



Universidade Federal de Uberlândia
Instituto de Biologia



**Programa de Pós-graduação em Ecologia e Conservação dos Recursos
Naturais**

**VERTEBRATE ROADKILL: IDENTIFYING WHERE,
WHEN AND WHO DIES ON WILDLIFE VEHICLE
COLLISIONS ON BRAZILIAN CERRADO**

Carine Firmino Carvalho Roel

2019

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Tese apresentada à Universidade Federal de
Uberlândia, como parte das exigências para
obtenção do título de Doutor em Ecologia e
Conservação de Recursos Naturais.

Orientador Prof. Dr. Oswaldo Marçal Júnior

Coorientadora Prof. Dra. Ana Elizabeth Iannini Custódio

Uberlândia

Fevereiro - 2019

Dados Internacionais de Catalogação na Publicação (CIP)
Sistema de Bibliotecas da UFU, MG, Brasil.

R714v
2019 Roel, Carine Firmino Carvalho, 1991
Vertebrate roadkill [recurso eletrônico] : identifying where, when
and who dies on wildlife vehicle collisions on brazilian Cerrado / Carine
Firmino Carvalho Roel. - 2019.

Orientador: Oswaldo Marçal Júnior.

Coorientadora: Ana Elizabeth Iannini Custódio.

Tese (Doutorado) - Universidade Federal de Uberlândia, Programa
de Pós-Graduação em Ecologia e Conservação de Recursos Naturais.

Disponível em: <http://dx.doi.org/10.14393/ufu.te.2019.1225>

Inclui bibliografia.

Inclui ilustrações.

1. Ecologia. 2. Animais dos cerrados. 3. Animais mortos. 4. Ecologia
animal. I. Marçal Júnior, Oswaldo, 1960, (Orient.). II. Custódio, Ana
Elizabeth Iannini, 1961, (Coorient.). III. Universidade Federal de
Uberlândia. Programa de Pós-Graduação em Ecologia e Conservação de
Recursos Naturais. IV. Título.

CDU: 574

Angela Aparecida Vicentini Tzi Tziboy – CRB-6/947

Carine Firmino Carvalho Roel

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Conservação de Recursos Naturais.

APROVADA em 18 de Fevereiro de 2019

| | |
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Fevereiro - 2019

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Ata

ATA DA 57ª DEFESA DE TESE de doutorado JUNTO AO PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA E CONSERVAÇÃO DE RECURSOS NATURAIS, INSTITUTO DE BIOLOGIA, UNIVERSIDADE FEDERAL DE UBERLÂNDIA

Aos dezoito dias de fevereiro de dois mil e dezenove (18/02/2019), às quatorze horas, na sala 14A, bloco 2D, *Campus* Umuarama, situado na Avenida Pará, 1720, Bairro Umuarama, Uberlândia-MG, teve início a 57ª Defesa de Tese de Doutorado do Programa de Pós-graduação em Ecologia e Conservação de Recursos Naturais da discente **Carine Firmino Carvalho Roel** - matrícula número **11513ECR001**, intitulada **"Vertebrate roadkill: identifying where, when and who dies on wildlife vehicle collisions on Brazilian Cerrado"**, área de concentração **Ecologia**, linha de pesquisa **Ecologia de comunidades e ecossistemas**, com banca examinadora composta pelos seguintes doutores: **Oswaldo Marçal Júnior (INBIO-UFU)**, presidente, **Clara Bentes Grilo (CDV - Transport Research Centre, Czech Republic)**, **Simone Rodrigues de Freitas (UFABC)**, **Kleber del Claro (INBIO-UFU)** e **André Rosalvo Terra Nascimento (INBIO-UFU)**. Ressalta-se que a Doutora Clara Bentes Grilo participou da defesa por meio de manifestação escrita fundamentada, enviada por *e-mail*. A Doutora Clara também acompanhou a apresentação da candidata, por meio do Skype, realizando breve arguição e assistindo boa parte das considerações dos demais membros da banca, que participaram *in loco*. Iniciando os trabalhos, o Presidente, Dr. Oswaldo Marçal Júnior, apresentou a comissão examinadora e a candidata; além disso, agradeceu a presença do público e concedeu a palavra à discente para exposição do seu trabalho. A seguir, concedeu a palavra aos examinadores, que passaram a arguir a candidata. O Sr. Presidente fez a leitura do parecer encaminhado pela Doutora Clara. A duração da apresentação da discente, bem como o tempo de arguição e de resposta estiveram de acordo com as normas do Programa. Finalizada a arguição, dentro dos termos regimentais, o Sr. Presidente pediu a todos os presentes que se retirassem da sala e a banca, em sessão secreta, atribuiu os conceitos finais. Em face do resultado obtido, a banca examinadora considerou a candidata **Aprovada**. Esta defesa é parte dos requisitos necessários à obtenção do título de Doutor. O competente diploma será expedido após o cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da Universidade Federal de Uberlândia. Nada mais havendo a tratar, foram encerrados os trabalhos às **17 horas e 20 minutos**. Foi lavrada a presente ata que, após lida e aprovada, foi assinada pela banca examinadora.



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Assinatura código verificador **1021244** e o código CRC **761E33DD**.

Dedicatória

À malacashaipeluweel
À todas as vidas perdidas nas estradas

Agradecimentos

Esse trabalho não seria possível ou teria sido muito mais difícil sem vocês, por isso serei eternamente agradecida, especialmente a Deus, por ter colocado cada um de vocês no meu caminho.

Aos meus pais, por terem me ensinado a sonhar, mesmo que a custo de muito sacrifício deles. A minha irmã, por ser a minha melhor amiga. Aos meus pequenos, Pedro e Lucas, que encheram nossa casa de felicidade. Ao meu marido, por estar sempre ao meu lado e me incentivar a correr atrás dos meus sonhos. Ao meu pequeno afilhado, Thomaz, por unir a nossa família. Aos meus sogros, por terem criado o homem que escolhi passar o resto da minha vida. Aos meus cunhados, por serem uma parte importante da minha vida. As minhas avós, tias e primas, por me mostrarem todos os dias, a força que uma mulher tem, morro de orgulho de vocês! Aos meus primos, por todas as Boas rlsadas que paRtilhAmos juntos. As minhas amigas, por fazerem da minha caminhada mais leve. Aos amigos brasileiros que fiz em Sevilla que são um dos melhores presentes que Sevilla me deu. Ao Alberto e Jimena por terem nos acolhido e nos mostrado como é a vida na Espanha. Hoje, tenho um pedacinho de família espalhado pelo Brasil e na Espanha.

Aos meus orientadores, Oswaldo, Ana e Eloy por serem essas pessoas maravilhosas. Ao Oswaldo por ter acreditado em mim, por todas as nossas conversas e pelos conselhos tão sabiamente partilhados. A Ana, por ter me apresentado a Ecologia de Estradas, temática que sou apaixonada e por ter se tornado uma amiga. Ao Oswaldo e Ana por toda a contribuição para a minha formação, não só científica, mas como pessoa também. Ao meu coorientador, Eloy Revilla, pelos oito meses de aprendizado que enriqueceram sobremaneira este trabalho.

Aos membros da banca: Clara, Simone, Kleber e André por terem dedicado horas preciosas na leitura desse texto. Ainda, à Clara e Simone pelo valioso trabalho que vêm realizando com Ecologia de Estradas. Ao Kleber e Oswaldo, pelas aulas maravilhosas de Ecologia na graduação, um pouco da culpa de estarmos todos aqui hoje é de vocês. Aos membros suplentes da banca, Natália Mundin e Helena Maura, por terem aceitado o convite, mesmo não recebendo nem um certificado em troca.

A Aline Carneiro Veloso, por ter feito boa parte da coleta de dados. A todos os colegas do Laboratório de Ecologia de Mamíferos que me acompanharam nas idas a campo. Especialmente, à Ana Paula, que se tornou muito querida para mim.

À professora Natália Oliveira Leiner pela identificação dos mamíferos de pequeno porte. À professora Celine de Melo, ao Gian Carlo e a Liliane Martins de Oliveira por terem me ajudado na identificação das aves. À professora Vera Lúcia de Campos Brites pela identificação dos répteis. Aos membros do grupo de Ecologia de Estradas e do grupo Lista Brasileira de Mastozoologia, pela contribuição na identificação dos mamíferos atropelados. Ao Frederico Gemésio Lemos, à Fernanda Cavalcanti de Azevedo e Mozart Caetano de Freitas pela ajuda com a identificação de mamíferos

À Universidade Federal de Uberlândia, ao Instituto de Biologia e ao Programa de Pós-graduação em Ecologia e Conservação de Recursos Naturais. Em especial as secretárias do programa, Maria Angélica e Juliana. A todos os professores do programa e do curso de Ciências Biológicas que contribuíram para a minha formação acadêmica, e em especial aos colegas de curso. As feias e fedorentas mais lindas e cheirosas desse mundo.

À CAPES, pela bolsa de estudo. Ao governo brasileiro pelo investimento feito em educação superior durante o período de 2003 a 2016, em especial pela criação do programa Ciências sem Fronteiras que possibilitou meu crescimento como cientista e pessoa.

Muito obrigada a todos vocês!

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Resumo

Carvalho-Roel, Carine Firmino; Iannini Custódio, Ana Elizabeth; Revilla, Eloy; Marçal Júnior, Oswaldo. *Vertebrate roadkill: identifying where, when and who dies on wildlife vehicle collisions on Brazilian Cerrado*. 2019. Tese (Doutorado em Ecologia e Conservação de Recursos Naturais) – Instituto de Biologia, Universidade Federal de Uberlândia, Uberlândia-MG. 153p.

Atropelamentos ameaçam a conservação da vida silvestre. Para mitigar essa ameaça de modo eficiente, é necessário entender onde, quando, como e quais espécies animais sofrem os maiores índices de atropelamentos. O principal objetivo desta tese foi responder a essas questões em uma área do Cerrado brasileiro. Nos dois primeiros capítulos, utilizamos dados de atropelamentos da rodovia BR-050. O monitoramento foi executado semanalmente de abril de 2012 a março de 2014, de carro, a 60 km/h, em média. Encontramos 1294 atropelamentos na estrada, 922 mamíferos, 265 aves e 107 répteis. Foram identificadas 78 espécies, 22 de mamíferos, 42 de aves e 14 de répteis. A taxa de atropelamento foi de 0,051 indivíduos/km/dia. No primeiro capítulo, investigamos como a paisagem e o clima influenciam os atropelamentos. Concluímos que a proximidade a corpos d'água e a distância a áreas urbanas são variáveis importantes na determinação da probabilidade de atropelamento para todos os grupos. A agricultura, as áreas naturais e de silvicultura também influenciam os atropelamentos de mamíferos. Silvicultura e pastagem são importantes para as aves. A temperatura mínima, a precipitação acumulada e a temperatura média influenciam os atropelamentos de mamíferos. Para aves, insolação, umidade e temperatura média são variáveis importantes. Para répteis, todas as variáveis do clima afetam a probabilidade de atropelamento. Os répteis tiveram uma taxa mais elevada de atropelamentos nos meses chuvosos e as aves, nos secos. No segundo capítulo, comparamos dois métodos diferentes para localizar agregações de atropelamento: o programa Siriema e modelos baseados em paisagem. O programa Siriema e modelos baseados na paisagem identificaram *hotspots* de atropelamentos para 50% e 70% dos dados, respectivamente. No que diz respeito à localização dos *hotspots* de atropelamentos, a classe Mammalia não parece representar bem as espécies pertencentes a esse taxon, embora as ordens o façam. Para as aves, nenhum dos métodos detectou *hotspots* de atropelamentos para um número satisfatório

de grupos. A localização dos *hotspots* de atropelamentos foi diferente de um ano para o outro, contudo, os dados agrupados dos dois anos representam relativamente bem os locais prioritários dos dois anos separadamente. A aplicação de medidas de mitigação em 9% da estrada protegeria 31% dos espécimes, utilizando dados do programa Siriema e 22% para modelos baseados na paisagem. O programa Siriema e modelos baseados na paisagem apresentaram baixa correlação em relação à localização dos *hotspots*. No terceiro capítulo, consultamos pesquisas científicas para investigar quais características específicas das espécies influenciam os atropelamentos e calcular suas respectivas taxas de atropelamento. Estimamos uma taxa de atropelamento para 51 espécies de mamíferos do Cerrado, 19 não foram observadas mortas. A taxa de atropelamento aumenta com a diminuição da densidade populacional, área de vida e período de amamentação e aumenta com a massa corporal. Animais carniceiros e territoriais tem maiores taxas de atropelamento. Mamíferos que preferem o habitat de floresta apresentam menores taxas de atropelamento. A taxa prevista de atropelamento de mamíferos foi de 1,35 ind./km/ano e 181.909 animais poderiam morrer a cada ano. No quarto capítulo, avaliamos os padrões gerais de acidentes entre animais e humanos, de 2007 a 2017, nas rodovias federais brasileiras. Para isso, utilizamos os dados públicos da Polícia Rodoviária Federal brasileira. Os 44.444 acidentes incluíram 68.775 pessoas, sendo 66,1% ilesos, 23,2% com ferimentos leves, 7,7% com ferimentos graves e 1,6% morreram. Os acidentes ocorreram principalmente de abril a agosto, aos domingos, com céu claro, à noite, em zonas rurais, em trechos retos, envolvendo apenas um veículo, especialmente um carro. As pessoas afetadas pelos acidentes foram principalmente motoristas, adultos e homens. A maioria dos acidentes envolvendo animais e humanos ocorreu na costa nordeste do Brasil. Apenas o atropelamento de animais silvestres custou R \$ 1.400.334.766,91, quantia suficiente para instalar cercas e uma estrutura de travessia de vida selvagem a cada dois quilômetros, passando por 517 km de estradas duplicadas.

Palavras-chave: Ecologia de Estradas, mortalidade nas rodovias, padrões espaciais, padrões temporais, características específicas das espécies, medidas de mitigação.

Abstract

Carvalho-Roel, Carine Firmino; Iannini Custódio, Ana Elizabeth; Revilla, Eloy; Marçal Júnior, Oswaldo. *Vertebrate roadkill: identifying where, when and who dies on wildlife vehicle collisions on Brazilian Cerrado*. 2019. Tese (Doutorado em Ecologia e Conservação de Recursos Naturais) – Instituto de Biologia, Universidade Federal de Uberlândia, Uberlândia-MG. 153p.

Roadkill is a serious threat to wildlife conservation. To efficiently mitigate roadkill it is necessary to understand where, when, how and who suffer higher roadkill rates and that was the main objective of this entire thesis. In the first two chapters we used roadkill data from BR-050 highway, an area of Cerrado biome in Brazil. The monitoring was executed weekly from April 2012 to March 2014, by car, at about 60 km/h. We found 1294 roadkills on the highway, 922 mammals, 265 birds and 107 reptiles. We identified 78 species, 22 mammals, 42 birds and 14 reptiles. The roadkill rate was 0.051 individuals/km/day. In the first chapter, we investigate how land cover and climate influence roadkill. We conclude that the proximity to water bodies and distance to urban areas are important variables in determining the roadkill probability for all groups. Agriculture, natural and silviculture areas also influence mammal roadkill. Silviculture and pasture are important for birds. Minimum temperature, accumulated precipitation and mean temperature influence mammal roadkill. For birds, insolation, humidity and mean temperature are important variables. For reptiles, all climate variables affect roadkill probability. Reptiles had a higher roadkill rate on rainy/hot months and birds on dry/cold ones. In the second chapter, we aimed to compare two different methods to locate roadkill hotspots: Siriema software and models based on landscape. Siriema software and landscape models identified roadkill hotspots for 50% and 70% of the data, respectively. With relation to the location of roadkill hotspots, the Mammalia class does not appear to represent well its species, although the orders do. For birds, neither methods detected roadkill hotspots for a satisfactory number of groups. The location of roadkill hotspots was different from one year to the other, and similar between one-year data and two. The application of mitigating measures on 9% of the road would protect 31% of the specimens for Siriema hotspots and 22% for landscape hotspots. Siriema and landscape hotspots in general presented a low correlation. Landscape models have a great advantage; it is not

necessary to have wildlife-vehicle collision data to identify the stretches of the highway with higher roadkill probability. In the third chapter, we consulted scientific researches to investigate what species-specific characteristics influence roadkill and to calculate a roadkill rate for the Cerrado species. We were able to estimate a roadkill rate for 51 species, 19 were not observed killed. Roadkill rate increases as population density, home range and weaning decrease and body mass increases. Scavengers and territorial animals have higher roadkill rates. Mammals that prefer forest habitat have lower roadkill rates. The predicted mammals roadkill rate was 1.35 ind./km/year and 181909 animals could die each year. In the fourth chapter, we evaluated general patterns of animal/human accidents, from 2007 to 2017, on federal Brazilian highways. For this, we used the public data from the Brazilian Federal Highway Police. The 44444 accidents comprised 68775 people, including 66.1% unharmed, 23.2% with minor injuries, 7.7% with serious injuries and 1.6% died. The accidents occurred mainly from April to August, on Sundays, with clear sky, at night, in rural zones, on straight stretches, involving just one vehicle, especially a car. People affected by accidents were mostly drivers, adults and men. Most of the animal/human accidents happened in Northeast Brazilian Coast. Only animal/human accidents costed R\$ 1 400 342 766.91, amount of money enough to install fences and one wildlife crossing structure each two kilometers through 517 km of four-lane roads.

Keywords: Road Ecology, road mortality, spatial patterns, temporal patterns, species-specific characteristics, mitigation measures.

Introdução Geral¹

¹ A formatação dessa seção obedece parcialmente às normas da ABNT.

Introdução geral

Múltiplos fatores promovem uma rápida expansão das estradas em nível mundial, incluindo a busca por recursos valiosos, tais como madeira, minerais, petróleo e terras aráveis, além de iniciativas para aumentar o comércio regional, transporte e infraestrutura energética (LAURANCE et al., 2014). No entanto, se novas estradas promovem o desenvolvimento social e econômico, também podem gerar diversos problemas ambientais, constituídos pelos efeitos químicos, físicos e biológicos sobre o ambiente (COFFIN, 2007; FORMAN; ALEXANDER, 1998; LAURANCE; GOOSEM; LAURANCE, 2009a; TROMBULAK; FRISSELL, 2000). Nessa perspectiva, atropelamentos da fauna silvestre estão entre os temas mais estudados (ASCENSÃO et al., 2017; CLEVINGER; CHRUSZCZ; GUNSON, 2003; D'AMICO et al., 2015; GONZÁLEZ-SUÁREZ; ZANCHETTA; GRILO, 2018).

Várias medidas tem sido utilizadas para mitigar os atropelamentos, incluindo sinais de alerta, barreiras eletrônicas, redutores de velocidade, repelentes olfatório, visual e sonoro, cercas e estruturas de passagem de fauna (GRILO; BISSONETTE; CRAMER, 2010; VAN DER GRIFT et al., 2012). Mas para mitigar os atropelamentos de forma eficiente, é necessário entender onde, quando e quem sofre maiores índices de atropelamentos (D'AMICO et al., 2015). Mamíferos afetados negativamente pelas estradas são espécies maiores, mais móveis, com menores taxas reprodutivas e espécies que evitam estradas (RYTWINSKI; FAHRIG, 2015). Os carnívoros são particularmente suscetíveis ao atropelamento porque muitas espécies exigem grandes áreas para sustentar suas populações, tem baixo índice reprodutivo e ocorrem em baixas densidades (GRILO; SMITH; KLAR, 2015). Morcegos com maior probabilidade de serem afetados pelas estradas são espécies de pequeno porte, de voo lento, adaptadas à floresta (ABBOTT et al., 2015). Para os animais arbóreos, o perigo está no comportamento de atravessar a estrada (LAURANCE; GOOSEM; LAURANCE, 2009a).

As espécies de aves que possuem grandes territórios e possivelmente espécies de voo baixo, terrícolas ou pesadas em relação ao tamanho das asas são mais suscetíveis à mortalidade rodoviária (RYTWINSKI; FAHRIG, 2015). Espécies de aves com alto risco de atropelamento incluem aquelas que se alimentam de carcaças, empoleiram,

forrageiam, nidificam e caçam perto de estradas (KOCIOLEK; GRILO; JACOBSON, 2015).

Todas as espécies de anfíbios e répteis são suscetíveis à mortalidade nas estradas (RYTWINSKI; FAHRIG, 2015). Os anfíbios são vulneráveis devido à locomoção lenta, pele úmida e delicada que está propensa à dessecação, com movimento sazonal e, para muitas espécies, uma aversão à luz e ao ruído (GRILO; BISSONETTE; CRAMER, 2010; HAMER; LANGTON; LESBARRÈRES, 2015; LAURANCE; GOOSEM; LAURANCE, 2009a). Muitos répteis encontram estradas durante movimentos sazonais, enquanto outras espécies são atraídos para as estradas para o forrageamento, nidificação ou regulação de temperatura, a maioria deles não consegue escapar de veículos, e muitos motoristas não conseguem detectá-los ou evitá-los (ANDREWS; LANGEN; STRUIJK, 2015; GRILO; BISSONETTE; CRAMER, 2010; LAURANCE; GOOSEM; LAURANCE, 2009a).

Colisões de veículos com animais silvestres geralmente ocorrem quando estradas passam por áreas de cobertura do solo favoráveis à ocorrência da espécie, por áreas de forrageamento ou de reprodução para espécies ou grupos específicos (GUNSON; MOUNTRAKIS; QUACKENBUSH, 2011), sendo de grande importância a cobertura do solo e a matriz de entorno para explicar padrões espaciais de atropelamentos (ASCENSÃO et al., 2017; BUENO; SOUSA; FREITAS, 2015). Matas ciliares, pastos e áreas agrícolas, assim como a distância até ao perímetro urbano parecem influenciar a localização das agregações de atropelamentos (ASCENSÃO et al., 2017; BUENO; SOUSA; FREITAS, 2015; FREITAS et al., 2015). As características da estrada também são importantes na identificação de maiores probabilidades de atropelamento, estando geralmente associadas a um maior tráfego de veículos, à baixa visibilidade, (GUNSON; MOUNTRAKIS; QUACKENBUSH, 2011), às estradas estreitas e pavimentadas (que incentivam o cruzamento por animais) (LAURANCE; GOOSEM; LAURANCE, 2009a) e ao tipo de topografia (GRILO; BISSONETTE; CRAMER, 2010). Esses locais com uma maior ocorrência de atropelamentos são chamados de *hotspots* ou agregações de atropelamentos e vários estudos os tem localizado nas rodovias (CARVALHO; IANNINI CUSTODIO; MARÇAL JUNIOR, 2015; CLEVENGER; CHRUSZCZ; GUNSON, 2003; COELHO; KINDEL; COELHO, 2008; SANTOS et al., 2017).

O clima é outra variável importante para determinar quando ocorrem *hotspots* de atropelamentos (D'AMICO et al., 2015; GARRIGA et al., 2017; GONÇALVES et al., 2018). GARRIGA *et al.* (2017) concluíram que os atropelamentos de anfíbios aumentaram com a umidade relativa, enquanto essa relação foi negativa para as aves; os atropelamentos de mamíferos foram associados à temperatura e os atropelamentos de répteis sofreram influência da precipitação, da irradiação solar e da temperatura. GONÇALVES *et al.* (2018) verificaram que os atropelamentos de répteis no sul do Brasil, ocorrem principalmente em dezembro, no verão, outros autores também encontraram sazonalidade nas taxas de atropelamento (BUENO et al., 2012; CUNHA; MOREIRA; SILVA, 2010; GARRIGA et al., 2017).

