservation biology, and thus have broader application for a wide international audience. **Manuscript subject matter more appropriate for another journal.** Natural history or biodiversity surveys, including site descriptions, are usually better suited for other outlets, such as a regional or taxon-specific journal. Similarly, manuscripts with a primarily behavioral, genetic or ecological focus are more appropriate for journals in those fields. For example, studies reporting on disturbance effects, species interactions (e.g., predator-prey, competitive, or pollinator-host plant interactions), species-habitat relationships, descriptive genetics (e.g., assays of genetic variation within or between populations), or behavioral responses to disturbance will be referred elsewhere if they lack a clear conservation message. Authors are advised to contact an Editor prior to submission if there are any questions regarding the appropriateness of a manuscript for the journal. **Study primarily of local or regional interest.** *Biological Conservation* is international in scope, and thus research published in the journal should have global relevance, in terms of the topics or issues addressed. **Study poorly designed or executed.** Research lacks spatial or temporal replication, has insufficient sample sizes, or inadequate data analysis. Such obvious indications of poor-quality science will be cause for immediate rejection. **Manuscript poorly written.** Poor writing interferes with the effective communication of science. Authors for whom English is not the first language are advised to consult with a technical language editor before submission. **Conservation research ethics violated.** Research was unnecessarily destructive, was conducted for the express purpose of causing harm/mortality (e.g., simulation of treatment or disturbance effects on survivorship), or violated ethics in the treatment and handling of animals. Where appropriate, authors must provide a statement and supporting documentation that research was approved by the authors' institutional animal care and use committee(s). Manuscripts that pass this first stage of editorial review are then subjected to a second stage of formal peer review. This involves evaluation of the manuscript by at least two specialists within the field of study, which may include one or more members of the editorial board. Beyond a critical assessment of the scientific content and overall presentation, referees are asked to evaluate the originality, likely impact and global relevance of the research. Referees make a recommendation to the handling editor, but note that it is ultimately the decision of the handling editor as to whether a manuscript is accepted for publication in *Biological Conservation*.

### Editor-in-Chief

#### Dr. Vincent Devictor

UMR CNRS-UM2 5554 cc065,  
Institut des Sciences de l'Evolution de Montpellier,  
Place Eugène Bataillon, 34090 Montpellier,  
France  
Email: vincent.devictor@univ-montp2.fr

### Editors

**Dr. Amanda Bates**, University of Southampton, England, UK, Email: A.E.Bates@soton.ac.uk

**Dr. Richard Corlett**, Richard Corlett Chinese Academy of Sciences (CAS), Menglun, Yunnan, China, Email: corlett@xtbg.org.cn

**Dr. Graeme Cumming**, James Cook University, Townsville, Queensland, Australia, Email: gscumming@gmail.com

**Dr. Liba Pejchar**, Colorado State University, Colorado, USA, Email: Liba.Pejchar@colostate.edu

**Dr. Lian Pin Koh**, University of Adelaide, Adelaide, South Australia, Australia, Email: lianpinkoh@gmail.com

**Dr. Rafael Loyola**, Uniersidade Federal de Gois, Goinia, Gois, Brazil, Email: rdiasloyola@gmail.com

**Dr. Bea Maas**, University of Vienna, Vienna, Austria, Email: beamaas@gmx.at

**Prof. Robin Pakeman**, The James Hutton Institute, Aberdeen, Scotland, UK, Email: robin.pakeman@hutton.ac.uk

**Dr. Richard B. Primack**, Boston University, Boston, Massachusetts, USA, Email: primack@bu.edu

**Dr. Tracey Regan**, Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria, Australia, Email: tregan@unimelb.edu.au

#### **Book Review Editor**

**David Johns**

PO Box 725, McMinneville, OR 97218, Email: johnsd@pdx.edu

### **PREPARATION**

#### **NEW SUBMISSIONS**

Submission to this journal proceeds totally online and you will be guided stepwise through the creation and uploading of your files. The system automatically converts your files to a single PDF file, which is used in the peer-review process.