Além disso, a resposta das espécies às estradas e ao tráfego irá variar de acordo com o estado de conservação, localização geográfica, tipo de estrada e/ou volume de tráfego das estradas, bem como as preferências de habitat das diferentes espécies. Mas existem muitas espécies para as quais não sabemos praticamente nada sobre os efeitos das estradas em nível populacional. A fim de garantir que a mitigação seja eficaz para o maior número possível de espécies, é necessário investigar os efeitos das estradas para uma gama mais ampla de espécies (RYTWINSKI et al., 2015).

O problema dos atropelamentos parece ser mais acentuado em países tropicais (LAURANCE; GOOSEM; LAURANCE, 2009b). Na América do Sul, a Ecologia de Estradas é uma ciência emergente, e o Brasil e a Argentina estão liderando o campo (BAGER; BORGHI; SECCO, 2015). A estimativa mais recente aponta que 14.7 (\pm 44.8) milhões de animais morrem devido às colisões de veículos com animais silvestres no Brasil (DORNAS et al., 2012). Este país, também está experimentando grandes investimentos em pavimentação de estradas e modernização da rede de transporte existente, impactando ainda mais as extensas áreas dos ecossistemas remanescentes em todo o país (TEIXEIRA et al., 2016).

Infelizmente, no Brasil, ainda existe a crença de que, para crescer, é necessário desmatar. O bioma Cerrado, um *hotspot* para a conservação da biodiversidade (MYERS et al., 2000) está sofrendo com isso. Enquanto o Brasil estava reduzindo o desmatamento da Amazônia, o Cerrado perdeu 46% de sua cobertura vegetal nativa, e apenas 19,8% permanecem inalterados (STRASSBURG et al., 2017). Apenas 20% das terras privadas devem ser reservadas para conservação e as áreas públicas protegidas cobrem apenas

7,5% do bioma. Projeções relatam que 31-34% do Cerrado remanescente provavelmente será derrubado até 2050. Além disso, o Cerrado compreende 14.443 espécies de plantas e vertebrados, 4.641 (32,2%) deles são endêmicos, pelo menos 901 espécies estão na Lista Vermelha Brasileira de espécies ameaçadas de extinção (SAWYER et al., 2016).

No presente estudo, buscamos identificar onde, quando, quem e como os animais silvestres são atropelados no bioma Cerrado. Para isso, dividimos esta tese em quatro capítulos:

Capítulo 1 - Padrões espaciais e temporais de atropelamentos em uma área de Cerrado, Brasil “*Spatial and temporal patterns of roadkill in a Cerrado area, Brazil*”. Neste capítulo, identificamos como a cobertura e uso do solo, assim como o clima influenciam na localização espacial e temporal dos atropelamentos para os diferentes *taxa* de vertebrados. Analisamos os níveis taxonômicos Classe, Ordem e Espécies. Também investigamos os meses do ano com taxas mais altas de atropelamentos.

Capítulo 2 - Comparando dois métodos diferentes para localizar medidas de mitigação de atropelamentos “*Comparing two different methods to locate roadkill mitigation measures*”. Neste capítulo, avaliamos atropelamentos, no sentido de localizar os principais pontos para instalação de medidas de mitigação, usando duas metodologias diferentes, o programa Siriema e modelos baseados em cobertura e uso do solo. Também exploramos se os táxons Classe (Mamíferos, Aves e Répteis) e/ou Ordem, podem ser usados para localizar pontos críticos de atropelamentos de espécies pertencentes a essas mesmas classes/ordens. Ainda, avaliamos se os *hotspots* de diferentes anos estão localizados nos mesmos trechos da estrada. Por fim, comparamos se essas duas metodologias são capazes de identificar pontos com alta frequência de atropelamentos nos mesmos trechos.

Capítulo 3 - Como as características específicas das espécies influenciam os atropelamentos de mamíferos no bioma Cerrado, Brasil? “*How species-specific characteristics influence mammal roadkill in Cerrado biome, Brazil?*”. No capítulo 3, nosso objetivo foi determinar a taxa de atropelamento para as espécies de mamíferos do Cerrado. Para isso, acessamos artigos publicados para avaliar a taxa empírica de atropelamento para cada espécie, a fim de determinar as características específicas da espécie que influenciam a sua mortalidade nas estradas. Após, calculamos a taxa prevista de atropelamento para cada espécie dentro de sua distribuição geográfica no bioma Cerrado.

Capítulo 4 - **Padrões de acidentes de trânsito entre animais e humanos nas rodovias federais brasileiras, de 2007 a 2017: uma visão geral** “*Patterns of animal and human traffic acidentes on federal Brazilian highways, from 2007 to 2017: an overview*”. Neste último capítulo, avaliamos os padrões gerais de acidentes entre animais e humanos, de 2007 a 2017, nas rodovias federais brasileiras, na tentativa de compreender como esses acidentes impactam a vida humana e a economia brasileira. Tentamos responder as seguintes questões: 1) quando ocorre mais acidentes entre animais/humanos? 2) o *design* da estrada afeta os acidentes? 3) quem está mais envolvido neste tipo de acidentes: homens ou mulheres, que idade tem, que tipo de veículo dirigem? 4) onde a maior frequência de acidentes entre animais e humanos ocorre no Brasil?

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Capítulo 1
**Spatial and temporal patterns of roadkill in a Cerrado area,
Brazil².**

² A formatação dessa seção obedece parcialmente às normas do periódico *Biological Conservation*.

Spatial and temporal patterns of roadkill in a Cerrado area, Brazil.

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Highlights

- The proximity to water bodies and distance to urban areas are important variables in determining the roadkill probability for wild vertebrates.
- Agriculture, natural and silviculture area influence mammal roadkill. Silviculture and pasture are important for birds.
- Minimum temperature, accumulated precipitation and mean temperature influence mammal roadkill. For birds, insolation, humidity and mean temperature are important variables. For reptiles, all climate variables affect roadkill probability.
- Reptiles had a higher roadkill rate on rainy/hot months and birds on dry/cold ones.

ABSTRACT

To efficiently mitigate roadkill, it is necessary to understand where, when and who suffer higher roadkill rates. This study aimed to evaluate the spatial and temporal patterns of roadkill, determining how land cover and climate influence roadkill. We monitored the highway BR-050, in a Cerrado area, from April 2012 to March 2014. Two observers performed a weekly monitoring by car, at a speed of approximately 60 km/h. We split the roadkill data into different groups, analyzing the classes, orders and species. We found 1294 roadkills on the highway, 922 mammals, 265 birds and 107 reptiles. We identified 78 species, 22 mammals, 42 birds and 14 reptiles. The roadkill rate was 0.051 individuals/km/day. In the proximity to water bodies, there was a higher roadkill probability for all groups. The distance to the urban perimeter was also important. As agriculture, natural and silviculture areas increase, mammal roadkills also increase.

Silviculture and pasture areas are important to explain bird roadkills. Higher minimum temperature and higher accumulated precipitation values increase wild mammal roadkills, mean temperature is also important for this group. For birds, insolation, humidity and mean temperature are important variables. In general, for reptiles, higher values of minimum humidity, precipitation, minimum and mean temperature increase the roadkill probability, insolation has the opposite effect. Reptiles had a higher roadkill rate on rainy/hot months, for birds, the result was the opposite. Mammals do not have a clear pattern. Therefore, we advise that land cover and climatic descriptors be considered when planning mitigation measures.

Keywords

wildlife-vehicle collision; road mortality; Road Ecology; seasonality; land cover; climate.

1. Introduction

Roads have a wide range of effects, mostly of them are deleterious to the environment (Coffin, 2007; Forman and Alexander, 1998; van der Ree et al., 2015) being the wildlife roadkill the most studied one (Ascensão, Desbiez, Medici, & Bager, 2017; Carvalho, Iannini Custodio, & Marçal Junior, 2015; Clevenger, Chruszcz, & Gunson, 2003; D'Amico, Román, Reyes, & Revilla, 2015; Grilo, Bissonette, & Santos-Reis, 2009; Grilo, Cardoso, Solar, & Bager, 2016). In order to mitigate this effect, some measures have been proposed, planned and implemented, like warning signs; electronic barriers; speed bumps; olfactory, light and sound repellent; fencing and wildlife crossing structures (Grilo et al., 2010; Laurance et al., 2009; Lesbarrères and Fahrig, 2012).

To efficiently mitigate roadkill, it is necessary to understand where, when and who suffer higher roadkill rates (D'Amico et al., 2015). Several studies have located roadkill aggregation on roads (Carvalho et al., 2015; Clevenger et al., 2003; Coelho, Kindel, & Coelho, 2008; Santos et al., 2017) as the sites with a higher roadkill occurrence. Wildlife-vehicle collisions usually occur when roads bisect favorable cover, foraging, or breeding habitat for specific species or groups (Gunson et al., 2011) highlighting the high importance of land cover and matrix in explaining roadkill spatial patterns (Ascensão et al., 2017; Bueno et al., 2015). The road characteristics also influence roadkill, it increases with higher traffic volumes, low visibility, when roads cut through drainage movement corridors (Gunson et al., 2011), in narrow roads (which encourage the crossing of

highways by animals) (Laurance et al., 2009), in paved roads and topography also influences roadkill (Grilo et al., 2010).

Climate is also an important variable in determining when roadkill hotspots happen (D'Amico et al., 2015; Garriga et al., 2017; Gonçalves et al., 2018). Garriga et al. (2017) stated that amphibian roadkills increased with relative humidity, while this relationship was negative for birds; mammal roadkills were associated with temperature, and reptile roadkills correlated with precipitation, solar irradiance, and temperature. Gonçalves et al. (2018) concluded that reptile roadkills in South Brazil, happen mostly in December during the summer, other authors also have found the influence of seasonality on roadkill rates (Bueno et al., 2012; Cunha et al., 2010; Garriga et al., 2017)

It is perceivable that most of the studies in Road Ecology have focused in grouping the species according to their class taxon (Garriga et al., 2017; Santos et al., 2017) or analyzing some few species (Ascensão et al., 2017; Freitas et al., 2015), however it is not clear yet if different groups/species inside the same taxon present the same spatial and temporal patterns. For example, investigating how landscape influences mammal roadkills in Brazil, Ascensão et al. (2017) concluded that the distance to urban areas had a considerable importance, although a contrasting influence of this variable was identified for two species of mammals.

While in Europe, Canada and USA, Road Ecology is a well-established science, in South America it is just an emerging one, and Brazil and Argentina are leading the field (Bager et al., 2015). However, the studies that investigate the influence of landscape or climate on roadkill in Brazil are just starting and broader researches are necessary. The most recent estimate points that 14.7 (\pm 44.8) million animals die due to wildlife vehicle collisions in Brazil (Dornas et al., 2012). Adding the governmental Brazilian planning of increase of nearly 20% of paved roads, this number increases to half a billion vertebrates annually (Bager et al., 2015). An aggravating scenario probably would be detected for Cerrado Biome, one of the 25 biodiversity hotspot (Myers et al., 2000) that has lost 46% of its native vegetation cover and just 19.8% remains undisturbed (Strassburg et al., 2017). That is why it is urgent to understand what influences roadkill patterns for Brazilian Cerrado species to mitigate it efficiently. Therefore, our goal was to investigate the spatial and temporal patterns of roadkill, determining how land cover

and climate influence roadkill in a Cerrado area from Brazil grouping the data according to different taxa classifications, class, order and species.

2. Material and Methods

2.1 Study Area

The study was carried out on the stretch of the highway BR-050 between the cities of Uberlândia and Uberaba, in Minas Gerais state. The highway BR-050, with 1094 kilometers (km) in length, is an important means of connection between Brazil's capital, Brasília, and the states of Goiás, Minas Gerais and São Paulo (Fig. 1). This stretch of the highway has approximately 96 km, is a paved four-lane road with hard shoulders and median strips. On March 2018, 356 930 vehicles transited in the area (Concessionária de rodovias Minas Gerais Goiás S/A, 2018).

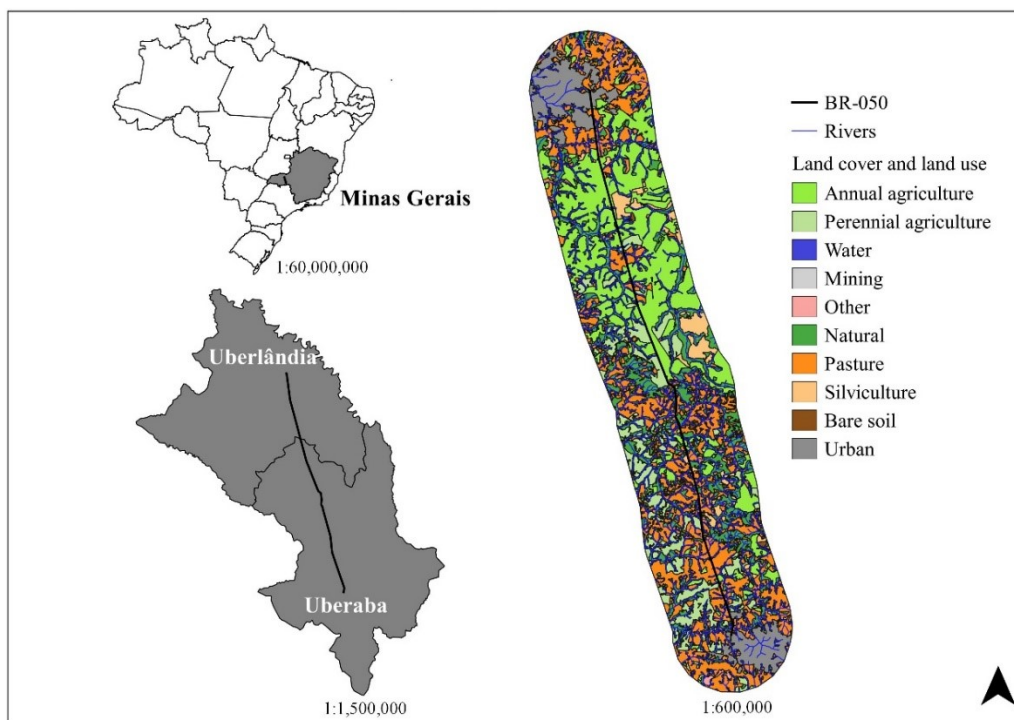


Fig. 1. Study area showing the land cover and land use in a buffer of 10 km around the BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (Ministério do Meio Ambiente, 2015).

The study area is in Cerrado biome, which presents from *campos* to forest formations, gallery forest and *veredas* (Araújo and Haridasan, 1997). The intense

agricultural activity reduced the Cerrado to small and isolated fragments (Araújo et al., 1997). The land use and land cover from Uberlândia city did not change from 2002 to 2010, just 18% from Uberlândia city area is still natural vegetation, 27% is agriculture and 45% pasture (Santos & Petronzio, 2011). In addition, the natural vegetation is usually near watercourses, in areas of a greater slope making it difficult to prepare the land for cultivation. From 2000 to 2013, the production of sugar cane increased 421% in Uberlândia city and 334.2% in Uberaba city (Petronzio, 2014). The climate is seasonal, the hot rainy months are from October to April and the cold dry months from May to September (Rosa, Lima, & Assunção, 1991) (Fig. 2).

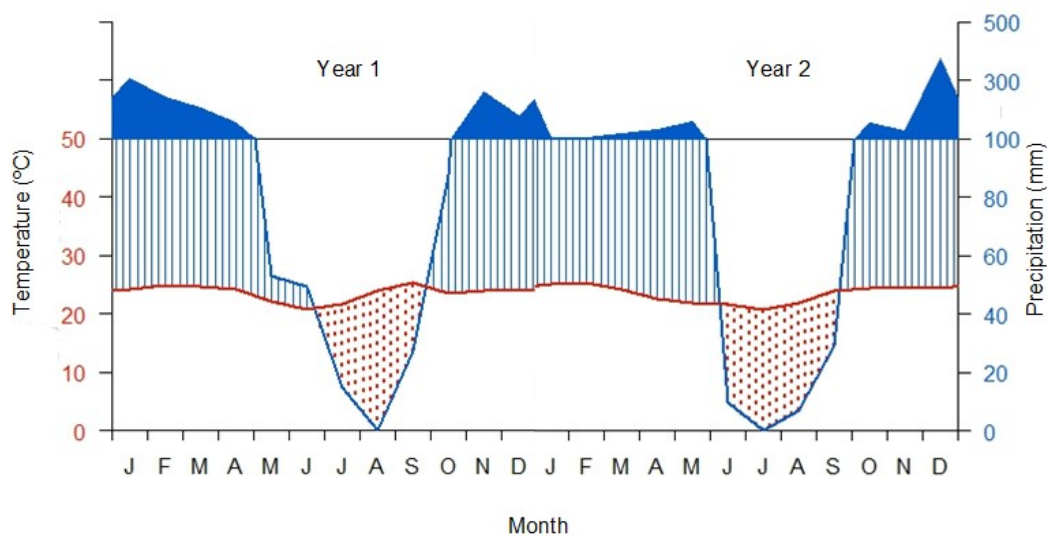


Fig. 2. Climate diagram (according to Walter and Lieth 1960) of monthly mean temperature (red solid line) and precipitation (blue solid line) at Uberlândia city, Cerrado biome, Brazil (April 2012 to March 2014). Where the precipitation curve is above the temperature curve, this period will be relatively humid (striped blue area). Where the precipitation curve falls below the temperature curve, this period will be relatively dry (dotted red area). Where the precipitation curve goes above 100 mm, this period will be relatively wet (solid blue area). We used the package *iki.dataclim* (Orlowsky, 2014). Data was provided by the Climatological Station of the Federal University of Uberlândia (UFU), Brazil.

2.2 Data collection

We monitored the highway from April 2012 to March 2014. Two observers performed this monitoring by car, at a speed of approximately 60 km/h, totaling 15 552

km and 81 monitoring events. In order to access data about the area, we used a map of land use and land cover produced by the Ministry of Environment (Ministério do Meio Ambiente, in Portuguese), with a 1:250 000 scale, resolution of approximately 6.25 hectares (0.0625 km²) and images from 2013 (Ministério do Meio Ambiente, 2015). We split the highway into 96 segments of one kilometer each and created a buffer of the same size around each segment. Then, we quantified the landscape characteristics around each segment (Table 1). We also selected climatic descriptors that could influence the species probability of being killed by a vehicle, these data were provided by the Climatological Station of the Federal University of Uberlândia (UFU), Brazil (Table 1) and was measured considering the week before each survey.

Table 1

Definition and description of the landscape and climatic variables used in the spatial and temporal analysis.

| Variable name | Description | Mean \pm SD (Minimum, Maximum) sum |
|----------------------------|--|---|
| Landscape variables | | |
| Agriculture | Agriculture cover within the buffer (km ²) | 0.75 \pm 0.78 (0.00, 2.03) 71889640.12 |
| Natural | Natural vegetation cover within the buffer (km ²) | 0.32 \pm 0.29 (0.00, 1.10) 30402175.85 |
| Pasture | Pasture cover within the buffer (km ²) | 0.77 \pm 0.62 (0.00, 2.00) 74054503.88 |
| Silviculture | Silviculture cover within the buffer (km ²) | 0.05 \pm 0.14 (0.00, 1.00) 4817846.81 |
| River_presence | River presence within the buffer | 0.84 \pm 0.36 (0.00, 1.000) |
| D_river | Distance to the nearest river (km) | 0.51 \pm 0.37 (0.05, 1.77) |
| D_urban | Distance to the nearest city (km) | 18.29 \pm 13.26 (0.01, 41.35) |
| D_fragment | Distance to the nearest fragment of natural vegetation (km) | 0.39 \pm 0.38 (0.01, 1.58) |
| N_fragments | Number of fragments of natural vegetation within the buffer | 2 \pm 1.26 (0.00, 6.00) |
| S_fragment | Area of the smallest fragment of natural vegetation (km ²) | 0.08 \pm 0.11 (0.00, 0.48) |
| L_fragment | Area of the largest fragment of natural vegetation (km ²) | 0.22 \pm 0.20 (0.00, 0.82) |
| Climatic variables | | |
| Temperature | Mean temperature (°C) | 23.6 \pm 2.0 (17.7, 29.6) |
| Temperature_min | Minimum mean temperature (°C) | 16.4 \pm 3.7 (7.5, 29.8) |
| Temperature_max | Maximum mean temperature (°C) | 30.6 \pm 3.5 (11.4, 37.8) |

| | | |
|--------------------|--------------------------------|--------------------------|
| Humidity | Mean air humidity (%) | 61.2 ± 11.7 (35.4, 84.6) |
| Humidity_min | Minimum mean air humidity (%) | 31.4 ± 9.2 (13.0, 50.0) |
| Humidity_max | Maximum mean air humidity (%) | 87.2 ± 11.5 (51.0, 98.0) |
| Precipitation | Mean precipitation (mm) | 2.5 ± 3.8 (0.0, 21.4) |
| Precipitation_acum | Accumulated precipitation (mm) | 37.9 ± 53.3 (0.0, 299.0) |
| Insolation | Mean insolation (hours) | 7.1 ± 2.0 (1.5, 10.5) |
| Insolation_acum | Accumulated insolation (hours) | 62.4 ± 32.5 (9.6, 186.4) |

Source: landscape data, Ministério do Meio Ambiente (2015); climatic data, Climatological Station of the Federal University of Uberlândia (UFU).

2.3 Data analysis

We excluded the correlated variables (D_fragment and L_fragment, for spatial analyses; Temperature_max, Humidity, Humidity_max, Precipitation and Insolation_acum, for temporal analyses; see Table A1). As the agriculture and pasture variables were correlated, we created two different models containing one of these variables and all the other ones. We analyzed the frequency of roadkills for the following taxonomic groups: classes (mammals, birds and reptiles) and orders (with two or more species). (Table 2). Birds were grouped in the orders with similar ecology to permit a more robust analysis. We also performed a specific analysis for species that had more than 15 roadkills (16 species) (Table 3).