As part of the Your Paper Your Way service, you may choose to submit your manuscript as a single file to be used in the refereeing process. This can be a PDF file or a Word document, in any format or layout that can be used by referees to evaluate your manuscript. It should contain high enough quality figures for refereeing. If you prefer to do so, you may still provide all or some of the source files at the initial submission. Please note that individual figure files larger than 10 MB must be uploaded separately.

Please use correct, continuous line numbering and page numbering throughout the document.

#### *References*

There are no strict requirements on reference formatting at submission. References can be in any style or format as long as the style is consistent. Where applicable, author(s) name(s), journal title/book title, chapter title/article title, year of publication, volume number/book chapter and the article number or pagination must be present. Use of DOI is highly encouraged. The reference style used by the journal will be applied to the accepted article by Elsevier at the proof stage. Note that missing data will be highlighted at proof stage for the author to correct.

#### *Formatting requirements*

There are no strict formatting requirements but all manuscripts must contain the essential elements needed to convey your manuscript, for example Abstract, Keywords, Introduction, Materials and Methods, Results, Conclusions, Artwork and Tables with Captions.

If your article includes any Videos and/or other Supplementary material, this should be included in your initial submission for peer review purposes.

Divide the article into clearly defined sections.

#### *Tables and Figures*

Please place legends above Tables and below Figures. They should follow the References at the end of the manuscript.

### **Peer review**

This journal operates a double blind review process. All contributions will be initially assessed by the editor for suitability for the journal. Papers deemed suitable are then typically sent to a minimum of two independent expert reviewers to assess the scientific quality of the paper. The Editor is responsible for the final decision regarding acceptance or rejection of articles. The Editor's decision is final. [More information on types of peer review.](#)

### **Double-blind review**

This journal uses double-blind review, which means the identities of the authors are concealed from the reviewers, and vice versa. [More information](#) is available on our website. To facilitate this, please include the following separately:

*Title page (with author details):* This should include the title, authors' names, affiliations, acknowledgements and any Declaration of Interest statement, and a complete address for the corresponding author including an e-mail address.

*Blinded manuscript (no author details):* The main body of the paper (including the references, figures, tables and any acknowledgements) should not include any identifying information, such as the authors' names or affiliations.

### **REVISED SUBMISSIONS**

*Use of word processing software*

**Please use correct, continuous line numbering and page numbering throughout the document.**

It is important that the file be saved in the native format of the word processor used. The text should be in single-column format. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. In particular, do not use the word processor's options to justify text or to hyphenate words. However, do use bold face, italics, subscripts, superscripts etc. When preparing tables, if you are using a table grid, use only one grid for each individual table and not a grid for each row. If no grid is used, use tabs, not spaces, to align columns. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier: <https://www.elsevier.com/guidepublication>). Note that source files of figures, tables and text graphics will be required whether or not you embed your figures in the text. See also the section on Electronic artwork.

To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.

Please use single spacing throughout the document. Use continuous line numbering throughout the document. Avoid full justification, i.e., do not use a constant right-hand margin. Ensure that each new paragraph is clearly indicated. Number every page of the manuscript, including the title page, references tables, etc. Present tables and figure legends on separate pages at the end of the manuscript. Layout and conventions must conform with those given in this guide to authors. **Journal style has changed over time so do not use old issues as a guide.** Number all pages consecutively. Italics are not to be used for expressions of Latin origin, for example, *in vivo*, *et al.*, *per se*. Use decimal points (not commas); use a space for thousands (10 000 and above).

*Use of word processing software*

Regardless of the file format of the original submission, at revision you must provide us with an editable file of the entire article. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the [Guide to Publishing with Elsevier](#)). See also the section on Electronic artwork.

To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.

### **Cover letter**

Submission of a manuscript must be accompanied by a cover letter that includes the following statements or acknowledgements: The work is all original research carried out by the authors. All authors agree with the contents of the manuscript and its submission to the journal. No part of the research has been published in any form elsewhere, unless it is fully acknowledged in the manuscript. Authors should disclose how the research featured in the manuscript relates to any other manuscript of a similar nature that they have published, in press, submitted or will soon

submit to Biological Conservation or elsewhere. The manuscript is not being considered for publication elsewhere while it is being considered for publication in this journal. Any research in the paper not carried out by the authors is fully acknowledged in the manuscript. All sources of funding are acknowledged in the manuscript, and authors have declared any direct financial benefits that could result from publication. All appropriate ethics and other approvals were obtained for the research. Where appropriate, authors should state that their research protocols have been approved by an authorized animal care or ethics committee, and include a reference to the code of practice adopted for the reported experimentation or methodology. The Editor will take account of animal welfare issues and reserves the right not to publish, especially if the research involves protocols that are inconsistent with commonly accepted norms of animal research. Please include a short paragraph that describes the main finding of your paper, and its significance to the field of conservation biology. The authors should state in the cover letter if the paper in any form has previously been submitted to *Biological Conservation*. In that case the authors should specify the original manuscript number.

## Article structure

### *Subdivision - numbered sections*

Divide your article into clearly defined and numbered sections. Subsections should be numbered 1.1 (then 1.1.1, 1.1.2, ...), 1.2, etc. (the abstract is not included in section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be given a brief heading. Each heading should appear on its own separate line.

### *Introduction*

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

### *Material and methods*

Provide sufficient details to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized, and indicated by a reference. If quoting directly from a previously published method, use quotation marks and also cite the source. Any modifications to existing methods should also be described.

### *Theory/calculation*

A Theory section should extend, not repeat, the background to the article already dealt with in the Introduction and lay the foundation for further work. In contrast, a Calculation section represents a practical development from a theoretical basis.

### *Results*

Results should be clear and concise.

### *Discussion*

This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

### *Conclusions*

The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

### *Glossary*

Please supply, as a separate list, the definitions of field-specific terms used in your article.

### *Appendices*

If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

## Essential title page information

- **Title.** Concise and informative, yet not overly general. If appropriate, include the species or ecosystem that was the subject of the study, or the location where the study was done. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible
- **Author names and affiliations.** Where the family name may be ambiguous (e.g., a double name), please indicate this clearly. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and, if available, the e-mail address of each author.

• **Corresponding author.** Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. **Ensure that phone numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address. Contact details must be kept up to date by the corresponding author.**

• **Present/permanent address.** If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

### Highlights

Highlights are mandatory for this journal as they help increase the discoverability of your article via search engines. They consist of a short collection of bullet points that capture the novel results of your research as well as new methods that were used during the study (if any). Please have a look at the examples here: [example Highlights](#).

Highlights should be submitted in a separate editable file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point).

### Abstract

A concise and factual abstract is required (maximum length of 250 words). The abstract should state briefly the purpose of the research, the methods used, the principal results and major conclusions. Please try to keep each sentence as specific as possible, and avoid such general statements as "The management implications of the results are discussed". An abstract is often presented separately from the article, so it must be able to stand alone. For this reason, References should be avoided, but if essential, they must be cited in full, without reference to the reference list. Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.

#### Graphical abstract

Although a graphical abstract is optional, its use is encouraged as it draws more attention to the online article. The graphical abstract should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of 531 × 1328 pixels (h × w) or proportionally more. The image should be readable at a size of 5 × 13 cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files. You can view [Example Graphical Abstracts](#) on our information site.

Authors can make use of Elsevier's [Illustration Services](#) to ensure the best presentation of their images and in accordance with all technical requirements.

#### Stereochemistry abstract

For each important chiral compound you are requested to supply a stereochemistry abstract detailing structure, name, formula and all available stereochemical information for eventual incorporation into a database. An abstract for only one enantiomer per compound is required.

### Keywords

Immediately after the abstract, provide a maximum of 6 keywords, using American spelling and avoiding general and plural terms and multiple concepts (avoid, for example, 'and', 'of'). Be sparing with abbreviations: only abbreviations firmly established in the field may be eligible. These keywords will be used for indexing purposes.

#### Abbreviations

Define abbreviations that are not standard in this field in a footnote to be placed on the first page of the article. Such abbreviations that are unavoidable in the abstract must be defined at their first mention there, as well as in the footnote. Ensure consistency of abbreviations throughout the article.

#### Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

#### Formatting of funding sources

List funding sources in this standard way to facilitate compliance to funder's requirements:

Funding: This work was supported by the National Institutes of Health [grant numbers xxxx, yyyy]; the Bill & Melinda Gates Foundation, Seattle, WA [grant number zzzz]; and the United States Institutes of Peace [grant number aaaa].