Table 2

Orders and classes of mammals roadkills used in the spatial and temporal analysis, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| Order | Family / Species | Roadkill number |
|-------------------------------|---------------------------------|-----------------|
| Mammals (N=479*, T=93) | | |
| Didelphimorphia (N=23, T=20) | Didelphidae | 12 |
| | <i>Didelphis albiventris</i> | 8 |
| | <i>Lutreolina crassicaudata</i> | 3 |
| Pilosa (N=34, T=29) | Myrmecophagidae | 1 |
| | <i>Myrmecophaga tridactyla</i> | 4 |
| | <i>Tamandua tetradactyla</i> | 29 |
| Cingulata (N=135, T=55) | Dasypodidae | 17 |
| | <i>Cabassoussp</i> | 4 |
| | <i>Dasypus novemcinctus</i> | 21 |
| | <i>Dasypus</i> sp. | 7 |
| | <i>Euphractus sexcinctus</i> | 86 |
| Carnivora (N=255, T=83) | <i>Cerdocyon thous</i> | 97 |

| | | |
|-------------------------------|----------------------------------|----|
| | <i>Chrysocyon brachyurus</i> | 17 |
| | <i>Lycalopex vetulus</i> | 12 |
| | <i>Puma yagouaroundi</i> | 2 |
| | <i>Leopardus pardalis</i> | 1 |
| | <i>Leopardus sp.</i> | 1 |
| | <i>Conepatus semistriatus</i> | 89 |
| | <i>Galictis cuja</i> | 13 |
| | <i>Procyon cancrivorus</i> | 23 |
| Rodentia (N=27, T=21) | <i>Hydrochoerus hydrochaeris</i> | 22 |
| | <i>Coendou prehensilis</i> | 5 |
| Birds (N=240*, T=83) | | |
| Accipitriformes + | Falconidae | 2 |
| Falconiformes (N=41, T=36) | <i>Gampsonyx swainsonii</i> | 1 |
| | <i>Ictinia plumbea</i> | 1 |
| | <i>Rupornis magnirostris</i> | 14 |
| | <i>Caracara plancus</i> | 20 |
| | <i>Milvago chimachima</i> | 3 |
| Columbiformes (N=20, T=15) | Columbidae | 6 |
| | <i>Columbina talpacoti</i> | 3 |
| | <i>Patagioenas picazuro</i> | 7 |
| | <i>Zenaida auriculata</i> | 4 |
| Cuculiformes + | <i>Crotophaga ani</i> | 14 |
| Caprimulgiformes (N=28, T=25) | <i>Guira guira</i> | 2 |
| | Caprimulgidae | 1 |
| | <i>Antrostomus rufus</i> | 3 |
| | <i>Hydropsalis albicollis</i> | 7 |
| | <i>Hydropsalis sp.</i> | 1 |
| Strigiformes (N=30, T=28) | <i>Tyto furcata</i> | 11 |
| | <i>Bubo virginianus</i> | 8 |
| | <i>Athene cunicularia</i> | 11 |
| Passeriformes (N=16, T=16) | <i>Furnarius rufus</i> | 1 |
| | <i>Cnemotriccus fuscatus</i> | 1 |
| | <i>Machetornis rixosa</i> | 1 |
| | <i>Pitangus sulphuratus</i> | 1 |
| | <i>Xolmis cinereus</i> | 1 |
| | <i>Tyrannus melancholicus</i> | 1 |
| | <i>Mimu ssaturinus</i> | 2 |
| | <i>Gnorimopsar chopi</i> | 1 |
| | <i>Sicalis flaveola</i> | 1 |
| | <i>Sporophila nigricollis</i> | 1 |
| | <i>Sporophila sp.</i> | 2 |
| | <i>Volatinia jacarina</i> | 2 |
| | <i>Euphonia chlorotica</i> | 1 |

Reptiles (N=102, T=53)

N= number of roadkill. T= number of segments with roadkill. * Besides the species cited on the table, other specimens were added to the class analysis (see Table A2)

Table 3

Species of mammal roadkills used in the spatial and temporal roadkill analysis, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| Species |
|---|
| <i>Tamandua tetradactyla</i> (N=29, T=25) |
| <i>Dasypus novemcinctus</i> (N=21, T=20) |
| <i>Euphractus sexcinctus</i> (N=86, T=39) |
| <i>Canis familiaris</i> (N=170, T=71) |
| <i>Cerdocyon thous</i> (N=97, T=57) |
| <i>Chrysocyon brachyurus</i> (N=16, T=14) |
| <i>Felis catus</i> (N=103, T=51) |
| <i>Conepatus semistriatus</i> (N=89, T=56) |
| <i>Procyon cancrivorus</i> (N=23, T=21) |
| <i>Hydrochoerus hydrochaeris</i> (N=22, T=16) |
| <i>Coragyps atratus</i> (N=15, T=10) |
| <i>Caracara plancus</i> (N=20, T=20) |
| <i>Cariama cristata</i> (N=41, T=33) |
| <i>Columba livia</i> (N= 19, T=11) |
| <i>Boa constrictor</i> (N=41, T=33) |
| <i>Crotalus durissus</i> (N=20, T=16) |

N= number of roadkill. T= number of segments with roadkill.

For the spatial analyses, we created two different GLM models for each group, the response variable of the first model was the presence/absence of roadkill in each segment (for this model we used a binomial distribution and a logit link function) and the response variable of the second model was the number of roadkill in each segment (for this model we used a poisson distribution and a log function). For the temporal analyses, the response variable was also the number of roadkill in the period before the last survey (poisson distribution and a log function).

We ran GLM analyses using GLmulti package in R, testing all the possible relations between the response and the predictor variables inside the group (Calcagno, 2015). Model selection was performed using the Akaike Information Criterion for small samples (AICc), retaining all models within $\Delta AICc < 2$. We calculated AICc weights (wAICc) to compare the relative support of each model. The Relative Importance Weight (RIW) was reckoned for the variables to understand the importance of each one using the package GLmulti (Calcagno, 2015). We chose the best temporal and spatial model that

comprehended all the variables that had a RIW >0.4 (Table A3) and we discuss the effect of these variables.

We used circular statistics to assess the months with higher roadkill rates in Oriana software 4.02 (Kovach, 2011). We converted the months into degrees (0° January, 30° February, and so on). In order to correct bias (because some months could have been monitored more times than others) we calculated the mean roadkill number for each month and multiplied per the mean time each month was surveyed, resulting in the sum of roadkills for each month that was used as a frequency for each angle. In order to evaluate if the data were distributed in a uniform manner, we used the Rayleigh test of uniformity, Z (Kovach, 2011). We also calculated the mean angle, which is the month with higher roadkill rates and the confidence intervals.

3. Results

We found 1294 roadkills on the highway, 922 mammals, 265 birds and 107 reptiles (Table A2). Talking about mammals, 288 were domestic animals, 485 wild ones and 149 were not possible to conclude if they were wild animals or not. About birds, 23 were domestic/introduced animals, 208 wild and 34 were indeterminate ones. All reptiles were wild animals, just five individuals were not identified at species level. We identified 78 species, 22 mammals, 42 birds and 14 reptiles; from these, five mammals and three birds were domestic species. The global roadkill rate was 0.083 individuals/km/day, considering just wild animals this rate drops to 0.051 individuals/km/day.

Land use and land cover variables influenced 79% of the roadkills (23 out of 29). For mammals, 94% were influenced by these descriptors (15 out of 16), 60% of the birds (6 out of 10) and 67% of the reptiles (2 out of 3) (Table A3.1). The distance to the urban perimeter was important for 13 groups; the distance to the nearest river and pasture cover for 12; agriculture and silviculture cover for ten; natural cover for eight; river presence for six and the number of fragments and the area of the smallest natural fragment for five (Table A4.1).

For wild mammals the most important variables were: the distance to the urban perimeter with a variable effect; the distance to the nearest river and pasture, higher values of these descriptors decrease wild mammal roadkills probability; agriculture, natural and silviculture cover, as these variables increase wild mammal roadkills

probability also increases. For wild birds, the distance to the nearest river, pasture cover and silviculture were important variables, do not showing a clear pattern; the nearest the urban perimeter is, the higher is wild bird roadkills probability. For reptiles, the most important variables were: pasture cover, having a variable effect; the distance to the nearest river, the higher is these values, the lower is the reptile roadkillw probability; the distance to the urban perimeter, as this descriptor increases, reptiles roadkill probability also increase.

About climate variables, they influenced 76% (22 out of 29) of the animal roadkills. From mammals, 62% of the groups showed influence of climate descriptors (10 out of 16) (Table A3.2). Although the class birds was not influenced by climate descriptors, 70% of its groups did (7 out of 10). All reptile groups were affected by these descriptors. Temperature was important for 12 groups, minimum temperature and insolation for ten, accumulated precipitation for seven and humidity for six. In general, the most important variables influencing wild mammal roadkillw were: temperature, the effect depends on the group; minimum temperature and accumulated precipitation, higher values of them increase roadkill probability (with one exception for each variable) (Table A4.2). For birds, insolation was the most important variable, having a variable effect; humidity and temperature were also relevant, higher values of the first one decrease the roadkill probability; the last one does not have a clear pattern. For reptiles, as temperature and minimum temperature increase, and insolation decreases, roadkill probability increases.

Reptiles presented higher roadkill rates from January to February, during the rainy season (Figure 3, Table A5). Although bird class taxa not showing circular temporal patterns, some of its groups did, with higher roadkill rates from April to September, the dry season. Mammals did not have so clear patterns, Mammals, Cingulata, *Tamandua tetradactyla*, *Euphractus sexcinctus* and *Dasypus novemcinctus* presented higher roadkill rates during the rainy/hot months; Carnivora, *Cerdocyon thous* and *Conepatus semistriatus* during the dry/cold season.

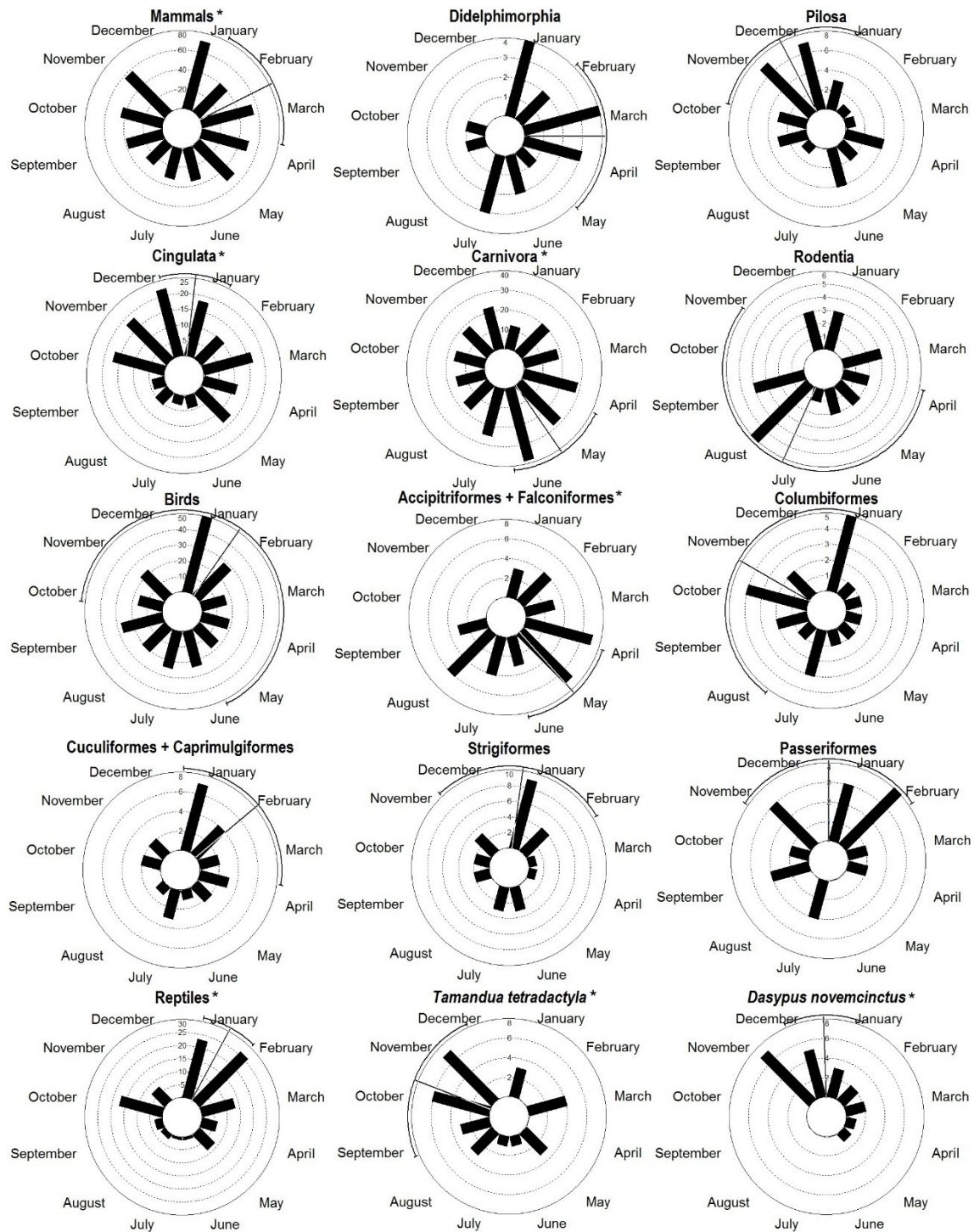


Fig. 3. Circular scatterplots (frequency) showing the number of roadkills per month (black columns) on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). The * means that the Rayleigh test of uniformity was significant. The line that starts from the center and goes to the edge of the circle represents the mean angle. The lines that start in the mean angle and go through the edges of the circle are the confidence intervals. For more details see Table A5.

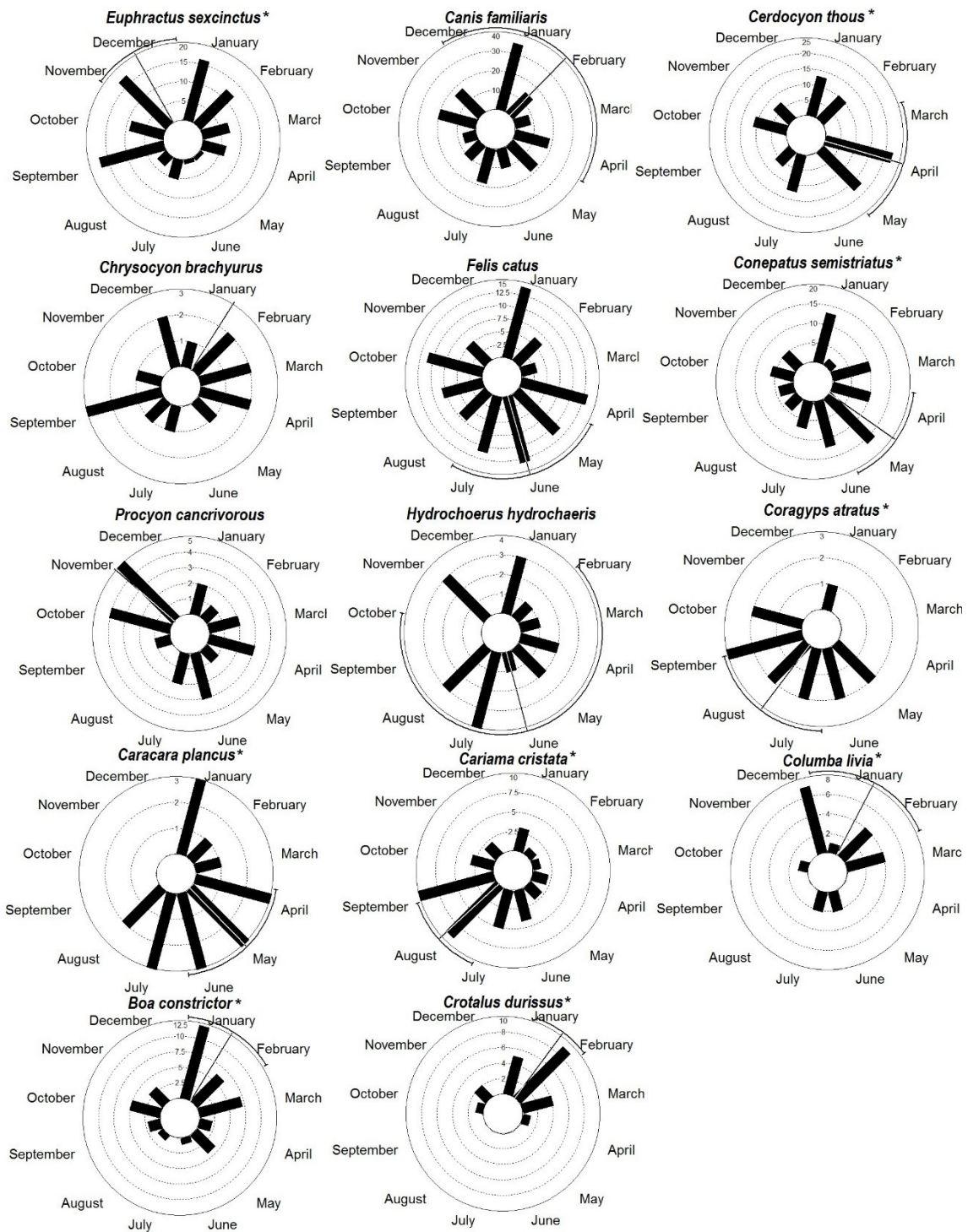


Fig. 3. cont.

4. Discussion

Fifty-six percent of the mammals that occur in the study area were found as roadkill (Alves et al., 2014; Bruna et al., 2010), 27% of the birds (Malacco et al., 2013; Marçal Júnior et al., 2009) and 47% of the reptiles (Costa et al., 2014). In Brazil, *Chrysocyon brachyurus*, *Myrmecophaga tridactyla*, *Lycalopex vetulus* and *Puma yagouaroundi* are vulnerable to extinction (Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio, 2016). In an international scale, *Myrmecophaga tridactyla* and *Crax fasciolata* are vulnerable to extinction and *Chrysocyon brachyurus* is near threatened (IUCN, 2018). Together, these species represent 2.85% of the roadkills. Comparing to other researches done in Cerrado biome, we observed a higher roadkill in relation to Brum et al. (2017); Carvalho, Bordignon, & Shapiro (2014) and Cunha, Moreira, & Silva (2010) (0.036, 0.042 and 0.014, respectively). On the other hand, our results were smaller than those found by Braz & França (2016); Santos, Rosa, & Bager (2012) and Santos (2017), which values ranged from 0.077 to 0.098. Anyway, this may indicate the importance of the study area, as just Santos et al. (2012) did not perform their survey near a conservation park.

Many landscape descriptors influence roadkill. The distance to the nearest river is the only variable that presents a clearer pattern through all wild animals, with the proximity to water bodies there is a higher roadkill probability (Ascensão et al., 2017; Bueno et al., 2015; Freitas et al., 2015). Some authors have shown that riparian vegetation areas function as corridors to movement and we should target these areas to promote biological restoration (Magioli et al., 2016).

The distance to the urban perimeter also plays a main role in explaining roadkill location (Ascensão et al., 2017). However, its effect is variable; for most mammals and birds, the roadkill probability is higher near the urban perimeter, presumably because the traffic volumes are higher in these areas and because these animals demand a higher home range being almost impossible for them to avoid being near the cities. On the contrary, for reptiles the roadkill probability is higher far from the cities, probably because in areas with lower human presence there is a greater abundance of wild animals (as found for mammals by Bogoni et al., 2016), also because these animals are less adapted to human disturbances and demand smaller home range areas.

Although agriculture and pasture present the same availability in the area, they have opposite effects for mammals, possibly because agriculture areas can offer some kind of shelter and food for mammals and pasture do not. Dotta & Verdade (2011) found lower species richness in pasture areas and a greatest frequency of occurrence of mammals in sugarcane areas. Magioli et al. (2016) concluded that agricultural and fragmented landscapes still sustain high biodiversity and ecological functions. Lyra-Jorge, Ciocheti, & Pivello (2008) showed that silviculture areas maintain a similar biodiversity of medium and large-sized mammals when compared to natural Cerrado areas, executing an important function in connecting patches of native vegetation. Therefore, we think that in our study area, agriculture areas are important for the movement and feeding of mammals.

Despite covering 2.34 less habitat than agriculture, natural areas appear as an important variable for mammals, for most of them, higher natural areas represent higher roadkill rates. Bigger natural areas support more complex and abundant communities (Garmendia et al., 2013; Primack, 2014) obviously increasing the roadkill rate (Caceres, 2011).

Silviculture covers a very small portion of land in the area, but influences bird roadkills, increasing the roadkill probability for some groups and decreasing for others. Zurita, Rey, Varela, Villagra, & Bellocq (2006) in an Atlantic area found 50% fewer birds in a silviculture area when compared to natural ones, on the other hand, Volpato, Prado, & Anjos (2010) in Southern Brazil found just 10% fewer birds species. Anyway, silviculture area seems to work as a habitat for some species, or at least as a connection among patches of native vegetation.

Pasture is also important for birds with a variable effect. Penteado, Yamashita, Marques, & Verdade (2016) detected that pasture had the largest abundance of birds, although natural forests had the highest diversity. Pasture usually presents arboreal/shrubby elements typical of the original vegetation that contribute to its structural complexity which may lead to high abundance.

Concerning climatic variables, for wild mammals, higher minimum temperature values increase mammal roadkill probability. Mammals usually have an optimal temperature on which they are more active and probably avoid moving on very

low temperatures. Accumulated precipitation is also an important variable to explain mammal roadkills, probably because this descriptor have higher values during the rainy/hot season and for most of the mammals this is also their breeding period, increasing their movement and consequently their roadkill probability (Reis, Peracchi, Adriano Lúcio Rossaneis, 2010). Three groups of mammals, all carnivorous, have higher roadkill probabilities on dry months. Bueno & Almeida (2010) and Cunha, Moreira, & Silva (2010) believe that due the scarcity of food, mammals have to move more, increasing the possibility of being evolved in an accident. Five groups of mammals, presented higher roadkill rates on rainy months, belonging to Cingulata or Pilosa orders, we believe that during mating/breeding, these animals move across long distances, increasing their roadkill probability (Reis, Peracchi, Adriano Lúcio Rossaneis, 2010).

For birds, insolation is the most important variable, higher values of insolation increase *Caracara plancus* and *Cariama cristata* roadkill, since these animals are diurnal, probably in days with more sunlight these animals are more active which increase their roadkill probability. For Strigiformes the effect of insolation is the contrary, which makes sense, seeing that these animals are nocturnal. Roadkill probability is higher when relative humidity is lower, possibly because during this period (dry/cold months) the availability of food is lower (Macedo, 2002).

Reptiles present a clearer temporal pattern, in general, higher values of minimum humidity, precipitation, minimum and mean temperature increase the roadkill probability, insolation has the opposite effect. In general, because of their natural characteristics, reptiles are more active in rainy/hot months; when it is also their breeding period (Andrews et al., 2015; Colli et al., 2002). The big taxon reptiles clearly represent the reptiles groups, others authors also have found more fatalities on summer for this group (Garriga et al., 2017; Gonçalves et al., 2018).

In general, the distance to a water body is important for all groups. So, we advise that mitigation measures be planed near these sites. Bridges, culverts and other structures can be adapted to work as a wildlife passage, it is easier and cheaper (Glista et al., 2009; Grilo et al., 2010; Smith et al., 2015). For reptiles, natural areas far from the urban perimeter are also crucial for protecting wildlife. In order to decrease mammal and bird roadkills, it is necessary to think about mitigating in the proximity to urban perimeters too, since unfortunately, they can not avoid these sites. As the area has few

remnants of Cerrado, sites that encompass natural areas and agriculture cover have higher roadkill probabilities for mammals than areas with natural and pasture cover. Therefore, the combination of Cerrado plus agriculture is preferable in order to decrease mammal roadkills. For birds, the better combination is natural areas of Cerrado plus silviculture or/and pasture.

Temporal patterns can also help to prevent roadkill. For reptiles, the months from January to March are responsible for 46% of the roadkill, temporal mitigation as temporal fencing and decreasing the maximum speed can decrease roadkill rates maintaining the expenditure lower (Glista et al., 2009; Grilo et al., 2010). However, road planers also need to think about maintaining wildlife genetic flow (Lesbarrères and Fahrig, 2012). For mammals and birds, it is more difficult to make great generalizations, but when the objective is to protect a species/group, temporal mitigation measures can also be employed. For example, August and September are responsible for 33% of *Cariama cristata* roadkill.