It is not necessary to include detailed descriptions on the program or type of grants and awards. When funding is from a block grant or other resources available to a university, college, or other research institution, submit the name of the institute or organization that provided the funding.

If no funding has been provided for the research, please include the following sentence:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### **Nomenclature and Units**

Follow internationally accepted rules and conventions: use the international system of units (SI) for all scientific and laboratory data. If other quantities are mentioned, give their equivalent in SI.

Common names must be in lower-case except proper nouns. All common names must be followed by a scientific name in parentheses in italics. For example, bottlenose dolphin (*Tursiops aduncus*). Where scientific names are used in preference to common names they should be in italics and the genus should be reduced to the first letter after the first mention. For example, the first mention is given as *Tursiops aduncus* and subsequent mentions are given as *T. aduncus*.

### **Math formulae**

Please submit math equations as editable text and not as images. Present simple formulae in line with normal text where possible and use the solidus (/) instead of a horizontal line for small fractional terms, e.g., X/Y. In principle, variables are to be presented in italics. Powers of e are often more conveniently denoted by exp. Number consecutively any equations that have to be displayed separately from the text (if referred to explicitly in the text).

### **Footnotes**

Footnotes should be used sparingly. Number them consecutively throughout the article. Many word processors build footnotes into the text, and this feature may be used. Should this not be the case, indicate the position of footnotes in the text and present the footnotes themselves separately at the end of the article.

### **Artwork**

#### **Electronic artwork**

#### **General points**

- Make sure you use uniform lettering and sizing of your original artwork.
- Preferred fonts: Arial (or Helvetica), Times New Roman (or Times), Symbol, Courier.
- Number the illustrations according to their sequence in the text.
- Use a logical naming convention for your artwork files.
- Indicate per figure if it is a single, 1.5 or 2-column fitting image.
- For Word submissions only, you may still provide figures and their captions, and tables within a single file at the revision stage.
- Please note that individual figure files larger than 10 MB must be provided in separate source files.

A detailed [guide on electronic artwork](#) is available.

**You are urged to visit this site; some excerpts from the detailed information are given here.**

#### **Formats**

Regardless of the application used, when your electronic artwork is finalized, please 'save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below):

EPS (or PDF): Vector drawings. Embed the font or save the text as 'graphics'.

TIFF (or JPG): Color or grayscale photographs (halftones): always use a minimum of 300 dpi.

TIFF (or JPG): Bitmapped line drawings: use a minimum of 1000 dpi.

TIFF (or JPG): Combinations bitmapped line/half-tone (color or grayscale): a minimum of 500 dpi is required.

#### **Please do not:**

- Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); the resolution is too low.

- Supply files that are too low in resolution.
- Submit graphics that are disproportionately large for the content.

#### *Color artwork*

Please make sure that artwork files are in an acceptable format (TIFF (or JPEG), EPS (or PDF), or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color online (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. **For color reproduction in print, you will receive information regarding the costs from Elsevier after receipt of your accepted article.** Please indicate your preference for color: in print or online only. [Further information on the preparation of electronic artwork.](#)

#### *Figure captions*

Ensure that each illustration has a caption. A caption should comprise a brief title (**not** on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

#### **Tables**

Please submit tables as editable text and not as images. Tables can be placed either next to the relevant text in the article, or on separate page(s) at the end. Number tables consecutively in accordance with their appearance in the text and place any table notes below the table body. Be sparing in the use of tables and ensure that the data presented in them do not duplicate results described elsewhere in the article. Please avoid using vertical rules and shading in table cells.

#### **References**

##### *Citation in text*

Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

##### *Reference links*

Increased discoverability of research and high quality peer review are ensured by online links to the sources cited. In order to allow us to create links to abstracting and indexing services, such as Scopus, CrossRef and PubMed, please ensure that data provided in the references are correct. Please note that incorrect surnames, journal/book titles, publication year and pagination may prevent link creation. When copying references, please be careful as they may already contain errors. Use of the DOI is highly encouraged.

A DOI is guaranteed never to change, so you can use it as a permanent link to any electronic article. An example of a citation using DOI for an article not yet in an issue is: VanDecar J.C., Russo R.M., James D.E., Ambeh W.B., Franke M. (2003). Aseismic continuation of the Lesser Antilles slab beneath northeastern Venezuela. *Journal of Geophysical Research*, <https://doi.org/10.1029/2001JB000884>. Please note the format of such citations should be in the same style as all other references in the paper.

##### *Web references*

As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

##### *Data references*

This journal encourages you to cite underlying or relevant datasets in your manuscript by citing them in your text and including a data reference in your Reference List. Data references should include the following elements: author name(s), dataset title, data repository, version (where available), year, and global persistent identifier. Add [dataset] immediately before the reference so we can properly identify it as a data reference. The [dataset] identifier will not appear in your published article.

### References in a special issue

Please ensure that the words 'this issue' are added to any references in the list (and any citations in the text) to other articles in the same Special Issue.

### Reference management software

Most Elsevier journals have their reference template available in many of the most popular reference management software products. These include all products that support [Citation Style Language styles](#), such as [Mendeley](#). Using citation plug-ins from these products, authors only need to select the appropriate journal template when preparing their article, after which citations and bibliographies will be automatically formatted in the journal's style. If no template is yet available for this journal, please follow the format of the sample references and citations as shown in this Guide. If you use reference management software, please ensure that you remove all field codes before submitting the electronic manuscript. [More information on how to remove field codes from different reference management software](#).

Users of Mendeley Desktop can easily install the reference style for this journal by clicking the following link:

<http://open.mendeley.com/use-citation-style/biological-conservation>

When preparing your manuscript, you will then be able to select this style using the Mendeley plug-ins for Microsoft Word or LibreOffice.

### Reference formatting

There are no strict requirements on reference formatting at submission. References can be in any style or format as long as the style is consistent. Where applicable, author(s) name(s), journal title/book title, chapter title/article title, year of publication, volume number/book chapter and the article number or pagination must be present. Use of DOI is highly encouraged. The reference style used by the journal will be applied to the accepted article by Elsevier at the proof stage. Note that missing data will be highlighted at proof stage for the author to correct. If you do wish to format the references yourself they should be arranged according to the following examples:

#### Reference style

*Text:* All citations in the text should refer to:

1. *Single author:* the author's name (without initials, unless there is ambiguity) and the year of publication;
2. *Two authors:* both authors' names and the year of publication;
3. *Three or more authors:* first author's name followed by 'et al.' and the year of publication.

Citations may be made directly (or parenthetically). Groups of references can be listed either first alphabetically, then chronologically, or vice versa.

Examples: 'as demonstrated (Allan, 2000a, 2000b, 1999; Allan and Jones, 1999)... Or, as demonstrated (Jones, 1999; Allan, 2000)... Kramer et al. (2010) have recently shown ...'

*List:* References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication.

#### Examples:

Reference to a journal publication:

Van der Geer, J., Hanraads, J.A.J., Lupton, R.A., 2010. The art of writing a scientific article. *J. Sci. Commun.* 163, 51–59. <https://doi.org/10.1016/j.Sc.2010.00372>.

Reference to a journal publication with an article number:

Van der Geer, J., Hanraads, J.A.J., Lupton, R.A., 2018. The art of writing a scientific article. *Heliyon.* 19, e00205. <https://doi.org/10.1016/j.heliyon.2018.e00205>.

Reference to a book:

Strunk Jr., W., White, E.B., 2000. *The Elements of Style*, fourth ed. Longman, New York.

Reference to a chapter in an edited book:

Mettam, G.R., Adams, L.B., 2009. How to prepare an electronic version of your article, in: Jones, B.S., Smith, R.Z. (Eds.), *Introduction to the Electronic Age*. E-Publishing Inc., New York, pp. 281–304.

Reference to a website:

Cancer Research UK, 1975. Cancer statistics reports for the UK. <http://www.cancerresearchuk.org/aboutcancer/statistics/cancerstatsreport/> (accessed 13 March 2003).