We urgently need to understand the factors that influence roadkill and this paper is a step in this direction. Anyway, it is necessary to locate the roadkill *hotspots* and investigate if they are coincident among the species/groups. However, we can not just consider the number of dead animals to identify roadkill hotspots, we must add land cover and movement data to efficiently mitigate wildlife vehicle collisions (Lesbarrères and Fahrig, 2012).

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

Acknowledgements

We acknowledge the Institute of Biology from the Federal University of Uberlândia for providing our transport to collect the data. We thank the Climatological Station of the Federal University of Uberlândia (UFU), Brazil, for providing the climate data. We especially thank the field surveyors who collected the field data and to the reviewers.

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Table A1.1 Spearman correlation between the landscape variables.

| | Agriculture | Natural | Pasture | Silviculture | River_ presence | D_ river | D_ urban | D_ fragment | N_ fragments | S_ fragment |
|----------------|-------------|---------|---------|--------------|--------------------|-------------|-------------|----------------|-----------------|----------------|
| Natural | -0.63 | | | | | | | | | |
| Pasture | -0.77 | 0.52 | | | | | | | | |
| Silviculture | -0.05 | 0.02 | -0.15 | | | | | | | |
| River_presence | -0.32 | 0.54 | 0.32 | 0.12 | | | | | | |
| D_river | 0.39 | -0.58 | -0.32 | 0.01 | -0.53 | | | | | |
| D_urban | 0.31 | 0.09 | -0.26 | -0.01 | -0.14 | 0.05 | | | | |
| D_fragment | 0.52 | -0.79 | -0.39 | -0.13 | -0.50 | 0.72 | 0.00 | | | |
| N_fragments | -0.34 | 0.65 | 0.45 | -0.04 | 0.50 | -0.37 | -0.01 | -0.55 | | |
| S_fragment | -0.51 | 0.55 | 0.36 | 0.06 | 0.45 | -0.47 | -0.08 | -0.47 | 0.04 | |
| L_fragment | -0.61 | 0.94 | 0.46 | 0.05 | 0.56 | -0.58 | 0.07 | -0.76 | 0.53 | 0.56 |

(see Table 1 for more details about the landscape variables)

Table A1.2 Spearman p values for the correlations between the landscape variables.

| | Agriculture | Natural | Pasture | Silviculture | River_ presence | D_ river | D_ urban | D_ fragment | N_ fragments | S_ fragment |
|----------------|-------------|---------|---------|--------------|--------------------|-------------|-------------|----------------|-----------------|----------------|
| Natural | 0.00 | | | | | | | | | |
| Pasture | 0.00 | 0.00 | | | | | | | | |
| Silviculture | 0.59 | 0.81 | 0.13 | | | | | | | |
| River_presence | 0.00 | 0.00 | 0.00 | 0.24 | | | | | | |
| D_river | 0.00 | 0.00 | 0.00 | 0.95 | 0.00 | | | | | |
| D_urban | 0.00 | 0.38 | 0.01 | 0.92 | 0.18 | 0.62 | | | | |
| D_fragment | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 0.00 | 0.99 | | | |
| N_fragments | 0.00 | 0.00 | 0.00 | 0.68 | 0.00 | 0.00 | 0.91 | 0.00 | | |
| S_fragment | 0.00 | 0.00 | 0.00 | 0.57 | 0.00 | 0.00 | 0.43 | 0.00 | 0.72 | |
| L_fragment | 0.00 | 0.00 | 0.00 | 0.66 | 0.00 | 0.00 | 0.48 | 0.00 | 0.00 | 0.00 |

Table A1.3 Spearman correlation between the climatic variables.

| | Temp | Temp_mim | Temp_max | Humidity | Humidity_min | Humidity_max | Precip | Precipi_acum | Insolation |
|--------------------|-------|----------|----------|----------|--------------|--------------|--------|--------------|------------|
| Temperature_min | 0.61 | | | | | | | | |
| Temperature_max | 0.82 | 0.36 | | | | | | | |
| Humidity | -0.03 | 0.41 | -0.07 | | | | | | |
| Humidity_min | 0.09 | 0.43 | -0.19 | 0.64 | | | | | |
| Humidity_max | 0.02 | 0.24 | 0.08 | 0.74 | 0.28 | | | | |
| Precipitation | 0.2 | 0.36 | 0.21 | 0.72 | 0.42 | 0.66 | | | |
| Precipitation_acum | 0.22 | 0.37 | 0.24 | 0.76 | 0.47 | 0.72 | 0.89 | | |
| Insolation | 0 | -0.39 | -0.07 | -0.73 | -0.34 | -0.59 | -0.5 | -0.55 | |
| Insolation_acum | 0.06 | -0.24 | 0.1 | -0.3 | -0.22 | -0.07 | -0.1 | 0.01 | 0.56 |

Temp: Temperature, Temp_mim: Temperature_min, Temp_max: Temperature_max, Precip: Precipitation_acum (see Table 1 for more details about the climatic variables)

Table A1.4 Spearman p values for the correlations between the climatic variables.

| | Temp | Temp_mim | Temp_max | Humidity | Humidity_min | Humidity_max | Precip | Precipi_acum | Insolation |
|--------------------|------|----------|----------|----------|--------------|--------------|--------|--------------|------------|
| Temperature_min | 0.00 | | | | | | | | |
| Temperature_max | 0.00 | 0.00 | | | | | | | |
| Humidity | 0.81 | 0.00 | 0.53 | | | | | | |
| Humidity_min | 0.43 | 0.00 | 0.08 | 0.00 | | | | | |
| Humidity_max | 0.85 | 0.03 | 0.50 | 0.00 | 0.01 | | | | |
| Precipitation | 0.07 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | | | |
| Precipitation_acum | 0.05 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| Insolation | 0.98 | 0.00 | 0.52 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| Insolation_acum | 0.57 | 0.03 | 0.37 | 0.01 | 0.05 | 0.51 | 0.35 | 0.94 | 0.00 |

Temp: Temperature, Temp_mim: Temperature_min, Temp_max: Temperature_max, Precip: Precipitation_acum (see table 1 for more details about the climatic varirables)

Table A2

Complete list of the species found killed on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| <u>Class / Order</u> / Family / <i>Species</i> | N |
|---|----------|
| <u>Mammalia</u> | 108 |
| Didelphimorphia | |
| Didelphidae | 12 |
| <i>Didelphis albiventris</i> Lund, 1840 | 8 |
| <i>Lutreolina crassicaudata</i> (Desmarest, 1804) | 3 |
| Pilosa | |
| Myrmecophagidae | 1 |
| <i>Myrmecophaga tridactyla</i> Linnaeus, 1758 | 4 |
| <i>Tamandua tetradactyla</i> (Linnaeus, 1758) | 29 |
| Cingulata | |
| Dasypodidae | 17 |
| <i>Cabassous</i> sp. McMurtie, 1831 | 4 |
| <i>Dasypus novemcinctus</i> Linnaeus, 1758 | 21 |
| <i>Dasypus</i> sp. Linnaeus, 1758 | 7 |
| <i>Euphractus sexcinctus</i> (Linnaeus, 1758) | 87 |
| Perissodactyla | |
| Equidae | |
| <i>Equus caballus</i> Linnaeus, 1758 | 1 |
| Artiodactyla | |
| Suidae | |
| <i>Sus domesticus</i> Erxleben, 1777 | 1 |
| Cervidae | |
| <i>Mazama</i> sp. (Rafinesque, 1817) | 2 |
| Primates | |
| Cebidae | |
| <i>Callithrix penicillata</i> (É. Geoffroy, 1812) | 4 |
| Carnivora | 3 |
| Canidae | 21 |
| <i>Canis familiaris</i> Linnaeus, 1758 | 177 |
| <i>Cerdocyon thous</i> (Linnaeus, 1758) | 99 |
| <i>Chrysocyon brachyurus</i> (Illiger, 1815) | 17 |
| <i>Lycalopex vetulus</i> (Lunda, 1842) | 12 |
| Felidae | 8 |
| <i>Felis catus</i> Linnaeus, 1758 | 107 |
| <i>Puma yagouaroundi</i> (Geoffroy, 1803) | 2 |
| <i>Leopardus pardalis</i> (Linnaeus, 1758) | 1 |
| <i>Leopardus</i> sp. Gray, 1842 | 1 |

| | |
|---|----|
| Mephitidae | |
| <i>Conepatus semistriatus</i> (Boddaert, 1785) | 89 |
| Mustelidae | |
| <i>Galictis cuja</i> (Molina, 1782) | 13 |
| Procyonidae | |
| <i>Procyon cancrivorus</i> (Cuvier, 1798) | 24 |
| Lagomorpha | |
| Leporidae | |
| <i>Lepus europaeus</i> Pallas, 1778 | 2 |
| Rodentia | 9 |
| Caviidae | 0 |
| <i>Hydrochoerus hydrochaeris</i> (Linnaeus, 1766) | 22 |
| Erethizontidae | |
| <i>Coendou prehensilis</i> (Linnaeus, 1758) | 6 |
| <u>Aves</u> | 27 |
| Tinamiformes | |
| Tinamidae | |
| <i>Nothura maculosa</i> (Temminck, 1815) | 4 |
| Galliformes | |
| Cracidae | |
| <i>Crax fasciolata</i> (Spix, 1825) | 2 |
| Numididae | |
| <i>Numida meleagris</i> (Linnaeus, 1758) | 2 |
| Phasianidae | |
| <i>Gallus gallus domesticus</i> (Linnaeus, 1758) | 2 |
| Cathartiformes | |
| Cathartidae | |
| <i>Coragyps atratus</i> (Bechstein, 1793) | 15 |
| Accipitriformes | |
| <i>Gampsonyx swainsonii</i> (Vigors, 1825) | 1 |
| <i>Ictinia plumbea</i> (Gmelin, 1788) | 1 |
| <i>Rupornis magnirostris</i> (Gmelin, 1788) | 14 |
| Falconiformes | |
| Falconidae | 2 |
| <i>Caracara plancus</i> (Jacquin, 1784) | 20 |
| <i>Milvago chimachima</i> (Vieillot, 1816) | 3 |
| Gruiformes | |
| Rallidae | |
| <i>Aramides cajanea</i> (Statius Muller, 1776) | 4 |

| | |
|---|----|
| Cariamiformes | |
| Cariamidae | |
| <i>Cariama cristata</i> (Linnaeus, 1766) | 41 |
| Columbiformes | |
| Columbidae | |
| <i>Columba livia</i> Gmelin, 1789 | 19 |
| <i>Columbina talpacoti</i> (Temminck, 1811) | 3 |
| <i>Patagioenas picazuro</i> (Temminck, 1813) | 7 |
| <i>Zenaida auriculata</i> (Des Murs, 1847) | 4 |
| Psittaciformes | |
| Psittacidae | |
| <i>Aratinga aurea</i> (Gmelin, 1788) | 2 |
| <i>Diopsittaca nobilis</i> (Linnaeus, 1758) | 1 |
| <i>Psittacara leucophthalmus</i> (Statius Muller, 1776) | 1 |
| Cuculiformes | |
| Crotophaginae | |
| <i>Crotophaga ani</i> Linnaeus, 1758 | 14 |
| <i>Guira guira</i> (Gmelin, 1788) | 2 |
| Strigiformes | |
| Tytonidae | |
| <i>Tyto furcata</i> (Temminck, 1827) | 11 |
| Strigidae | |
| <i>Bubo virginianus</i> (Gmelin, 1788) | 8 |
| <i>Athene cunicularia</i> (Molina, 1782) | 11 |
| Caprimulgiformes | |
| Caprimulgidae | |
| <i>Antrostomus rufus</i> (Boddaert, 1783) | 3 |
| <i>Hydropsalis albicollis</i> (Gmelin, 1789) | 7 |
| <i>Hydropsalis</i> sp. | 1 |
| Piciformes | |
| Picidae | |
| <i>Colaptes campestris</i> (Vieillot, 1818) | 5 |
| <i>Dryocopus lineatus</i> (Linnaeus, 1766) | 1 |
| Ramphastidae | |
| <i>Ramphastos toco</i> (Statius Muller, 1776) | 1 |
| <i>Pteroglossus castanotis</i> (Gould, 1834) | 1 |
| Passeriformes | |
| Furnariidae | |
| <i>Furnarius rufus</i> (Gmelin, 1788) | 1 |
| Tyrannidae | |
| <i>Cnemotriccus fuscatus</i> (Wied, 1831) | 1 |

| | |
|--|----|
| <i>Machetornis rixosa</i> (Vieillot, 1819) | 1 |
| <i>Pitangus sulphuratus</i> (Linnaeus, 1766) | 1 |
| <i>Xolmis cinereus</i> (Vieillot, 1816) | 1 |
| <i>Tyrannus melancholicus</i> Vieillot, 1819 | 1 |
| Mimidae | |
| <i>Mimus saturninus</i> (Lichtenstein, 1823) | 2 |
| Icteridae | |
| <i>Gnorimopsar chopi</i> (Vieillot, 1819) | 1 |
| Thraupidae | |
| <i>Sicalis flaveola</i> (Linnaeus, 1766) | 1 |
| <i>Sporophila nigracollis</i> (Vieillot, 1823) | 1 |
| <i>Sporophila</i> sp. | 2 |
| <i>Volatinia jacarina</i> (Linnaeus, 1766) | 2 |
| Fringillidae | |
| <i>Euphonia chlorotica</i> (Linnaeus, 1766) | 1 |
| <u>Lepidosauria</u> | 2 |
| Squamata | 2 |
| Teiidae | |
| <i>Ameiva ameiva</i> (Linnaeus, 1758) | 2 |
| <i>Salvator merianae</i> (Linnaeus, 1758) | 9 |
| <i>Tupinambis</i> sp. | 1 |
| Amphisbaenidae | |
| <i>Amphisbaena alba</i> (Linnaeus, 1758) | 4 |
| Boidae | |
| <i>Boa constrictor amarali</i> (Stull, 1932) | 42 |
| Colubridae | |
| <i>Spilotes pullatus</i> (Linnaeus, 1758) | 3 |
| <i>Sibynomorphus mikanii</i> (Schlegel, 1837) | 2 |
| Dipsadidae | |
| <i>Oxyrhopus guibei</i> (Hoge & Romano, 1978) | 5 |
| <i>Philodryas mattogrossensis</i> (Koslowsky, 1898) | 1 |
| <i>Philodryas patagoniensis</i> (Girard, 1858) | 1 |
| <i>Phimophis guerini</i> (Duméril, Bibron & Duméril, 1854) | 1 |
| <i>Erythrolamprus poecilogyrus poecilogyrus</i> (Wied, 1825) | 1 |
| Viperidae | |
| <i>Bothrops alternatus</i> Duméril, Bibron & Duméril, 1854 | 1 |
| <i>Bothrops moojeni</i> (Hoge, 1966) | 9 |
| <i>Crotalus durissus collilineatus</i> (Amaral, 1926) | 21 |

Table A3.1

Models chosen as the best ones to explain spatial patterns of roadkill on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). Among the models with $\Delta AICc$ lower than two, the criteria used to choose the best models were the relative importance weight (RIW) of each variable, we chose the model that contains all the variables with $RIW \geq 0.4$. When the agriculture and pasture models had $\Delta AICc$ lower than two, we present the model with the lower $\Delta AICc$.

| | Binomial models | Poisson models |
|------------------------------------|---|--|
| Mammals | * | + Agriculture + Natural + Silviculture - River_presence - D_river + N_fragments |
| Didelphimorphia | Null | - Agriculture |
| Pilosa | + Natural - River_presence - D_river + D_urban + N_fragments | + Natural - D_river + D_urban |
| Cingulata | + Agriculture + Silviculture - D_river | + Agriculture + Silviculture - D_river + N_fragments + S_fragment |
| Carnivora | + Pasture + D_urban - S_fragment | + Agriculture + Natural - Silviculture - River_presence + D_river |
| Rodentia | - D_river - D_urban | - D_river - D_urban |
| Birds | - Natural - D_river - D_urban | - D_river - D_urban |
| Accipitriformes + Falconiformes | Null | Null |
| Columbiformes | - Silviculture + D_river - D_urban + S_fragment | - Silviculture + D_river - D_urban |
| Cuculiformes + Caprimulgiformes | - D_urban | Null |
| Strigiformes | Null | Null |
| Passeriformes | Null | Null |
| Reptiles | - Natural + D_urban - S_fragment | - Natural + D_urban - S_fragment |
| <i>Tamandua tetradactyla</i> | - Agriculture - River_presence - D_river + D_urban + N_fragments | - D_river + D_urban |

| | | |
|----------------------------------|--|--|
| <i>Dasypus novemcinctus</i> | + Agriculture + Natural + Silviculture - D_urban - N_fragments | + Agriculture + Natural + Silviculture - D_urban |
| <i>Euphractus sexcinctus</i> | + Agriculture - Natural + Silviculture - D_river + D_urban | + Agriculture - Natural + Silviculture - D_river + N_fragments |
| <i>Canis familiaris</i> | Null | + Agriculture + Natural - Silviculture + D_river + S_fragment |
| <i>Cerdocyon thous</i> | Null | Null |
| <i>Chrysocyon brachyurus</i> | + Agriculture + Natural | Null |
| <i>Felis catus</i> | - Silviculture + D_river - D_urban + S_fragment | Natural - Silviculture + S_fragment |
| <i>Conepatus semistriatus</i> | + Agriculture + D_urban | + Agriculture - Natural - River_presence - D_river + D_urban |
| <i>Procyon cancrivorous</i> | + Agriculture + River_presence + N_fragments - S_fragment | + Agriculture + River_presence - S_fragment |
| <i>Hydrochoerus hydrochaeris</i> | - D_river - D_urban | - D_river - D_urban |
| <i>Coragyps atratus</i> | - Agriculture - Silviculture + River_presence - D_river | + Pasture - Silviculture + -D_river + S_fragment |
| <i>Caracara plancus</i> | Null | Null |
| <i>Cariama cristata</i> | + Pasture + Silviculture | + Pasture + Silviculture |
| <i>Columba livia</i> | - Silviculture - D_urban | + Pasture - Natural - Silviculture + D_river - D_urban |
| <i>Boa constrictor</i> | Null | Null |
| <i>Crotalus durissus</i> | Null | - Pasture + Silviculture - D_river |

* As mammals had roadkill events at almost all the stretches it was not possible to run a GLM with binomial distribution.

Table A3.2

Models chosen as the best ones to explain temporal patterns of roadkill on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). Among the models with $\Delta AICc$ lower than two, the criteria used to choose the best model was the relative importance weight (RIW) of each variable, we chose the model that contained all the variables with $RIW \geq 0.4$.

| | Model |
|------------------------------------|--|
| Mammals | + Temperature_min + Precipitation_acum |
| Didelphimorphia | + Temperature - Temperature_min - Precipitation_acum - Insolation |
| Pilosa | + Temperature |
| Cingulata | + Temperature_min + Humidity_min |
| Carnivora | - Temperature + Humidity_min |
| Rodentia | Null |
| Birds | Null |
| Accipitriformes + Falconiformes | - Temperature - Humidity_min - Insolation |
| Columbiformes | Null |
| Cuculiformes + Caprimulgiformes | Null |
| Strigiformes | - Insolation |
| Passeriformes | - Insolation |
| Reptiles | + Temperature + Temperature_min - Insolation |
| <i>Tamandua tetradactyla</i> | + Temperature + Precipitation_acum + Insolation |
| <i>Dasyurus novemcinctus</i> | + Temperature_min |
| <i>Euphractus sexcinctus</i> | + Temperature + Precipitation_acum - Insolation |
| <i>Canis familiaris</i> | Null |
| <i>Cerdocyon thous</i> | Null |
| <i>Chrysocyon brachyurus</i> | Null |
| <i>Felis catus</i> | - Temperature |
| <i>Conepatus semistriatus</i> | - Temperature + Temperature_min |
| <i>Procyon cancrivorous</i> | + Humidity_min + Precipitation_acum |
| <i>Hydrochoerus hydrochaeris</i> | Null |
| <i>Coragyps atratus</i> | - Humidity_min - Precipitation_acum |
| <i>Caracara plancus</i> | - Temperature + Insolation |
| <i>Cariama cristata</i> | + Temperature - Temperature_min - Humidity_min + Insolation |
| <i>Columba livia</i> | + Precipitation_acum |
| <i>Boa constrictor</i> | + Temperature_min + Precipitation_acum - Insolation |
| <i>Crotalus durissus</i> | + Temperature + Temperature_min + Humidity_min |

Table A4.1 Relative Importance weight for the variables among all the spatial models that explain roadkill on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). A: agriculture models, P: pasture models, E: variable effect.

| Roadkill presence/absence (binomial distribution) | | | | | | | | | | | | | | | | | | | | | |
|--|----------------------------|----------|----------|------------------------|----------|----------|---------------|----------|----------|------------------|----------|----------|------------------|----------|----------|-----------------|----------|----------|--------------|----------|----------|
| Variable | Mammals¹ | | | Didelphimorphia | | | Pilosa | | | Cingulata | | | Carnivora | | | Rodentia | | | Birds | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | - | - | - | 0.50 | - | - | 0.31 | - | - | 1 | - | + | 0.38 | - | + | 0.28 | - | + | 0.31 | - | + |
| D_river | - | - | - | 0.30 | 0.31 | - | 0.69 | 0.69 | - | 0.58 | 0.51 | - | 0.39 | 0.35 | - | 0.76 | 0.76 | - | 0.75 | 0.73 | - |
| D_urban | - | - | - | 0.38 | 0.44 | - | 0.67 | 0.68 | + | 0.27 | 0.47 | + | 0.93 | 0.99 | + | 0.43 | 0.44 | - | 0.53 | 0.49 | - |
| N_fragments | - | - | - | 0.27 | 0.28 | - | 0.57 | 0.57 | + | 0.26 | 0.27 | + | 0.31 | 0.29 | - | 0.26 | 0.26 | + | 0.27 | 0.28 | + |
| Natural | - | - | - | 0.46 | 0.56 | + | 0.55 | 0.56 | + | 0.26 | 0.41 | - | 0.37 | 0.31 | + | 0.30 | 0.30 | - | 0.48 | 0.51 | - |
| Pasture | - | - | - | - | 0.30 | + | - | 0.32 | + | - | 0.93 | - | - | 0.42 | + | - | 0.29 | - | - | 0.26 | - |
| River_presence | - | - | - | 0.31 | 0.31 | - | 0.44 | 0.45 | - | 0.29 | 0.27 | - | 0.27 | 0.26 | - | 0.29 | 0.28 | - | 0.30 | 0.30 | - |
| S_fragment | - | - | - | 0.30 | 0.29 | - | 0.35 | 0.36 | + | 0.35 | 0.26 | + | 0.55 | 0.58 | - | 0.29 | 0.29 | - | 0.27 | 0.27 | + |
| Silviculture | - | - | - | 0.25 | 0.25 | + | 0.25 | 0.26 | + | 0.41 | 0.29 | + | 0.27 | 0.26 | - | 0.35 | 0.34 | + | 0.25 | 0.25 | + |
| Roadkill number (poisson distribution) | | | | | | | | | | | | | | | | | | | | | |
| Agriculture | 1.00 | - | + | 0.65 | - | - | 0.31 | - | - | 1.00 | - | + | 0.99 | - | + | 0.26 | - | + | 0.28 | - | + |
| D_river | 1.00 | 1.00 | - | 0.27 | 0.29 | - | 0.74 | 0.74 | - | 0.97 | 0.98 | - | 0.95 | 0.93 | - | 0.91 | 0.91 | - | 0.46 | 0.46 | - |
| D_urban | 0.27 | 0.43 | - | 0.32 | 0.40 | - | 0.62 | 0.63 | + | 0.25 | 0.37 | + | 0.27 | 0.56 | + | 0.53 | 0.53 | - | 0.94 | 0.94 | - |
| N_fragments | 0.46 | 0.30 | + | 0.27 | 0.28 | - | 0.35 | 0.36 | + | 0.43 | 0.4 | + | 0.26 | 0.26 | - | 0.31 | 0.31 | + | 0.30 | 0.3 | + |
| Natural | 0.70 | 0.27 | + | 0.38 | 0.52 | + | 0.68 | 0.70 | + | 0.32 | 0.77 | - | 0.88 | 0.32 | + | 0.29 | 0.29 | - | 0.34 | 0.34 | - |
| Pasture | - | 0.96 | - | - | 0.32 | + | - | 0.30 | + | - | 1.00 | - | - | 0.47 | + | - | 0.26 | - | - | 0.28 | - |
| River_presence | 0.80 | 0.68 | - | 0.26 | 0.27 | - | 0.33 | 0.33 | - | 0.30 | 0.27 | - | 0.45 | 0.42 | - | 0.28 | 0.28 | - | 0.37 | 0.37 | - |
| S_fragment | 0.34 | 0.73 | - | 0.28 | 0.27 | - | 0.28 | 0.28 | + | 0.52 | 0.81 | + | 0.25 | 0.28 | - | 0.38 | 0.38 | - | 0.27 | 0.28 | + |
| Silviculture | 0.99 | 0.92 | + | 0.30 | 0.32 | + | 0.25 | 0.25 | + | 1.00 | 0.88 | + | 0.44 | 0.39 | - | 0.28 | 0.28 | + | 0.27 | 0.28 | + |

¹ As mammals had roadkill events at almost all the stretches it was not possible to run a GLM with binomial distribution.