Reference to a dataset:

[dataset] Oguro, M., Imahiro, S., Saito, S., Nakashizuka, T., 2015. Mortality data for Japanese oak wilt disease and surrounding forest compositions. *Mendeley Data*, v1. <https://doi.org/10.17632/xwj98nb39r.1>.

## Video

Elsevier accepts video material and animation sequences to support and enhance your scientific research. Authors who have video or animation files that they wish to submit with their article are strongly encouraged to include links to these within the body of the article. This can be done in the same way as a figure or table by referring to the video or animation content and noting in the body text where it should be placed. All submitted files should be properly labeled so that they directly relate to the video file's content. In order to ensure that your video or animation material is directly usable, please provide the file in one of our recommended file formats with a preferred maximum size of 150 MB per file, 1 GB in total. Video and animation files supplied will be published online in the electronic version of your article in Elsevier Web products, including [ScienceDirect](#). Please supply 'stills' with your files: you can choose any frame from the video or animation or make a separate image. These will be used instead of standard icons and will personalize the link to your video data. For more detailed instructions please visit our [video instruction pages](#). Note: since video and animation cannot be embedded in the print version of the journal, please provide text for both the electronic and the print version for the portions of the article that refer to this content.

## Data visualization

Include interactive data visualizations in your publication and let your readers interact and engage more closely with your research. Follow the instructions [here](#) to find out about available data visualization options and how to include them with your article.

## Supplementary material

Supplementary material such as applications, images and sound clips, can be published with your article to enhance it. Submitted supplementary items are published exactly as they are received (Excel or PowerPoint files will appear as such online). Please submit your material together with the article and supply a concise, descriptive caption for each supplementary file. If you wish to make changes to supplementary material during any stage of the process, please make sure to provide an updated file. Do not annotate any corrections on a previous version. Please switch off the 'Track Changes' option in Microsoft Office files as these will appear in the published version.

The supplementary material should be cited as an online Appendix to the paper, usually in the Methods. If it contains several tables, images and/or figures, these should be cited as Table A1, Figure A1 and so on.

Authors are strongly encouraged to make the data supporting their paper available to readers through an open-access data repository and/or as an Appendix to the paper. For more details on journal data policy see the paragraphs on *Data Depositing and Linking to and depositing data at PANGAEA*.

## Data Depositing

Ideally, data should be freely available online through a specialist data centre that provides a permanent archive (repository) for the dataset, and may integrate the data with other datasets using international standards. Examples include PANGAEA, and GBIF and its major contributors such as OBIS and VertNet. Some Ocean Data Centres may also provide this service. Where such a data centre does not exist, we ask that the data be made freely available online from a permanent archive (repository). Where possible, it should follow international data standards. This may be an institutional repository for its staff. The data should be accompanied by sufficient information (metadata) for the reader to understand its composition and origins, and determine if it is fit for their purpose. In particular, the data should allow the results of the publication to be reproduced. Data being downloadable from departmental or personal websites is not regarded as permanently archived.

## Research data

This journal encourages and enables you to share data that supports your research publication where appropriate, and enables you to interlink the data with your published articles. Research data refers to the results of observations or experimentation that validate research findings. To facilitate reproducibility and data reuse, this journal also encourages you to share your software, code, models, algorithms, protocols, methods and other useful materials related to the project.

Below are a number of ways in which you can associate data with your article or make a statement about the availability of your data when submitting your manuscript. If you are sharing data in one of these ways, you are encouraged to cite the data in your manuscript and reference list. Please refer to the "References" section for more information about data citation. For more information on depositing, sharing and using research data and other relevant research materials, visit the [research data](#) page.

#### *Data linking*

If you have made your research data available in a data repository, you can link your article directly to the dataset. Elsevier collaborates with a number of repositories to link articles on ScienceDirect with relevant repositories, giving readers access to underlying data that gives them a better understanding of the research described.

There are different ways to link your datasets to your article. When available, you can directly link your dataset to your article by providing the relevant information in the submission system. For more information, visit the [database linking page](#).

For [supported data repositories](#) a repository banner will automatically appear next to your published article on ScienceDirect.

In addition, you can link to relevant data or entities through identifiers within the text of your manuscript, using the following format: Database: xxxx (e.g., TAIR: AT1G01020; CCDC: 734053; PDB: 1XFN).

#### *Mendeley Data*

This journal supports Mendeley Data, enabling you to deposit any research data (including raw and processed data, video, code, software, algorithms, protocols, and methods) associated with your manuscript in a free-to-use, open access repository. During the submission process, after uploading your manuscript, you will have the opportunity to upload your relevant datasets directly to *Mendeley Data*. The datasets will be listed and directly accessible to readers next to your published article online.

For more information, visit the [Mendeley Data for journals page](#).

#### *Data in Brief*

You have the option of converting any or all parts of your supplementary or additional raw data into one or multiple data articles, a new kind of article that houses and describes your data. Data articles ensure that your data is actively reviewed, curated, formatted, indexed, given a DOI and publicly available to all upon publication. You are encouraged to submit your article for *Data in Brief* as an additional item directly alongside the revised version of your manuscript. If your research article is accepted, your data article will automatically be transferred over to *Data in Brief* where it will be editorially reviewed and published in the open access data journal, *Data in Brief*. Please note an open access fee of 600 USD is payable for publication in *Data in Brief*. Full details can be found on the [Data in Brief website](#). Please use [this template](#) to write your Data in Brief.

#### *MethodsX*

You have the option of converting relevant protocols and methods into one or multiple MethodsX articles, a new kind of article that describes the details of customized research methods. Many researchers spend a significant amount of time on developing methods to fit their specific needs or setting, but often without getting credit for this part of their work. MethodsX, an open access journal, now publishes this information in order to make it searchable, peer reviewed, citable and reproducible. Authors are encouraged to submit their MethodsX article as an additional item directly alongside the revised version of their manuscript. If your research article is accepted, your methods article will automatically be transferred over to MethodsX where it will be editorially reviewed. Please note an open access fee is payable for publication in MethodsX. Full details can be found on the [MethodsX website](#). Please use [this template](#) to prepare your MethodsX article.

#### *Data statement*

To foster transparency, we encourage you to state the availability of your data in your submission. This may be a requirement of your funding body or institution. If your data is unavailable to access or unsuitable to post, you will have the opportunity to indicate why during the submission process, for example by stating that the research data is confidential. The statement will appear with your published article on ScienceDirect. For more information, visit the [Data Statement page](#).

## **AFTER ACCEPTANCE**

### **Online proof correction**

To ensure a fast publication process of the article, we kindly ask authors to provide us with their proof corrections within two days. Corresponding authors will receive an e-mail with a link to our online proofing system, allowing annotation and correction of proofs online. The environment is similar to MS Word: in addition to editing text, you can also comment on figures/tables and answer questions from the Copy Editor. Web-based proofing provides a faster and less error-prone process by allowing you to directly type your corrections, eliminating the potential introduction of errors.

If preferred, you can still choose to annotate and upload your edits on the PDF version. All instructions for proofing will be given in the e-mail we send to authors, including alternative methods to the online version and PDF.

We will do everything possible to get your article published quickly and accurately. Please use this proof only for checking the typesetting, editing, completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with permission from the Editor. It is important to ensure that all corrections are sent back to us in one communication. Please check carefully before replying, as inclusion of any subsequent corrections cannot be guaranteed. Proofreading is solely your responsibility.

### **Offprints**

The corresponding author will, at no cost, receive a customized [Share Link](#) providing 50 days free access to the final published version of the article on [ScienceDirect](#). The Share Link can be used for sharing the article via any communication channel, including email and social media. For an extra charge, paper offprints can be ordered via the offprint order form which is sent once the article is accepted for publication. Both corresponding and co-authors may order offprints at any time via Elsevier's [Author Services](#). Corresponding authors who have published their article gold open access do not receive a Share Link as their final published version of the article is available open access on ScienceDirect and can be shared through the article DOI link.

### **AUTHOR INQUIRIES**

Visit the [Elsevier Support Center](#) to find the answers you need. Here you will find everything from Frequently Asked Questions to ways to get in touch.

You can also [check the status of your submitted article](#) or find out [when your accepted article will be published](#).

© Copyright 2018 Elsevier | <https://www.elsevier.com>