Table A4.1 cont.

| Variable | Roadkill presence/absence (binomial distribution) | | | | | | | | | | | | | | | | | | | | |
|----------------|---|------|---|---------------|------|---|------------------------------------|------|---|--------------|------|---|---------------|------|---|----------|------|---|----------------------------------|------|---|
| | Accipitriformes + Falconiformes | | | Columbiformes | | | Cuculiformes + Caprimulgiformes | | | Strigiformes | | | Passeriformes | | | Reptiles | | | <i>Tamandua tetradactyla</i> | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | 0.33 | - | + | 0.28 | - | + | 0.27 | - | + | 0.28 | - | + | 0.29 | - | + | 0.33 | - | + | 0.50 | - | - |
| D_river | 0.29 | 0.29 | - | 0.74 | 0.74 | + | 0.27 | 0.27 | - | 0.26 | 0.27 | - | 0.31 | 0.31 | - | 0.36 | 0.35 | - | 0.86 | 0.89 | - |
| D_urban | 0.26 | 0.25 | - | 1.00 | 1.00 | - | 0.74 | 0.73 | - | 0.33 | 0.33 | - | 0.25 | 0.25 | + | 0.80 | 0.88 | + | 0.88 | 0.85 | + |
| N_fragments | 0.28 | 0.29 | | 0.29 | 0.29 | - | 0.28 | 0.28 | - | 0.37 | 0.39 | + | 0.26 | 0.26 | + | 0.29 | 0.28 | - | 0.51 | 0.55 | + |
| Natural | 0.26 | 0.26 | - | 0.29 | 0.28 | + | 0.27 | 0.26 | + | 0.27 | 0.27 | + | 0.28 | 0.28 | - | 0.57 | 0.50 | + | 0.31 | 0.35 | - |
| Pasture | - | 0.41 | - | - | 0.26 | + | - | 0.26 | - | - | 0.34 | - | - | 0.27 | - | - | 0.31 | + | - | 0.36 | + |
| River_presence | 0.38 | 0.36 | - | 0.34 | 0.34 | + | 0.26 | 0.26 | - | 0.31 | 0.31 | - | 0.27 | 0.27 | - | 0.29 | 0.29 | - | 0.59 | 0.60 | - |
| S_fragment | 0.29 | 0.29 | + | 0.42 | 0.41 | + | 0.25 | 0.25 | - | 0.26 | 0.26 | + | 0.27 | 0.26 | + | 0.41 | 0.41 | - | 0.30 | 0.32 | + |
| Silviculture | 0.45 | 0.42 | + | 0.63 | 0.61 | - | 0.33 | 0.32 | - | 0.28 | 0.27 | + | 0.60 | 0.6 | - | 0.31 | 0.30 | + | 0.29 | 0.31 | + |
| | Roadkill number (poisson distribution) | | | | | | | | | | | | | | | | | | | | |
| | Accipitriformes + Falconiformes | | | Columbiformes | | | Cuculiformes + Caprimulgiformes | | | Strigiformes | | | Passeriformes | | | Reptiles | | | <i>Tamandua tetradactyla</i> | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | 0.32 | - | + | 0.25 | - | + | 0.31 | - | + | 0.28 | - | + | 0.31 | - | + | 0.35 | - | + | 0.41 | - | - |
| D_river | 0.29 | 0.29 | - | 0.67 | 0.67 | + | 0.25 | 0.26 | - | 0.26 | 0.26 | - | 0.25 | 0.26 | - | 0.41 | 0.41 | - | 0.88 | 0.91 | - |
| D_urban | 0.26 | 0.26 | - | 1.00 | 1.00 | - | 0.64 | 0.62 | - | 0.31 | 0.31 | - | 0.64 | 0.62 | + | 0.72 | 0.82 | + | 0.84 | 0.82 | + |
| N_fragments | 0.28 | 0.28 | | 0.27 | 0.27 | - | 0.27 | 0.27 | - | 0.37 | 0.38 | + | 0.27 | 0.27 | + | 0.28 | 0.28 | - | 0.36 | 0.38 | + |
| Natural | 0.28 | 0.28 | - | 0.26 | 0.26 | + | 0.27 | 0.28 | + | 0.27 | 0.27 | + | 0.27 | 0.28 | - | 0.75 | 0.68 | + | 0.37 | 0.40 | - |
| Pasture | - | 0.32 | - | - | 0.26 | + | - | 0.26 | - | - | 0.34 | - | - | 0.26 | - | - | 0.33 | + | - | 0.32 | + |
| River_presence | 0.33 | 0.32 | - | 0.32 | 0.32 | + | 0.26 | 0.26 | - | 0.28 | 0.27 | - | 0.26 | 0.26 | - | 0.27 | 0.27 | - | 0.44 | 0.44 | - |
| S_fragment | 0.26 | 0.26 | + | 0.32 | 0.42 | + | 0.26 | 0.26 | - | 0.26 | 0.26 | + | 0.26 | 0.26 | + | 0.28 | 0.28 | - | 0.27 | 0.26 | + |
| Silviculture | 0.31 | 0.30 | + | 0.56 | 0.56 | - | 0.30 | 0.30 | - | 0.26 | 0.26 | + | 0.3 | 0.3 | - | 0.25 | 0.25 | + | 0.27 | 0.29 | + |

Table A4.1 cont.

| Variable | Roadkill presence/absence (binomial distribution) | | | | | | | | | | | | | | | | | | | | |
|----------------|---|------|---|------------------------------|------|---|-------------------------|------|---|------------------------|------|---|------------------------------|------|---|--------------------|------|---|-------------------------------|------|---|
| | <i>Dasyus novemcinctus</i> | | | <i>Euphractus sexcinctus</i> | | | <i>Canis familiaris</i> | | | <i>Cerdocyon thous</i> | | | <i>Chrysocyon brachyurus</i> | | | <i>Felis catus</i> | | | <i>Conepatus semistriatus</i> | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | 0.48 | - | + | 0.91 | - | + | 0.26 | - | + | 0.26 | - | + | 0.80 | - | + | 0.28 | - | + | 0.57 | - | + |
| D_river | 0.34 | 0.36 | - | 0.45 | 0.54 | - | 0.26 | 0.26 | + | 0.4 | 0.39 | - | 0.37 | 0.38 | - | 0.68 | 0.68 | + | 0.28 | 0.28 | - |
| D_urban | 0.62 | 0.58 | - | 0.54 | 0.96 | + | 0.29 | 0.29 | - | 0.28 | 0.27 | - | 0.32 | 0.37 | + | 0.41 | 0.40 | - | 0.98 | 1.00 | + |
| N_fragments | 0.48 | 0.43 | - | 0.26 | 0.29 | + | 0.43 | 0.43 | - | 0.27 | 0.27 | - | 0.32 | 0.29 | - | 0.30 | 0.31 | + | 0.28 | 0.27 | - |
| Natural | 0.66 | 0.64 | + | 0.48 | 0.95 | - | 0.29 | 0.28 | + | 0.26 | 0.26 | + | 0.57 | 0.39 | + | 0.31 | 0.31 | - | 0.37 | 0.26 | + |
| Pasture | - | 0.51 | - | - | 0.50 | - | - | 0.26 | - | - | 0.3 | + | - | 0.72 | - | - | 0.26 | - | - | 0.25 | - |
| River_presence | 0.27 | 0.27 | - | 0.28 | 0.33 | + | 0.28 | 0.28 | + | 0.27 | 0.27 | - | 0.27 | 0.28 | + | 0.30 | 0.30 | - | 0.38 | 0.36 | - |
| S_fragment | 0.30 | 0.3 | - | 0.31 | 0.38 | - | 0.44 | 0.45 | + | 0.44 | 0.45 | - | 0.29 | 0.27 | - | 0.51 | 0.50 | + | 0.34 | 0.39 | - |
| Silviculture | 0.83 | 0.76 | + | 0.64 | 0.60 | + | 0.53 | 0.55 | - | 0.25 | 0.25 | + | 0.31 | 0.27 | + | 0.94 | 0.94 | - | 0.29 | 0.30 | - |
| Variable | Roadkill number (poisson distribution) | | | | | | | | | | | | | | | | | | | | |
| | <i>Dasyus novemcinctus</i> | | | <i>Euphractus sexcinctus</i> | | | <i>Canis familiaris</i> | | | <i>Cerdocyon thous</i> | | | <i>Chrysocyon brachyurus</i> | | | <i>Felis catus</i> | | | <i>Conepatus semistriatus</i> | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | 0.33 | - | + | 1 | - | + | 0.49 | - | + | 0.28 | - | + | 0.61 | - | + | 1.00 | 1.00 | + | 0.54 | - | + |
| D_river | 0.39 | 0.40 | - | 0.78 | 0.89 | - | 0.70 | 0.71 | + | 0.48 | 0.45 | - | 0.43 | 0.42 | - | 0.31 | - | + | 0.49 | 0.47 | - |
| D_urban | 0.46 | 0.45 | - | 0.35 | 0.75 | + | 0.29 | 0.26 | - | 0.31 | 0.29 | - | 0.30 | 0.31 | + | 0.26 | 0.26 | - | 0.88 | 1.00 | + |
| N_fragments | 0.34 | 0.33 | - | 0.92 | 0.95 | + | 0.35 | 0.36 | - | 0.26 | 0.26 | - | 0.28 | 0.27 | - | 0.39 | 0.40 | + | 0.35 | 0.34 | - |
| Natural | 0.45 | 0.45 | + | 0.77 | 0.99 | - | 0.80 | 0.74 | + | 0.26 | 0.26 | + | 0.45 | 0.33 | + | 0.32 | 0.32 | - | 0.54 | 0.33 | + |
| Pasture | - | 0.39 | - | - | 0.96 | - | - | 0.25 | - | - | 0.31 | + | - | 0.49 | - | 0.56 | 0.55 | - | - | 0.25 | - |
| River_presence | 0.27 | 0.27 | - | 0.29 | 0.27 | + | 0.28 | 0.28 | + | 0.39 | 0.38 | - | 0.27 | 0.27 | + | - | 0.29 | - | 0.45 | 0.43 | - |
| S_fragment | 0.28 | 0.28 | - | 0.30 | 0.34 | - | 0.93 | 0.95 | + | 0.26 | 0.26 | - | 0.29 | 0.27 | - | 0.26 | 0.26 | + | 0.26 | 0.26 | - |
| Silviculture | 0.67 | 0.62 | + | 0.99 | 0.92 | + | 0.94 | 0.94 | - | 0.27 | 0.26 | + | 0.27 | 0.26 | + | 0.48 | 0.50 | - | 0.26 | 0.26 | - |

Table A4.1 cont.

| Variable | Roadkill presence/absence (binomial distribution) | | | | | | | | | | | | | | | | | | | | |
|----------------|---|------|---|----------------------------------|------|---|-------------------------|------|---|-------------------------|------|---|-------------------------|------|---|----------------------|------|---|------------------------|------|---|
| | <i>Procyon cancrivorous</i> | | | <i>Hydrochoerus hydrochaeris</i> | | | <i>Coragyps atratus</i> | | | <i>Caracara plancus</i> | | | <i>Cariama cristata</i> | | | <i>Columba livia</i> | | | <i>Boa constrictor</i> | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | 0.54 | - | + | 0.33 | - | + | 0.73 | - | - | 0.46 | - | + | 0.31 | - | - | 0.29 | - | - | 0.29 | - | - |
| D_river | 0.40 | 0.41 | - | 0.86 | 0.85 | - | 0.46 | 0.52 | - | 0.27 | 0.27 | - | 0.31 | 0.3 | - | 0.26 | 0.26 | + | 0.41 | 0.40 | - |
| D_urban | 0.28 | 0.26 | - | 0.48 | 0.45 | - | 0.26 | 0.26 | + | 0.27 | 0.26 | - | 0.26 | 0.26 | + | 0.85 | 0.88 | - | 0.40 | 0.37 | + |
| N_fragments | 0.57 | 0.47 | + | 0.30 | 0.30 | + | 0.26 | 0.27 | + | 0.28 | 0.28 | + | 0.34 | 0.33 | + | 0.31 | 0.31 | - | 0.34 | 0.34 | + |
| Natural | 0.31 | 0.33 | - | 0.35 | 0.37 | - | 0.27 | 0.29 | - | 0.35 | 0.31 | + | 0.29 | 0.29 | - | 0.33 | 0.32 | - | 0.34 | 0.34 | - |
| Pasture | - | 0.38 | - | - | 0.27 | - | - | 0.69 | + | - | 0.44 | - | - | 0.40 | + | - | 0.29 | + | - | 0.36 | + |
| River_presence | 0.54 | 0.58 | + | 0.27 | 0.27 | - | 0.45 | 0.41 | + | 0.41 | 0.40 | - | 0.32 | 0.31 | + | 0.25 | 0.25 | + | 0.29 | 0.29 | - |
| S_fragment | 0.70 | 0.82 | - | 0.27 | 0.27 | + | 0.32 | 0.41 | + | 0.27 | 0.28 | - | 0.30 | 0.29 | - | 0.27 | 0.27 | + | 0.38 | 0.39 | + |
| Silviculture | 0.29 | 0.28 | + | 0.31 | 0.30 | + | 0.72 | 0.65 | - | 0.32 | 0.34 | - | 0.67 | 0.71 | + | 0.62 | 0.61 | - | 0.47 | 0.45 | - |
| | Roadkill number (poisson distribution) | | | | | | | | | | | | | | | | | | | | |
| | <i>Procyon cancrivorous</i> | | | <i>Hydrochoerus hydrochaeris</i> | | | <i>Coragyps atratus</i> | | | <i>Caracara plancus</i> | | | <i>Cariama cristata</i> | | | <i>Columba livia</i> | | | <i>Boa constrictor</i> | | |
| | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E | A | P | E |
| Agriculture | 0.54 | - | + | 0.26 | - | + | 0.87 | - | - | 0.41 | - | + | 0.61 | - | - | 0.33 | - | - | 0.27 | - | - |
| D_river | 0.45 | 0.44 | - | 0.98 | 0.98 | - | 0.6 | 0.69 | - | 0.26 | 0.26 | - | 0.32 | 0.29 | - | 0.81 | 0.90 | + | 0.49 | 0.48 | - |
| D_urban | 0.26 | 0.25 | - | 0.60 | 0.58 | - | 0.26 | 0.27 | + | 0.27 | 0.26 | - | 0.26 | 0.27 | + | 0.91 | 0.91 | - | 0.26 | 0.27 | + |
| N_fragments | 0.54 | 0.46 | + | 0.43 | 0.42 | + | 0.31 | 0.32 | + | 0.27 | 0.27 | + | 0.36 | 0.33 | + | 0.28 | 0.29 | - | 0.29 | 0.28 | + |
| Natural | 0.30 | 0.32 | - | 0.32 | 0.33 | - | 0.29 | 0.35 | - | 0.32 | 0.29 | + | 0.29 | 0.27 | - | 0.45 | 0.41 | - | 0.30 | 0.30 | - |
| Pasture | - | 0.37 | - | - | 0.27 | - | - | 0.91 | + | - | 0.4 | - | - | 0.81 | + | - | 0.71 | + | - | 0.35 | + |
| River_presence | 0.50 | 0.52 | + | 0.26 | 0.16 | - | 0.45 | 0.39 | + | 0.37 | 0.36 | - | 0.32 | 0.28 | + | 0.31 | 0.28 | + | 0.29 | 0.29 | - |
| S_fragment | 0.60 | 0.71 | - | 0.30 | 0.30 | + | 0.47 | 0.73 | + | 0.27 | 0.27 | - | 0.45 | 0.39 | - | 0.31 | 0.33 | + | 0.29 | 0.28 | + |
| Silviculture | 0.27 | 0.26 | + | 0.26 | 0.26 | + | 0.82 | 0.69 | - | 0.31 | 0.32 | - | 0.84 | 0.93 | + | 0.80 | 0.71 | - | 0.52 | 0.50 | - |

Table A4.1 cont.

| Roadkill presence/absence (binomial distribution) | | | |
|--|--------------------------|----------|----------|
| Variable | <i>Crotalus durissus</i> | | |
| | A | P | E |
| Agriculture | 0.56 | - | + |
| D_river | 0.44 | 0.46 | - |
| D_urban | 0.49 | 0.49 | + |
| N_fragments | 0.27 | 0.27 | - |
| Natural | 0.30 | 0.28 | + |
| Pasture | - | 0.62 | - |
| River_presence | 0.27 | 0.27 | - |
| S_fragment | 0.35 | 0.38 | - |
| Silviculture | 0.29 | 0.26 | + |
| Roadkill number (poisson distribution) | | | |
| Agriculture | 0.30 | - | + |
| D_river | 0.05 | 0.44 | - |
| D_urban | 0.08 | 0.32 | + |
| N_fragments | 0.08 | 0.30 | - |
| Natural | 0.08 | 0.30 | + |
| Pasture | - | 0.68 | - |
| River_presence | 0.05 | 0.28 | - |
| S_fragment | 0.08 | 0.36 | - |
| Silviculture | 0.15 | 0.45 | + |

Table A4.2

Relative Importance Weight (RIW) for the variables among all the temporal models and its effects.

| | Humidity | | Insolation | | Precipitation | | Temperature | | Temperature_ | |
|--|----------|---|------------|---|---------------|---|-------------|---|--------------|---|
| | min | | | | acum | | | | min | |
| Mammals | 0.26 | - | 0.27 | + | 0.52 | + | 0.33 | - | 0.98 | + |
| Didelphimorphia | 0.28 | + | 0.69 | - | 0.75 | - | 0.59 | - | 0.64 | + |
| Pilosa | 0.27 | + | 0.16 | + | 0.36 | - | 0.48 | + | 0.20 | - |
| Cingulata | 0.21 | + | 0.29 | + | 0.15 | - | 0.54 | + | 0.89 | + |
| Carnivora | 0.58 | + | 0.14 | - | 0.37 | + | 0.63 | - | 0.42 | - |
| Rodentia | 0.18 | + | 0.23 | + | 0.39 | - | 0.15 | + | 0.19 | + |
| Birds | 0.26 | + | 0.47 | - | 0.28 | + | 0.33 | + | 0.34 | - |
| Accipitriformes + Falconiformes | 0.55 | - | 0.74 | - | 0.29 | - | 0.88 | - | 0.10 | + |
| Columbiformes | 0.26 | - | 0.27 | + | 0.28 | + | 0.35 | + | 0.28 | + |
| Cuculiformes + Caprimulgiformes | 0.27 | + | 0.35 | - | 0.30 | + | 0.32 | - | 0.26 | + |
| Strigiformes | 0.37 | + | 0.60 | - | 0.28 | - | 0.27 | - | 0.30 | + |
| Passeriformes | 0.33 | - | 0.77 | - | 0.26 | + | 0.29 | + | 0.27 | + |
| Reptiles | 0.29 | + | 0.75 | - | 0.36 | + | 0.64 | + | 0.94 | + |
| <i>Tamandua</i> <i>tetradactyla</i> | 0.26 | + | 0.69 | + | 0.62 | + | 0.56 | + | 0.34 | + |
| <i>Dasypus</i> <i>novemcinctus</i> | 0.20 | + | 0.34 | + | 0.12 | + | 0.18 | - | 0.93 | + |
| <i>Euphractus</i> <i>sexcinctus</i> | 0.34 | - | 0.64 | - | 0.81 | + | 1.00 | + | 0.27 | + |
| <i>Canis familiaris</i> | 0.24 | - | 0.37 | + | 0.15 | + | 0.22 | - | 0.51 | + |
| <i>Cerdocyon thous</i> | 0.26 | - | 0.26 | + | 0.26 | - | 0.42 | - | 0.26 | + |
| <i>Chrysocyon</i> <i>brachyurus</i> | 0.18 | - | 0.21 | - | 0.17 | - | 0.23 | + | 0.17 | - |
| <i>Felis catus</i> | 0.18 | - | 0.41 | + | 0.18 | + | 0.46 | - | 0.19 | + |
| <i>Conepatus</i> <i>semistriatus</i> | 0.31 | + | 0.30 | + | 0.25 | + | 0.90 | - | 0.41 | + |
| <i>Procyon</i> <i>cancrivorous</i> | 0.53 | + | 0.26 | + | 0.48 | + | 0.26 | + | 0.35 | + |
| <i>Hydrochoerus</i> <i>hydrochaeris</i> | 0.35 | - | 0.26 | - | 0.26 | - | 0.30 | - | 0.26 | + |
| <i>Coragyps atratus</i> | 0.86 | - | 0.27 | - | 0.44 | - | 0.27 | - | 0.31 | - |
| <i>Caracara plancus</i> | 0.27 | + | 0.71 | + | 0.34 | + | 0.67 | - | 0.31 | + |
| <i>Cariama cristata</i> | 0.48 | - | 0.41 | + | 0.30 | - | 0.88 | + | 0.88 | - |
| <i>Columba livia</i> | 0.15 | - | 0.14 | + | 0.92 | + | 0.14 | - | 0.16 | + |
| <i>Boa constrictor</i> | 0.27 | - | 0.75 | - | 0.60 | + | 0.32 | + | 0.47 | + |
| <i>Crotalus durissus</i> | 0.42 | + | 0.31 | - | 0.29 | - | 0.53 | + | 0.78 | + |

Table A5

Results of the circular statistics for the roadkill data, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| | Mean Vector (μ) | Month | Length of Mean Vector (r) | 95% Confidence Interval (-/+) for μ | | Rayleigh Test (Z) | Rayleigh Test (p) |
|---------------------------------|-----------------------------|----------|---------------------------------|--|---------|----------------------|----------------------|
| Mammals | 63.32° | March | 0.10 | 27.42° | 99.22° | 4.87 | 0.008 |
| Didelphimorphia | 90° | March | 0.37 | 45.13° | 134.86° | 2.91 | 0.053 |
| Pilosa | 332.25° | December | 0.27 | 284.44° | 20.06° | 2.66 | 0.069 |
| Cingulata | 6.57° | January | 0.32 | 345.87° | 27.26° | 13.98 | 0.000 |
| Carnivora | 145.28° | May | 0.17 | 116.17° | 174.38° | 7.34 | 0.001 |
| Rodentia | 204.40° | July | 0.15 | 101.86° | 306.93° | 0.59 | 0.557 |
| Birds | 35.00° | February | 0.04 | 275.97° | 154.04° | 0.45 | 0.641 |
| Accipitriformes + Falconiformes | 138.07° | May | 0.41 | 108.75° | 167.39° | 6.70 | 0.001 |
| Columbiformes | 300° | October | 0.20 | 216.81° | 23.19° | 0.89 | 0.414 |
| Cuculiformes + Caprimulgiformes | 50.10° | February | 0.31 | 1.75° | 98.46° | 2.57 | 0.076 |
| Strigiformes | 8.01° | January | 0.29 | 316.69° | 59.33° | 2.30 | 0.100 |
| Passeriformes | 0° | January | 0.34 | 304.46° | 55.53° | 1.93 | 0.146 |
| Reptiles | 28.36° | January | 0.45 | 12.27° | 44.46° | 21.77 | 0.000 |
| <i>Tamandua tetradactyla</i> | 291.16° | October | 0.32 | 247.04° | 335.28° | 3.08 | 0.045 |
| <i>Dasypus novemcinctus</i> | 358.12° | December | 0.66 | 335.39° | 20.84° | 9.08 | 0.000 |
| <i>Euphractus sexcinctus</i> | 330.57° | December | 0.32 | 305.27° | 355.87° | 9.35 | 0.000 |
| <i>Canis familiaris</i> | 44.67° | February | 0.08 | 328.37° | 121.02° | 1.08 | 0.340 |
| <i>Cerdocyon thous</i> | 106.42° | April | 0.22 | 71° | 141.83° | 4.90 | 0.007 |
| <i>Chrysocyon brachyurus</i> | 32.37° | February | 0.11 | 205.33° | 219.41° | 0.18 | 0.840 |
| <i>Felis catus</i> | 163.77° | June | 0.17 | 117.74° | 209.81° | 2.93 | 0.053 |
| <i>Conepatus semistriatus</i> | 124.98° | May | 0.29 | 96.26° | 153.70° | 7.33 | 0.001 |
| <i>Procyon cancrivorus</i> | 310.67° | November | 0.08 | 94.01° | 167.32° | 0.13 | 0.877 |

| | | | | | | | |
|----------------------------------|---------|----------|------|---------|---------|-------|-------|
| <i>Hydrochoerus hydrochaeris</i> | 165° | June | 0.15 | 48.63° | 281.37° | 0.46 | 0.637 |
| <i>Coragyps atratus</i> | 217.37° | August | 0.54 | 180.06° | 254.68° | 4.15 | 0.013 |
| <i>Caracara plancus</i> | 135.88° | May | 0.46 | 98.80° | 172.96° | 4.07 | 0.015 |
| <i>Cariama cristata</i> | 227.58° | August | 0.48 | 203.80° | 251.36° | 9.79 | 0.000 |
| <i>Columba livia</i> | 27.59° | January | 0.43 | 349.67° | 65.51° | 3.96 | 0.017 |
| <i>Boa constrictor</i> | 31.57° | February | 0.43 | 4.70° | 58.44° | 7.90 | 0.000 |
| <i>Crotalus durissus</i> | 36.53° | February | 0.78 | 19.87° | 53.20° | 13.41 | 0.000 |

Capítulo 2

Comparing two different methods to locate roadkill mitigation measures ³

³ A formatação dessa seção obedece parcialmente às normas do periódico *European Journal of Wildlife Research*.

Comparing two different methods to locate roadkill mitigation measures

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Abstract

A crucial step to efficiently mitigate roadkill is the identification of the best places to implement such measures. This study aimed to identify roadkill hotspots using two different methods: Siriema software and models based on land cover and land use, considering different animal groups. We performed the roadkill monitoring on a stretch of 96 km of the BR-050 highway, a Cerrado biome area, Brazil. Two observers monitored the highway by car, at 60 km/h, weekly, during two years. We split the data into 26 groups of wild animals. Using Siriema software enabled us to identify roadkill hotspots for 50% of the data, while landscape models identified roadkill hotspots for 70%. With relation to the location of roadkill hotspots, the Mammalia class does not appear to represent well its species, although the orders Cingulata, Pilosa and Rodentia do. For Carnivora, we advise analyzing the data at family level. For birds, neither Siriema Software neither landscape models detected roadkill hotspots for a satisfactory number of groups. The location of roadkill hotspots was different from one year to the other, however the two-years roadkill hotspots encompass most of the hotspots of both years. Mitigating 9% of the road would protect 31% of the specimens for Siriema hotspots and 22% for landscape hotspots. Siriema and landscape hotspots in general presented a low correlation. Landscape models have a great advantage; it is not necessary to have wildlife-vehicle collision data to identify the stretches of the highway with higher roadkill probability.

Keywords: Wildlife-vehicle collision, Road ecology, K Statics, Land use, Land cover, Cerrado biome.

Introduction

Wildlife vehicle collision is a recognized problem that is decreasing biodiversity worldwide (Forman and Alexander 1998; Coffin 2007; Laurance et al. 2009; van der Ree et al. 2015). If severe enough, roadkill can reduce the size of populations of wildlife, with a concomitant increase in the risk of local extinction (van der Ree et al. 2015).

Many researches worldwide trying to understand the roadkill patterns are increasing, with a special focus on identifying stretches of a road with higher roadkill probability (Ascensão, Desbiez, Medici, & Bager, 2017; Bueno, Sousa, & Freitas, 2015; Carvalho, Iannini Custodio, & Marçal Junior, 2015; Coelho, Kindel, & Coelho, 2008; Santos et al., 2017; Santos, Lourenço, Mira, & Beja, 2013; Teixeira et al., 2013), since it is economically impossible to mitigate an entire road or propose mitigation measures that encompass all species involved on wildlife vehicle collisions. In addition, the effectiveness of mitigation measures aiming at reducing roadkill rates depends on their placement along the road (Glista et al. 2009). Therefore, many researches have evaluated roadkill hotspots at species level (Freitas et al. 2015; Ascensão et al. 2017). However, if roadkill hotspots are coincident among species/groups, it would be easier to plan mitigation measures. Unfortunately, it seems that roadkill hotspots are not coincident for mammals, birds and reptiles (Teixeira et al., 2013) and for different time periods (Santos et al., 2017). Anyway, we need to find a way to group species alike and plan mitigation measures that can prevent roadkill for a bigger spectrum of species.

Another important step to decrease animal road mortality is to identify factors related to roadkill in space and time. This will allow us to build predictive models that can be validated and applied to different road networks to plan mitigation measures in advance (Teixeira et al., 2016). Models are advantageous because they can predict likely roadkill patterns and the need for mitigation planning on proposed roads or on roads without data on wildlife-vehicle collision or wildlife movement (Gunson and Teixeira 2015).

Roadkill is a more dangerous problem in tropical countries, since they are ecologically more diverse and in development, choosing to build roads instead of protecting the biodiversity or enforcing the law (Laurance et al. 2009). The road and rail

network across South America are rapidly expanding and there is an urgent need to better understand their effects on biodiversity to guide the growth of the transport sector (Bager et al. 2015). Focusing in Brazil, an aggravating factor is that this country is experiencing huge investments in road paving and upgrading of the existing transportation network, further impacting large areas of the remaining ecosystems in the whole country (Bager et al., 2015; Teixeira et al., 2016).

Brazil encompasses 9.5% of the world's known species, totaling 170 000 to 210 000 species, predictions estimate a total of 1.8 million species - known plus undiscovered (Lewinsohn and Prado 2005). In addition, in Brazil are located two of the 25 hotspots for biodiversity conservation (Myers et al. 2000). Cerrado biome is one of them, with at least 9566 species of vertebrates and plants (Klink and Machado 2005) with over 4800 plant and vertebrate species found nowhere else (Strassburg et al. 2017). Projections estimate that 31–34% of the remaining Cerrado is likely to be cleared by 2050, leading 480 endemic plant species to extinction — over three times all documented plant extinctions since the year 1500 (Strassburg et al. 2017). For these reasons, we performed the present study in the Cerrado biome.

This study was carried out to identify roadkill hotspots, using two different methodologies: Siriema software and models based on landscape cover (Teixeira et al., 2016); investigate if the level class (Mammals, Birds and Reptiles) and/or Order, can be used to locate roadkill hotspots of species belonging to these same classes/orders; evaluate if roadkill hotspots of different years are in the same stretches and compare if these two methodologies are able to identify roadkill hotspots at the same stretches.

Material and Methods

Study area

We monitored the stretch of the highway BR-050 between the cities of Uberlândia and Uberaba, in Minas Gerais state, Brazil (Fig. 1). This stretch of the highway has approximately 96 km, is a paved four-lane road with hard shoulders and median strips. From January to August 2018, an average of 349 675 vehicles per month transited in the area (Concessionária de rodovias Minas Gerais Goiás S/A 2018). The study area is in Cerrado biome, however the intense agricultural activity reduced the

Cerrado to small and isolated fragments (Araújo, Nunes, Rosa, & Resende, 1997). In 2010, just 18% from Uberlândia city area was still natural vegetation, 27% agriculture and 45% pasture (Santos & Petronzio, 2011). In addition, the natural vegetation is usually near watercourses, in difficult areas to prepare the land for cultivation. The climate is seasonal, the hot rainy months are from October to April and the cold dry months from May to September (Rosa et al. 1991).

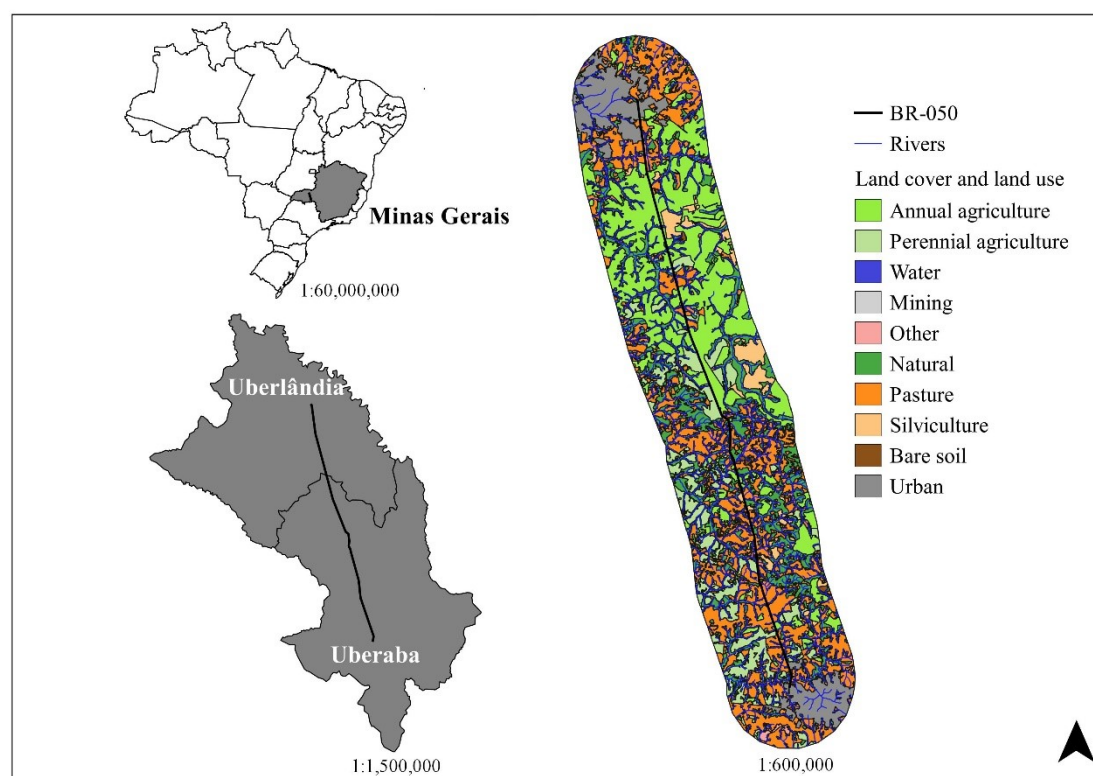


Fig. 1 Study area highlighting the location of Minas Gerais state in Brazil, the cities Uberlândia and Uberaba and the land cover and land use in a buffer of 10 km around the BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil. Source: (Carvalho-Roel et al. 2019)

Monitoring

Two observers realized the monitoring from April 2012 to March 2014, weekly, by car, at 60 km/h (for more details consult Carvalho-Roel et al. (2019)). Carvalho-Roel et al. (2019) split the data into 26 groups of wild animals (analyzing different hierarchical vertebrate classification: classes, mammals, birds and reptiles;

orders, five of mammals and five of birds; species, eight of mammals, three of birds and two of reptiles; (for more details see Carvalho-Roel et al. (2019)).

Data analysis

In order to evaluate if roadkill events occur in an aggregated way we executed the 2D Ripley's K-Statistics test (Coelho, Coelho, Teixeira, & Kindel, 2014). We used an initial radius of one km, an increment of radius of one km, one thousand simulations and a 95% confidence level. We performed the 2D HotSpot Identification test (Coelho et al., 2014) to locate the stretches with higher roadkill probability. We used the smallest significant radius according to the 2D Ripley's K-Statistics results and it varied for the groups/species (see Fig. S1 to check the smallest significant radius for each group/species). We selected to split the data into 96 segments of one km each, one thousand simulations and 95% confidence interval. We ran these analysis in the software Siriema v.2.0 (Coelho et al., 2014). We transformed the results from 2D HotSpot Identification into a binary data, representing the presence/absence of roadkill hotspot for each stretch of one km (Santos et al., 2017; Teixeira et al., 2013), than we used a phi correlation to assess if roadkill hotspots location were similar between the groups/species (Santos et al., 2017). When the groups/species had more than 10 roadkill events for a one-year-period we also analyzed the first and the second years separately in order to check if the hotspots location of the same species would be different depending on the year.

We also applied a new approach to determine roadkill hotspots. For this, we used the spatial variables that best explain roadkill provided by Carvalho-Roel et al. (2019). We added a variable related to the abundance of roadkilled animals, because roadkill location of other specimens can help identifying places with higher roadkill probability (Ascensão et al. 2017). This variable was calculated for each stretch and for each species/group, as the sum of dead animals from the same class taxon (mammals, birds or reptiles) in the stretch analyzed and in the surrounding ones (the kilometer before and after the stretch analyzed). We evaluated three different models, one that the descriptors were related to the landscape and land use cover (called as landscape model from now), another one with just the variable related to the roadkills in the surrounding (called as abundance model from now) and the last one composed of the “landscape” and “abundance” variables (called as the landscape + abundance model from now). Our

response variable was the presence of a dead animal in the stretch that is why we performed a GLM with binomial distribution and a logit link function (the only exception was the group mammals, that had a roadkill event in almost all the stretches, so we ran a GLM with a poisson distribution and a log function for this taxon). Model selection was performed using Akaike Information Criterion for small samples (AICc), the best models were those with $\Delta AICc < 2$. The AICc weights ($wAICc$) were calculated to indicate the relative support of every model. The hierarchical partitioning was reckoned to understand the importance of each variable, using the package *hier.part* (Walsh and Nally 2013). To evaluate if the model would classify correctly an observation the Area Under the Cover (AUC) was calculated (values ranging from 0.5-0.6, fail classification; 0.6-0.7, bad; 0.7-0.8, satisfactory; 0.8-0.9, good; 0.9-1, excellent) (Mazerolle 2017). The evidence ratio was calculated relating the model probabilities of each model with the null model, this allows to state how better is one model relatively to another (Santos, Lourenço, Mira, & Beja, 2013).

We reckoned a roadkill probability based on the effect of landscape and land cover on roadkill. In order to compare the similarity of the roadkill probability among the groups/species we performed a Spearman correlation. We defined as landscape hotspots the same number of stretches identified by 2D HotSpot Identification (for example, the 2D HotSpot Identification located seven hotspots for *Conepatus semistriatus*, so we chose the seven stretches with the highest roadkill probabilities for this species). To compare the hotspots location defined by the software Siriema (called as Siriema hotspots from now) and landscape models, we used a phi correlation. We used the Kruskal-Wallis test to analyze if the roadkill probability and the number of dead animals differ between hotspots and non-hotspots segments (defined by 2D HotSpot Identification and landscape models). These tests were performed in R 3.4.1 (R Core Team 2018).

Results

Siriema software

We identified roadkill aggregations for 13 groups (50% from a total of 26, Fig. S1). Evaluating the 13 groups all together, we located 62 stretches as roadkill hotspots, 32 of them were coincident (51.6%) (Fig. S2). For mammals, from the 14

groups, nine presented roadkill aggregations (64%). The five species of mammals (*Tamandua tetradactyla*, *Eupractus sexcinctus*, *Conepatus semistriatus*, *Procyon crancrivorus* and *Hydrochoerus hydrochaeris*) together presented 36 hotspots, just two of them were coincident for more than one species. The three mammal orders (Pilosa, Cingulata and Carnivora) showed 30 hotspots, none of them overlap. For the class Mammals alone, we localized 12 hotspots. Comparing the mammal orders hotspots localization with the mammal species ones, 21 hotspots overlap from a total of 45 (47%). Although when the comparison is made between the class Mammals and the mammal species or the mammal orders, just nine hotspots are in the same stretch from a total of 39 (23%) for mammal species and 33 for mammal orders (27%). Analyzing the Mammal class, orders and species all together, we identified 47 hotspots, 24 coincident (51%). For birds, from nine groups, just three (Columbiformes, *Coragyps atratus* and *Cariama cristata*) presented roadkill aggregations (33%), totaling 20 hotspots with no overlap. For reptiles, just the level class showed 13 roadkill hotspots.

The small overlapping between hotspots location is shown on Table 1. Just two groups had a higher correlation (Cingulata and *Eupractus sexcinctus*; Pilosa and Reptiles) and one a moderate one (Pilosa and *Tamandua tetradactyla*). We identified no correlation between the hotspot location of the first and the second year of research for the five groups/species analyzed and a moderate one for the combined data (year one and year two) and the first and second years of research (Table 2).

Table 1 Phi correlation between the location of all groups/species hotspots defined by the 2D HotSpot Identification, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| | Mammals | Pilosa | Cingulata | Carnivora | Colum ¹ | Reptiles | <i>T. tetradactyla</i> | <i>E. sexcinctus</i> | <i>C. semistriatus</i> | <i>P. cancrivorus</i> | <i>H. hydrochaeris</i> | <i>C. atratus</i> |
|--------------------------------------|---------|--------|-----------|-----------|--------------------|----------|----------------------------|--------------------------|----------------------------|---------------------------|----------------------------|-----------------------|
| Pilosa | 0.16 | | | | | | | | | | | |
| Cingulata | 0.43 | 0.16 | | | | | | | | | | |
| Carnivora | 0.39 | 0.09 | 0.08 | | | | | | | | | |
| Columbiformes | 0.09 | 0.10 | 0.09 | 0.05 | | | | | | | | |
| Reptiles | 0.15 | 0.79 | 0.15 | 0.08 | 0.09 | | | | | | | |
| <i>Tamandua tetradactyla</i> | 0.11 | 0.57 | 0.11 | 0.06 | 0.07 | 0.47 | | | | | | |
| <i>Euphractus sexcinctus</i> | 0.38 | 0.17 | 0.83 | 0.09 | 0.10 | 0.16 | 0.12 | | | | | |
| <i>Conepatus semistriatus</i> | 0.14 | 0.11 | 0.11 | 0.14 | 0.07 | 0.01 | 0.08 | 0.12 | | | | |
| <i>Procyon cancrivorus</i> | 0.02 | 0.12 | 0.11 | 0.14 | 0.07 | 0.11 | 0.08 | 0.12 | 0.08 | | | |
| <i>Hydrochoerus hydrochaeris</i> | 0.11 | 0.07 | 0.07 | 0.04 | 0.04 | 0.07 | 0.05 | 0.07 | 0.05 | 0.05 | | |
| <i>Coragyps atratus</i> | 0.11 | 0.02 | 0.11 | 0.06 | 0.07 | 0.01 | 0.08 | 0.02 | 0.06 | 0.08 | 0.05 | |
| <i>Cariama cristata</i> | 0.11 | 0.22 | 0.11 | 0.06 | 0.07 | 0.12 | 0.08 | 0.12 | 0.08 | 0.08 | 0.05 | 0.08 |

* $p \leq 0.05$; ** $p \leq 0.01$, ¹ Colum = Columbiformes

Table 2 Comparison of the roadkill hotspots location and the year of data collection for the class/orders/species that presented more than ten roadkill events per year and that roadkills are aggregated according to the 2D Ripley's K-Statistics results, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| | Year 1 and 2 X | Year 1 and 2 X | Year 1 X |
|-------------------------------|----------------|----------------|----------|
| | Year 1 | Year 2 | Year 2 |
| Mammals | 0.62** | 0.34* | 0.11 |
| Cingulata | 0.55** | 0.70** | 0.33* |
| Carnivora | 0.09 | 0.38* | 0.06 |
| <i>Euphractus sexcinctus</i> | 0.68** | 0.57** | 0.06 |
| <i>Conepatus semistriatus</i> | 0.40** | 0.46** | 0.08 |

* $p \leq 0.05$; ** $p \leq 0.001$. For more information about the 2D Ripley's K-Statistics results consult the Supplementary table 1.

Landscape Models

Landscape cover influenced roadkill for 18 groups (70%, Fig. S3). The models “landscape + abundance” and “landscape” had a similar performance, “abundance” models had the worst one (Table 3). The correlation between the “landscape + abundance” and “landscape” roadkill probabilities was strong ($r_s \geq 0.84$, Table 4). The correlation between the hotspots defined by the “landscape + abundance” and “landscape” models was strong for twelve groups and moderate or weak for six. The variability explained by landscape variables was on average 31.85% for each variable and 87% considering all the variables (Table 5). The abundance variable explained on average 13% of the variability. That is why we considered the “landscape” models as the best ones to explain our roadkill data. Most of the correlations among the roadkill probabilities defined using landscape models were weak, just 8.5% of them were strong and 20.3% moderate (Table 6).

Table 3 Models that influence wild animal roadkills, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| Species/group | Null | | Landscape | | | | Landscape + abundance | | | | Abundance | | | |
|------------------------------------|---------------|-------|---------------|-------|------|----------------|-----------------------|-------|------|----------------|---------------|-------|------|----------------|
| | $\Delta AICc$ | wAICc | $\Delta AICc$ | wAICc | AUC | Evidence ratio | $\Delta AICc$ | wAICc | AUC | Evidence ratio | $\Delta AICc$ | wAICc | AUC | Evidence ratio |
| Mammals | 50.08 | 0.00 | 0.00 | 0.58 | - | 7.49E+10 | 0.63 | 0.42 | - | 5.5E+10 | 32.89 | 0.00 | - | 5398.72 |
| Pilosa | 6.79 | 0.00 | 0.00 | 0.60 | 0.78 | 124.38 | 0.98 | 0.37 | 0.78 | 197.85 | 11.43 | 0.00 | 0.58 | 0.65 |
| Cingulata | 15.20 | 0.00 | 0.00 | 0.69 | 0.79 | 1995.59 | 1.62 | 0.31 | 0.82 | 888.36 | 10.28 | 0.00 | 0.66 | 11.67 |
| Carnivora | 12.66 | 0.00 | 2.06 | 0.23 | 0.82 | 200.53 | 0.00 | 0.65 | 0.82 | 561.91 | 3.38 | 0.12 | 0.77 | 103.78 |
| Rodentia | 1.47 | 0.19 | 0.00 | 0.40 | 0.65 | 2.09 | 0.75 | 0.28 | 0.67 | 1.43 | 2.19 | 0.13 | 0.59 | 0.70 |
| Birds | 2.36 | 0.13 | 0.36 | 0.36 | 0.71 | 2.72 | 0.00 | 0.43 | 0.74 | 3.25 | 3.72 | 0.07 | 0.59 | 0.51 |
| Columbiformes | 14.93 | 0.00 | 0.00 | 0.72 | 0.86 | 1743.68 | 1.88 | 0.28 | 0.86 | 679.45 | 15.48 | 0.00 | 0.60 | 0.76 |
| Cuculiformes + Caprimulgiformes | 2.24 | 0.18 | 0.00 | 0.55 | 0.63 | 3.06 | 1.97 | 0.20 | 0.64 | 1.14 | 4.07 | 0.07 | 0.52 | 0.40 |
| Reptiles | 5.11 | 0.05 | 0.00 | 0.67 | 0.70 | 12.89 | 1.90 | 0.26 | 0.70 | 4.99 | 6.93 | 0.02 | 0.53 | 0.40 |
| <i>Tamandua tetradactyla</i> | 11.84 | 0.00 | 0.00 | 0.64 | 0.81 | 371.89 | 1.16 | 0.36 | 0.82 | 208.12 | 13.46 | 0.00 | 0.55 | 0.44 |
| <i>Dasyurus novemcinctus</i> | 5.33 | 0.03 | 0.00 | 0.49 | 0.78 | 14.36 | 0.38 | 0.41 | 0.80 | 11.88 | 4.04 | 0.07 | 0.63 | 1.91 |
| <i>Euphractus sexcinctus</i> | 23.43 | 0.00 | 0.00 | 0.76 | 0.83 | 122199.60 | 2.27 | 0.24 | 0.83 | 3.94E+4 | 19.13 | 0.00 | 0.65 | 8.57 |
| <i>Chrysocyon brachyurus</i> | 2.96 | 0.12 | 0.00 | 0.52 | 0.71 | 4.39 | 1.61 | 0.23 | 0.71 | 1.96 | 2.87 | 0.12 | 0.61 | 1.04 |
| <i>Conepatus semistriatus</i> | 19.34 | 0.00 | 0.00 | 0.74 | 0.77 | 15823.24 | 2.13 | 0.26 | 0.77 | 5447.46 | 20.21 | 0.00 | 0.56 | 0.65 |
| <i>Procyon cancrivorus</i> | 7.36 | 0.02 | 1.75 | 0.25 | 0.75 | 16.54 | 0.00 | 0.60 | 0.79 | 39.71 | 3.07 | 0.13 | 0.66 | 8.55 |
| <i>Hydrochoerus hydrochaeris</i> | 3.46 | 0.08 | 0.00 | 0.44 | 0.70 | 5.64 | 0.15 | 0.41 | 0.73 | 5.24 | 3.54 | 0.07 | 0.62 | 0.96 |
| <i>Coragyps atratus</i> | 5.52 | 0.04 | 0.00 | 0.71 | 0.86 | 15.83 | 2.26 | 0.23 | 0.86 | 5.12 | 7.52 | 0.02 | 0.50 | 0.37 |
| <i>Cariama cristata</i> | 1.82 | 0.20 | 0.00 | 0.49 | 0.65 | 2.48 | 1.43 | 0.24 | 0.63 | 1.22 | 3.86 | 0.07 | 0.51 | 0.36 |

ΔAIC = difference between the AICc of a given model and that of the best model; wAICc = Akaike weights (based on AIC corrected for small sample sizes); AUC = Area Under Cover. Landscape = these models comprehend only land use and land cover variables. Landscape + abundance = these models contain land use and land cover variables and also the abundance variable. Abundance = these models encompass only the abundance variable.

Tale 4 Correlations between the “landscape + abundance” and “landscape” roadkill probability (rs results, Spearman correlation); and correlations between the “landscape + abundance” and “landscape” hotspots location (rPhi results, Phi correlation), BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| Group | rs | P | rPhi | P |
|----------------------------------|------|--------|------|--------|
| Mammals | 0.98 | <0.001 | 0.71 | <0.001 |
| Pilosa | 0.92 | <0.001 | 0.75 | <0.001 |
| Cingulata | 0.97 | <0.001 | 0.81 | <0.001 |
| Carnivora | 0.88 | <0.001 | 0.22 | 0.16 |
| Rodentia | 0.87 | <0.001 | 0.33 | 0.01 |
| Birds | 0.84 | <0.001 | 0.44 | <0.001 |
| Columbiformes | 0.99 | <0.001 | 0.99 | <0.001 |
| Cuculiformes + Caprimulgiformes | 0.98 | <0.001 | 0.55 | <0.001 |
| Reptiles | 0.99 | <0.001 | 0.91 | <0.001 |
| <i>Tamandua tetradactyla</i> | 0.98 | <0.001 | 0.85 | <0.001 |
| <i>Dasyurus novemcinctus</i> | 0.92 | <0.001 | 0.78 | <0.001 |
| <i>Euphractus sexcinctus</i> | 0.99 | <0.001 | 0.99 | <0.001 |
| <i>Chrysocyon brachyurus</i> | 0.96 | <0.001 | 0.78 | <0.001 |
| <i>Conepatus semistriatus</i> | 0.99 | <0.001 | 0.85 | <0.001 |
| <i>Procyon cancrivorus</i> | 0.90 | <0.001 | 0.54 | <0.001 |
| <i>Hydrochoerus hydrochaeris</i> | 0.89 | <0.001 | 0.31 | 0.09 |
| <i>Coragyps atratus</i> | 0.99 | <0.001 | 0.99 | <0.001 |
| <i>Cariama cristata</i> | 0.90 | <0.001 | 0.99 | 0.38 |

Table 5 Hierarchical partitioning of the “landscape + abundance” model. Variability explained in percent.

| Species/group | Abundance Variable (%) | Landscape Variables (%) | Number of variables | Landscape mean contribution* (%) |
|---------------------------------|------------------------|-------------------------|---------------------|----------------------------------|
| Mammals | 16.55 | 83.45 | 6.0 | 13.91 |
| Pilosa | 8.99 | 91.01 | 5.0 | 18.20 |
| Cingulata | 18.37 | 81.63 | 3.0 | 27.21 |
| Carnivora | 36.99 | 63.01 | 3.0 | 21.00 |
| Rodentia | 20.49 | 79.51 | 2.0 | 39.76 |
| Birds | 15.65 | 84.35 | 3.0 | 28.12 |
| Columbiformes | 4.89 | 95.11 | 4.0 | 23.78 |
| Cuculiformes + Caprimulgiformes | 4.61 | 95.39 | 1.0 | 95.39 |
| Reptiles | 2.00 | 98.00 | 3.0 | 32.67 |
| <i>Tamandua tetradactyla</i> | 3.79 | 96.21 | 5.0 | 19.24 |
| <i>Dasyurus novemcinctus</i> | 16.44 | 83.56 | 5.0 | 16.71 |
| <i>Euphractus sexcinctus</i> | 8.85 | 91.15 | 5.0 | 18.23 |
| <i>Chrysocyon brachyurus</i> | 18.69 | 81.31 | 2.0 | 40.66 |
| <i>Conepatus semistriatus</i> | 1.86 | 98.14 | 2.0 | 49.07 |

| | | | | |
|----------------------------------|-------|-------|-----|-------|
| <i>Procyon cancrivorus</i> | 28.67 | 71.33 | 4.0 | 17.83 |
| <i>Hydrochoerus hydrochaeris</i> | 21.67 | 78.33 | 2.0 | 39.17 |
| <i>Coragyps atratus</i> | 0.55 | 99.45 | 4.0 | 24.86 |
| <i>Cariama cristata</i> | 5.06 | 94.94 | 2.0 | 47.47 |

* In order to understand the importance of the “abundance” variable, we present the median percent contribution of landscape variables (the sum of all the percent contribution divided by the number of variables in the model).

Siriema software X Landscape Models

Siriema hotspots had a higher roadkill probability for nine groups (out of thirteen) (Fig. 2, Table S1) and a higher roadkill number for eleven groups (Fig. 3, Table S1). In general, Siriema hotspots protect 3.8 times more than uniformly distributed hotspots (Table 7). Landscape hotspots had a higher roadkill number (eleven) (Fig. 4, Table S1) and cover 2.8 times more specimens than uniformly distributed hotspots. Just for Reptiles, Siriema hotspots were moderately correlated to landscape hotspots (Figure 5, Table S2).

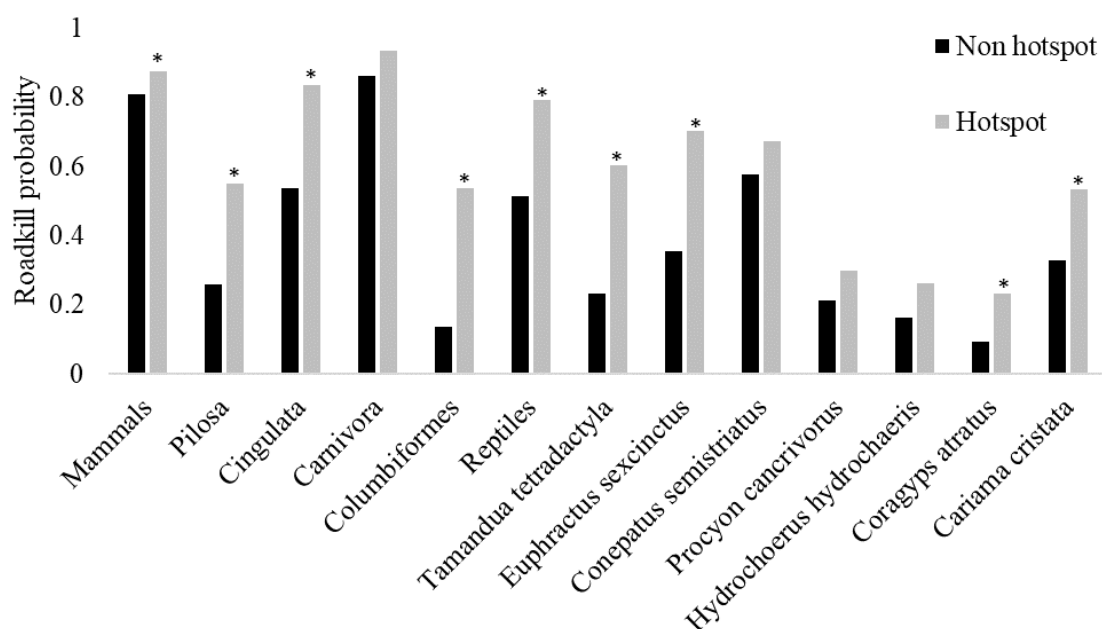


Fig. 2 Roadkill probability for hotspots and non-hotspots stretches defined by the software Siriema, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). The asterisk means significant difference.

Table 6 Spearman correlation between the roadkill probabilities of the landscape models, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| | Mammals | Pilosa | Cingulata | Carnivora | Rodentia | Birds | Columbiformes | Cuculiformes + Caprimulgiformes | Reptiles |
|------------------------------------|---------|---------|-----------|-----------|----------|---------|---------------|------------------------------------|----------|
| Pilosa | 0.51** | | | | | | | | |
| Cingulata | 0.75** | -0.04 | | | | | | | |
| Carnivora | 0.19 | 0.46** | 0.13 | | | | | | |
| Rodentia | 0.10 | 0.30* | -0.21* | -0.49** | | | | | |
| Birds | 0.08 | -0.07 | 0.03 | -0.53** | 0.81** | | | | |
| Columbiformes | -0.63** | -0.53** | -0.46** | -0.67** | 0.23* | 0.29* | | | |
| Cuculiformes + Caprimulgiformes | -0.39** | -0.44** | -0.38** | -0.9** | 0.55** | 0.6** | 0.73** | | |
| Reptiles | 0.31* | 0.70** | 0.06 | 0.67** | -0.17 | -0.51** | -0.62** | -0.79** | |
| <i>T. tetradactyla</i> | 0.39** | 0.96** | -0.15 | 0.52** | 0.27* | -0.06 | -0.53** | -0.46** | 0.69* |
| <i>D. novemcinctus</i> | 0.26* | -0.02 | 0.15 | -0.53** | 0.26* | 0.03 | 0.08 | 0.35** | -0.03 |
| <i>E. sexcinctus</i> | 0.54** | -0.18 | 0.87** | 0.3* | -0.35** | 0.03 | -0.51** | -0.47** | 0.02 |
| <i>C. brachyurus</i> | 0.66** | 0.23* | 0.73** | 0.36** | -0.35** | -0.37** | -0.43** | -0.6** | 0.43* |
| <i>C. semistriatus</i> | 0.47** | 0.29* | 0.58** | 0.81** | -0.62** | -0.56** | -0.69** | -0.96** | 0.65* |
| <i>P. cancrivorus</i> | 0.36** | 0.09 | 0.42** | 0.19 | -0.02 | 0.13 | -0.28** | -0.1 | -0.15 |
| <i>H. hydrochaeris</i> | 0.13 | 0.35** | -0.19 | -0.45** | 0.99** | 0.8** | 0.19 | 0.51** | -0.13 |
| <i>C. atratus</i> | -0.25* | 0.32* | -0.48** | -0.06 | 0.58** | 0.31* | 0.23* | 0.19 | 0.15 |
| <i>Cariama cristata</i> | -0.20 | 0.18 | -0.45** | -0.07 | 0.34** | 0.15 | -0.16 | 0.26* | 0.01 |

* $p \leq 0.05$; ** $p \leq 0.001$

Table 6 cont.

| | <i>Tamandua tetradactyla</i> | <i>Dasypus novemcinctus</i> | <i>Euphractus sexcinctus</i> | <i>Chrysocyon brachyurus</i> | <i>Conepatus semistriatus</i> | <i>Procyon cancrivorus</i> | <i>Hydrochoerus hydrochaeris</i> | <i>Coragyps atratus</i> |
|------------------------|----------------------------------|---------------------------------|----------------------------------|----------------------------------|-----------------------------------|--------------------------------|--------------------------------------|-----------------------------|
| <i>D. novemcinctus</i> | -0.18 | | | | | | | |
| <i>E. sexcinctus</i> | -0.17 | -0.2 | | | | | | |
| <i>C. brachyurus</i> | 0.06 | 0.21* | 0.49** | | | | | |
| <i>C. semistriatus</i> | 0.28* | -0.29* | 0.63** | 0.73** | | | | |
| <i>P. cancrivorus</i> | -0.05 | -0.14 | 0.3* | 0.39** | 0.21* | | | |
| <i>H. hydrochaeris</i> | 0.32* | 0.25* | -0.33** | -0.33** | -0.58** | -0.02 | | |
| <i>C. atratus</i> | 0.32* | -0.01 | -0.56** | -0.25* | -0.32** | -0.04 | 0.59** | |
| <i>C. cristata</i> | 0.24* | 0.16 | -0.35** | -0.55** | -0.42** | -0.14 | 0.33** | 0.2 |

* $p \leq 0.05$; ** $p \leq 0.001$

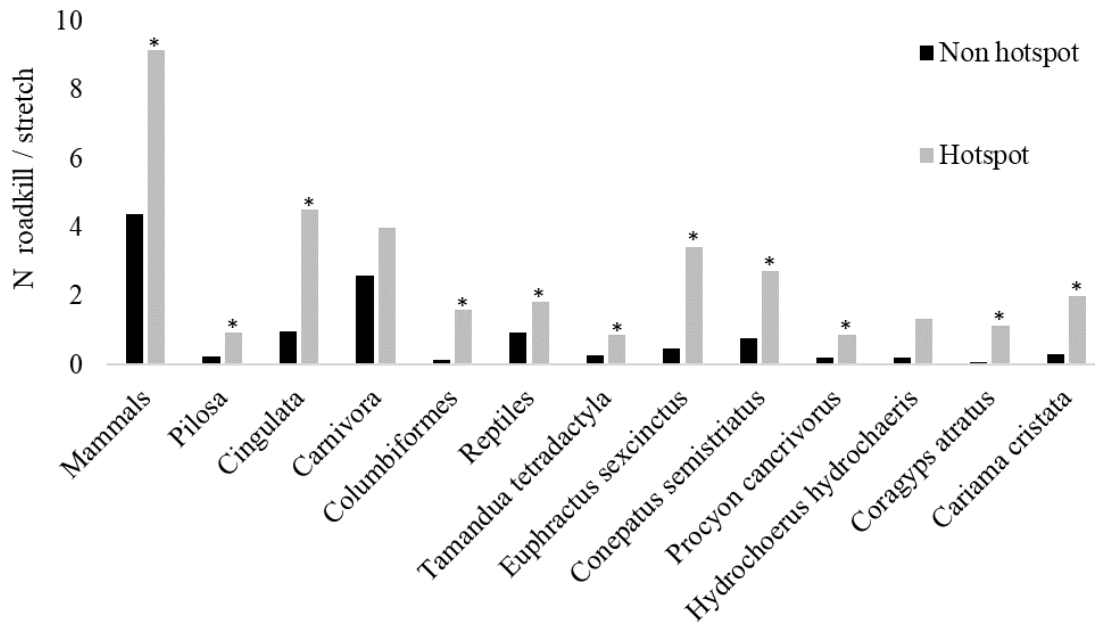


Fig. 3 Number of roadkilled animals for hotspots and non-hotspots stretches defined by the Siriema program, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). The asterisk means significant difference.

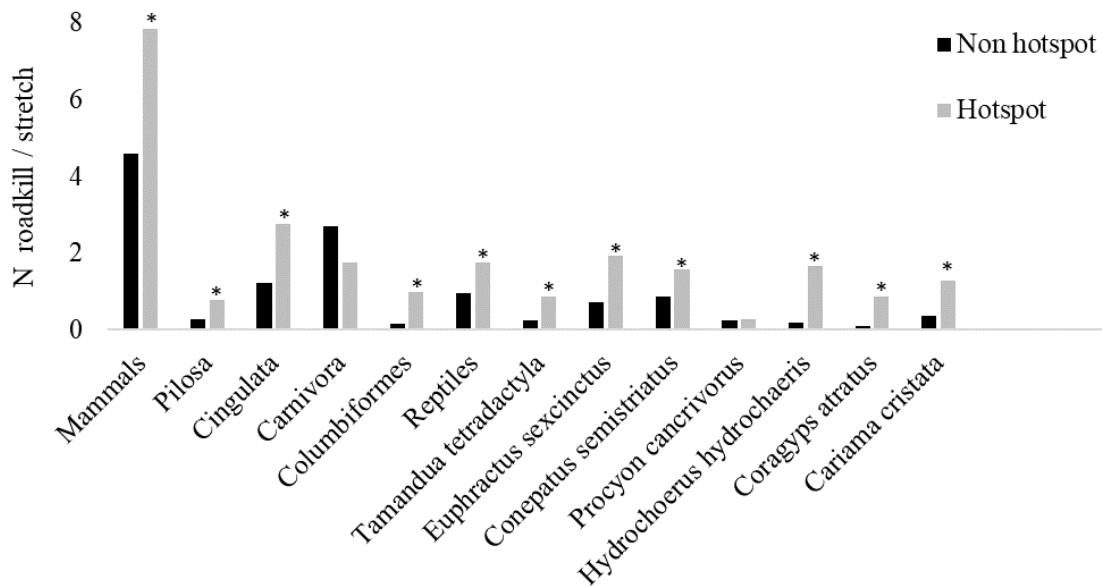


Fig. 4 Number of roadkilled animals for hotspots and non-hotspots stretches defined by the landscape models, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). The asterisk means significant difference.

Table 7 Number of roadkill for Siriema and Landscape hotspots and their relation to uniformly distributed hotspots, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| | A | B | C | D | E | F | G | H | I |
|----------------------------------|-----|----|-----|----|------|------|------|------|------|
| Mammals | 110 | 94 | 479 | 12 | 4.99 | 9.17 | 7.83 | 1.84 | 1.57 |
| Pilosa | 13 | 11 | 34 | 14 | 0.35 | 0.93 | 0.79 | 2.62 | 2.22 |
| Cingulata | 54 | 33 | 135 | 12 | 1.41 | 4.50 | 2.75 | 3.20 | 1.96 |
| Carnivora | 16 | 7 | 255 | 4 | 2.66 | 4.00 | 1.75 | 1.51 | 0.66 |
| Columbiformes | 8 | 5 | 20 | 5 | 0.21 | 1.60 | 1.00 | 7.68 | 4.80 |
| Reptiles | 24 | 23 | 102 | 13 | 1.06 | 1.85 | 1.77 | 1.74 | 1.67 |
| <i>Tamandua tetradactyla</i> | 6 | 6 | 29 | 7 | 0.30 | 0.86 | 0.86 | 2.84 | 2.84 |
| <i>Euphractus sexcinctus</i> | 48 | 27 | 86 | 14 | 0.90 | 3.43 | 1.93 | 3.83 | 2.15 |
| <i>Conepatus semistriatus</i> | 19 | 11 | 89 | 7 | 0.93 | 2.71 | 1.57 | 2.93 | 1.70 |
| <i>Procyon cancrivorus</i> | 6 | 2 | 23 | 7 | 0.24 | 0.86 | 0.29 | 3.58 | 1.19 |
| <i>Hydrochoerus hydrochaeris</i> | 4 | 5 | 22 | 3 | 0.23 | 1.33 | 1.67 | 5.82 | 7.27 |
| <i>Coragyps atratus</i> | 9 | 7 | 15 | 8 | 0.16 | 1.13 | 0.88 | 7.20 | 5.60 |
| <i>Cariama cristata</i> | 14 | 9 | 41 | 7 | 0.43 | 2.00 | 1.29 | 4.68 | 3.01 |

A= number of roadkills for Siriema hotspots; B= number of roadkills for Landscape models; C= total number of roadkills; D= number of stretches identified as hotspots by the Siriema program; E= number of roadkill per stretch if roadkills are uniformly distributed; F=number of roadkills per stretch for Siriema hotspots (A/D); G= number of roadkills per stretch for landscape models (B/D); H= relation between the number of roadkills per stretch for Siriema hotspots and the number of roadkills per stretch if roadkills are uniformly distributed (F/E); I= relation between the number of roadkills per stretch for landscape hotspots and the number of roadkills per stretch if roadkills are uniformly distributed (G/E).

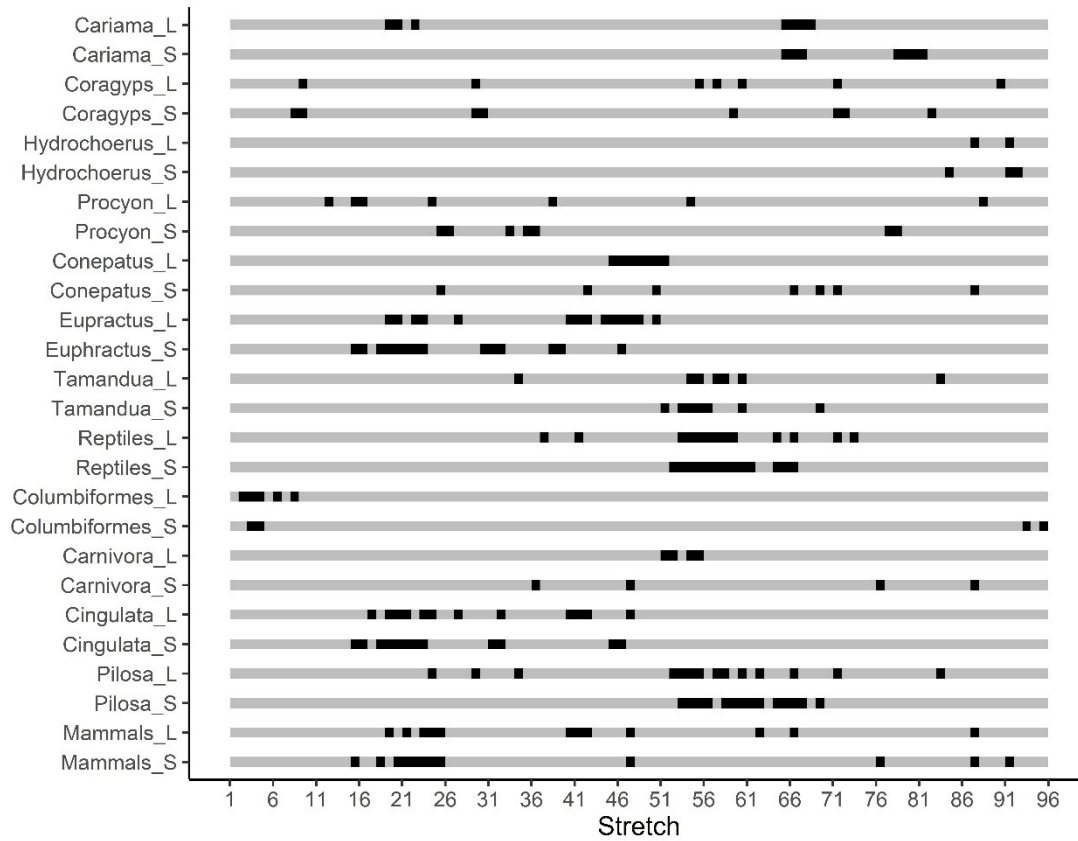


Fig. 5 Roadkill hotspots (in black) location defined by the two different methods, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). The methods used to localize the hotspots were: the 2D HotSpot Identification from the Siriema program (identified with a S after the name of the class/order/species) and the landscape models (identified with a L after the name of the class/order/species).

Discussion

Almost half of the road is a Siriema hotspot for mammals. Ascensão et al. (2017) localized 12% of the road as a hotspot, just 2% of them belonging to more than one species. It is important that a hotspot protect as many species as possible, though, it is very difficult. That is why, the class Mammals do not represent well the mammal orders and species since only 27% and 23% of the hotspots overlap, respectively. On the other hand, the orders Pilosa and Cingulata encompass a significant amount of its species hotspots, overlapping 40% and 73% respectively. The order Carnivora, however, include just 20% of its species hotspots. Carnivora is a much more diverse group with 33 species, Pilosa and Cingulata group just eight and eleven species, respectively (Paglia et al. 2012). As Brazilian Cerrado is very diverse with 251 species, 51 of them weighing more than one kilogram, it is impossible to investigate roadkill hotspots for all of them. Furthermore, just some species have higher roadkill records, many of them having just a few individuals killed in accidents.

The similarity between roadkill probabilities shows the same patterns of Siriema hotspots. The class Mammals do not represent well the mammal species, since the roadkill probability of just two species (out of seven) is moderately correlated to the class Mammals. In contrast, the roadkill probability of the orders Pilosa, Cingulata and Rodentia are strongly correlated to its species. The order Carnivora is not correlated to all its species. Therefore, we think that hotspots should be investigated for the orders Pilosa, Cingulata and Rodentia, but for Carnivora, it might be necessary to investigate the hotspots location at family level.

Just 33% of the birds showed Siriema roadkill hotspots, we think it may be a result of the big number of birds species (856 species in Cerrado biome (Sawyer et al. 2016), which leads to a greater diversity of behaviors and responses to landscape and road characteristics. It may seem obvious but we must remember that birds are an animal group adapted to flight and although some species are constantly exploring the ground, such adaptations are an important advantage in terms of the chances of escaping from road accidents (Kociolek and Grilo 2015). The same result is observed for landscape hotspots, birds class/orders and species are not correlated either.

It seems that roadkill hotspots location changes from one year to the other, what is a huge problem, since most of the environmental licensing studies consider just one year (Ministério do Meio Ambiente 2013). Roadkill hotspots might not indicate the best locations for mitigation of road mortality when past roadkill has depressed population (Eberhardt et al. 2013). However, it depends on three assumptions, road segments should have different traffic volumes, habitat around the low and high-traffic road segments to maintain a population without the effect of road mortality, the spatial extent of the road needs to be large relative to the spatial extent of populations (Teixeira et al. 2017). As we do not have different traffic volumes in the stretch analyzed, we do not think that the roadkill hotspots do not indicate the best sites to mitigate roadkill. In addition, a two-years analyzes seem to be able to encompass roadkill hotspots of the two years separately. Therefore, longer studies are necessary to address if roadkill hotspots changes over a longer period.

Differently from the expected, the “abundance” variable was not of big importance in our models. Ascensão et al. (2017) and Santos et al. (2013) identified the “abundance” variable as one of the most important one. Furthermore, the “landscape + abundance” models are not different from the “landscape” ones. Therefore, we opted by the “landscape” models as they could be used for planning mitigation measures for roads that are still being built (Gunson and Teixeira 2015).

Usually, roadkill hotspots have great potential at reducing roadkill. For example, Santos et al. (2017) showed that 5–10% mitigation of the road could potentially result in an avoidance of 20–50% of casualties for amphibians, reptiles or mammals. Gonçalves et al. (2018) concluded that 45% of reptile deaths could be avoided if 21.7% of the segments of the road had been mitigated, a twofold efficiency in a cost-benefit relationship. In general, our results also demonstrate a good cost-benefit relation, mitigating 9% of the road would protect 31% of the specimens for Siriema hotspots and 22% for landscape hotspots.

Siriema and landscape hotspots in general present a low correlation. Probably, the hotspots identified using the Siriema software reflect the interaction between road and landscape characteristics, so it may indicate where animals crossed the road and died in a two-years period. Alternatively, landscape models represent the stretches where animals potentially will cross the road and be killed. That is why, the definition of roadkill hotspots

should not rely only on wildlife vehicle collision (Gunson and Teixeira 2015) but should also consider the landscape cover and land use.

After defining the stretches of a road with higher roadkill probabilities, it is necessary to implement the mitigation measures. For vertebrates, mitigation measures as under and over-passes along with fences seem to be the better alternative (Rytwinski et al. 2016). Besides of preventing roadkill, this type of measures also reduces the barrier effect of the road, reconnecting animal populations and restoring ecological processes (Smith et al. 2015). Despite of the importance of correctly identifying roadkill hotspots, many questions still need an answer, like: how many crossing structures should be built; how far apart; how should be its structure (length and width) (Rytwinski et al. 2015). In addition, the answer to these questions will depend on the group analyzed. As example, for birds and bats, as they fly, structures that force these animals to fly higher and bigger crossing structures seem to be the better alternative (Abbott et al. 2015; Kociolek and Grilo 2015).

It seems that Siriema software is a better alternative in relation to cost/benefits, although landscape models also present a good result. On the other hand, landscape models were able to identify hotspots for 1.4 times more species/groups than the Siriema software. Landscape models still have one more advantage, it is not necessary to have wildlife-vehicle collision data to identify the stretches of the highway with higher roadkill probability (Gunson and Teixeira 2015; Teixeira et al. 2016). As models do not need data on wildlife-vehicle collision, road ecologists need to start exploring more this alternative instead of considering just hotspots defined based on roadkill location.

Acknowledgements This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. We acknowledge the Institute of Biology from the Federal University of Uberlândia for providing our transport to collect the data. We thank the Climatological Station of the Federal University of Uberlândia (UFU), Brazil, for providing the climate data. We especially thank the field surveyors who collected the field data and to the reviewers.

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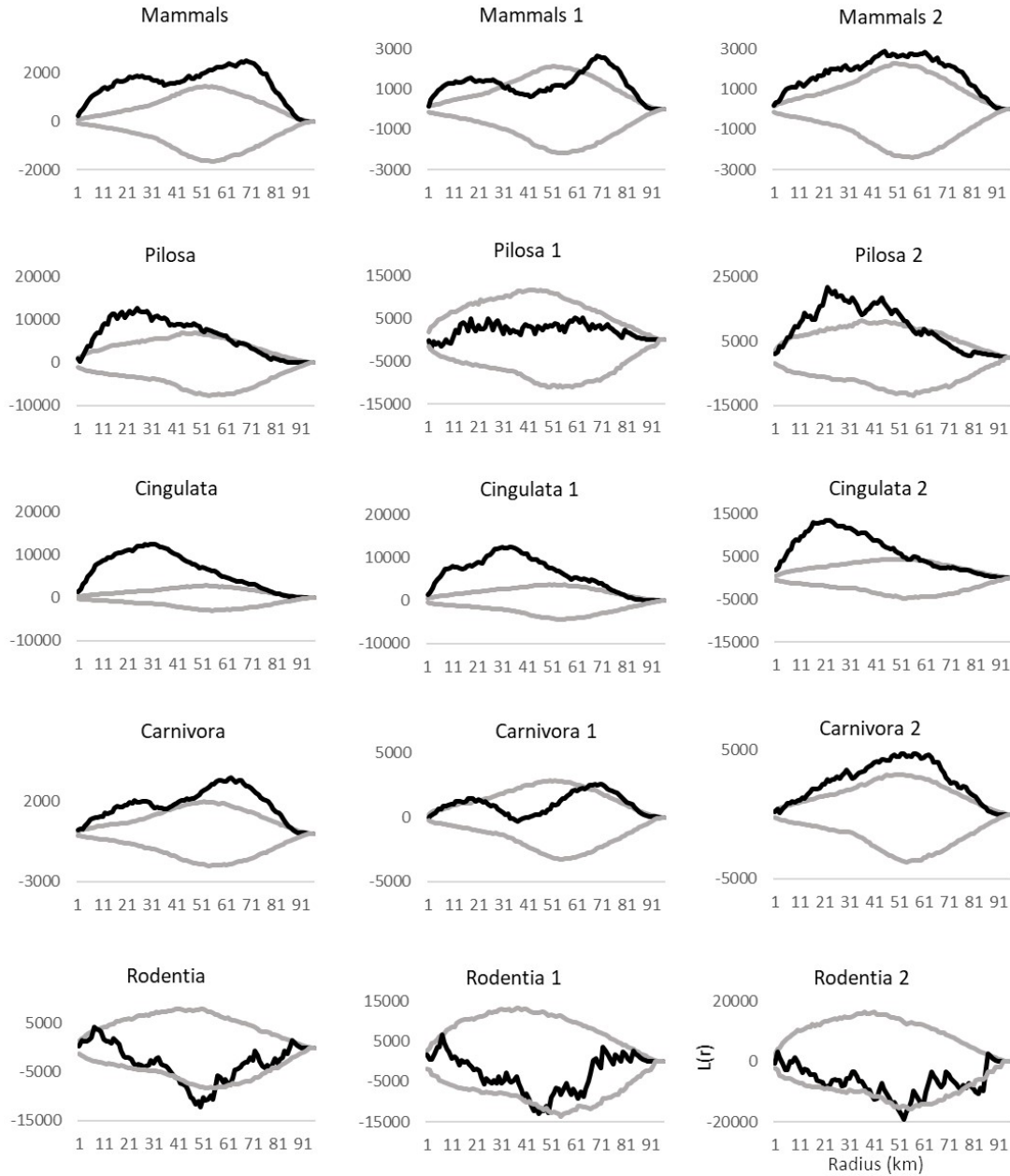


Fig. S1 Roadkill aggregation according to an increasing radius on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). The aggregation is demonstrated by the curve $L(r)$ (black line), which values above the confidence limits (gray lines) indicate significant aggregation and values below these thresholds indicate significant dispersion (Coelho et al. 2014). The numbers one and two after a class/order/species name means that the results are displayed considering the data of the first or the second year of monitoring, respectively. When no number is after a class/order/species name, it means that the data of both years were analyzed together.

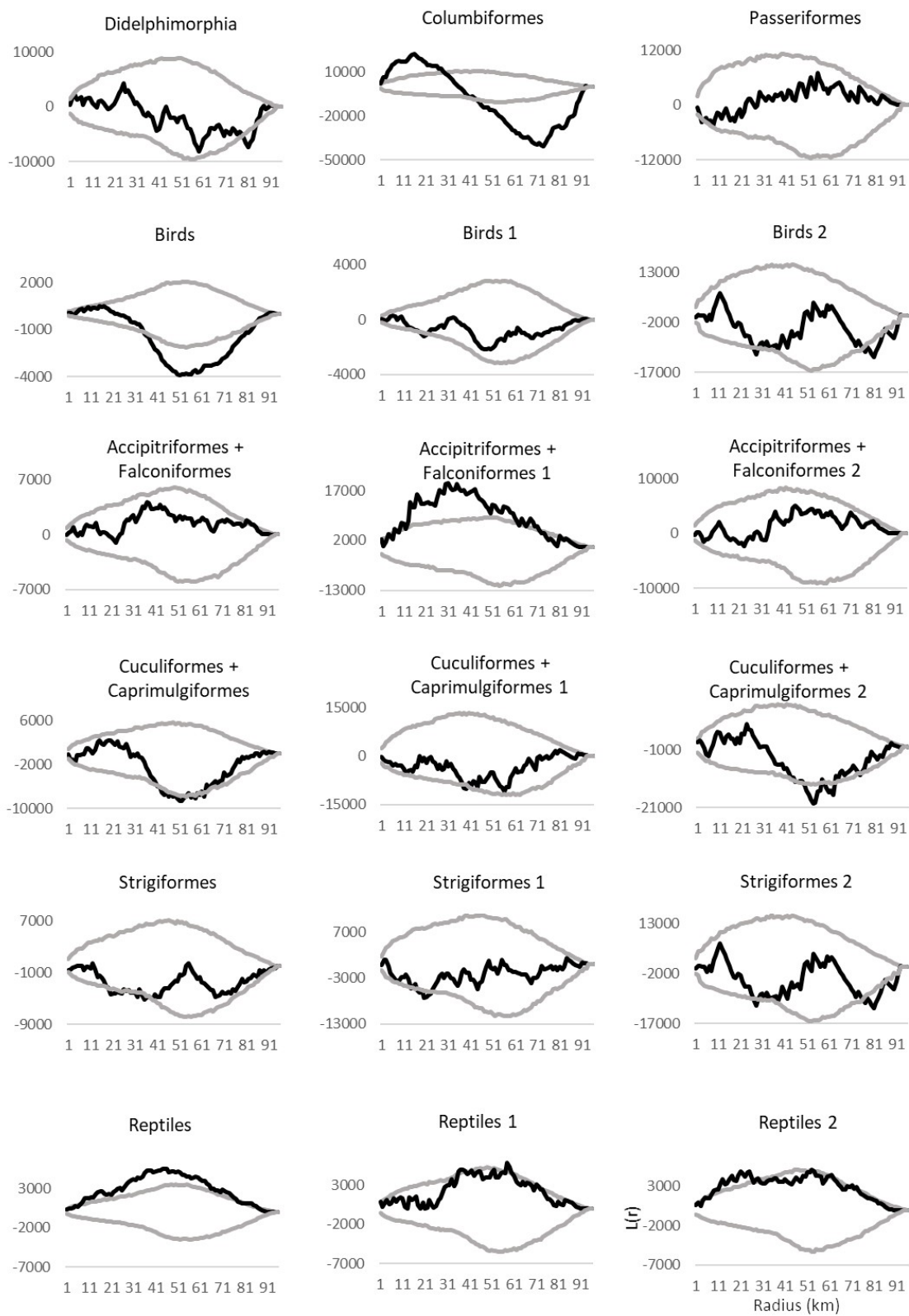


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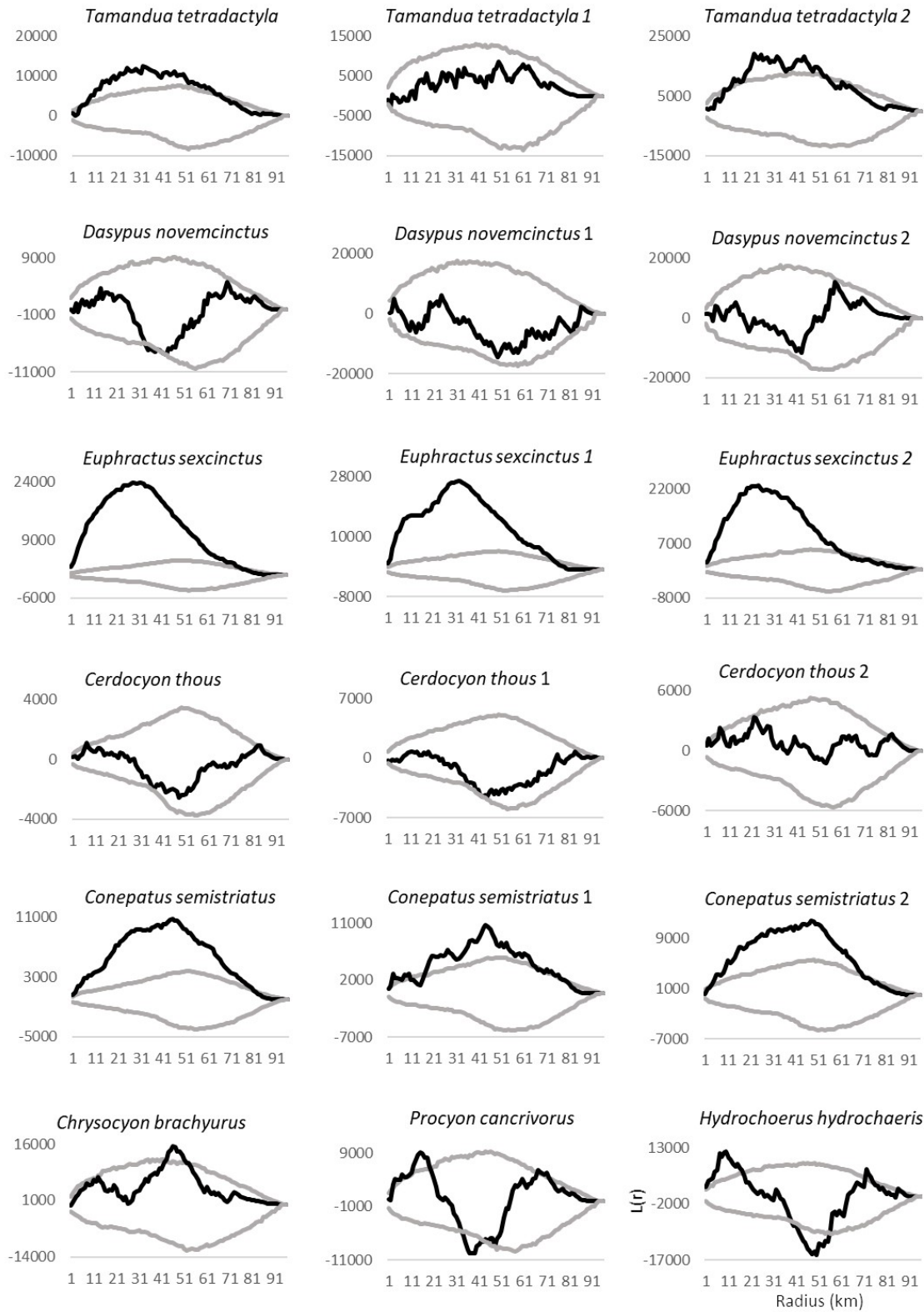


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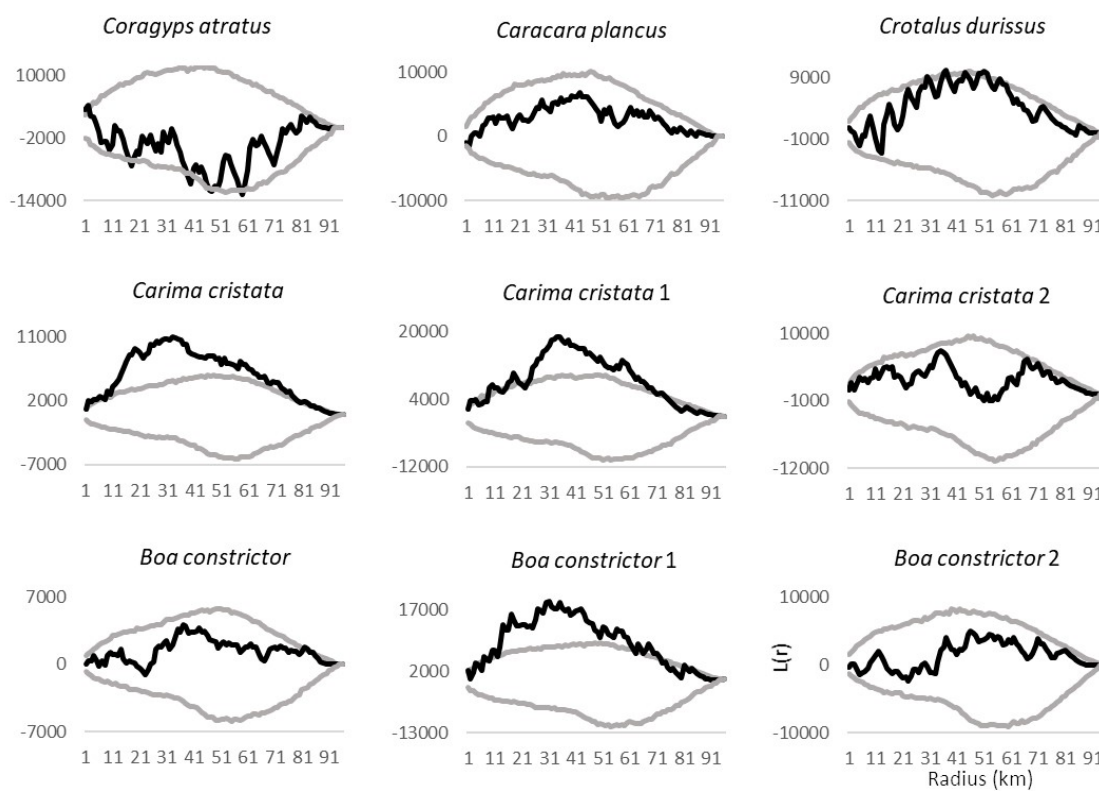


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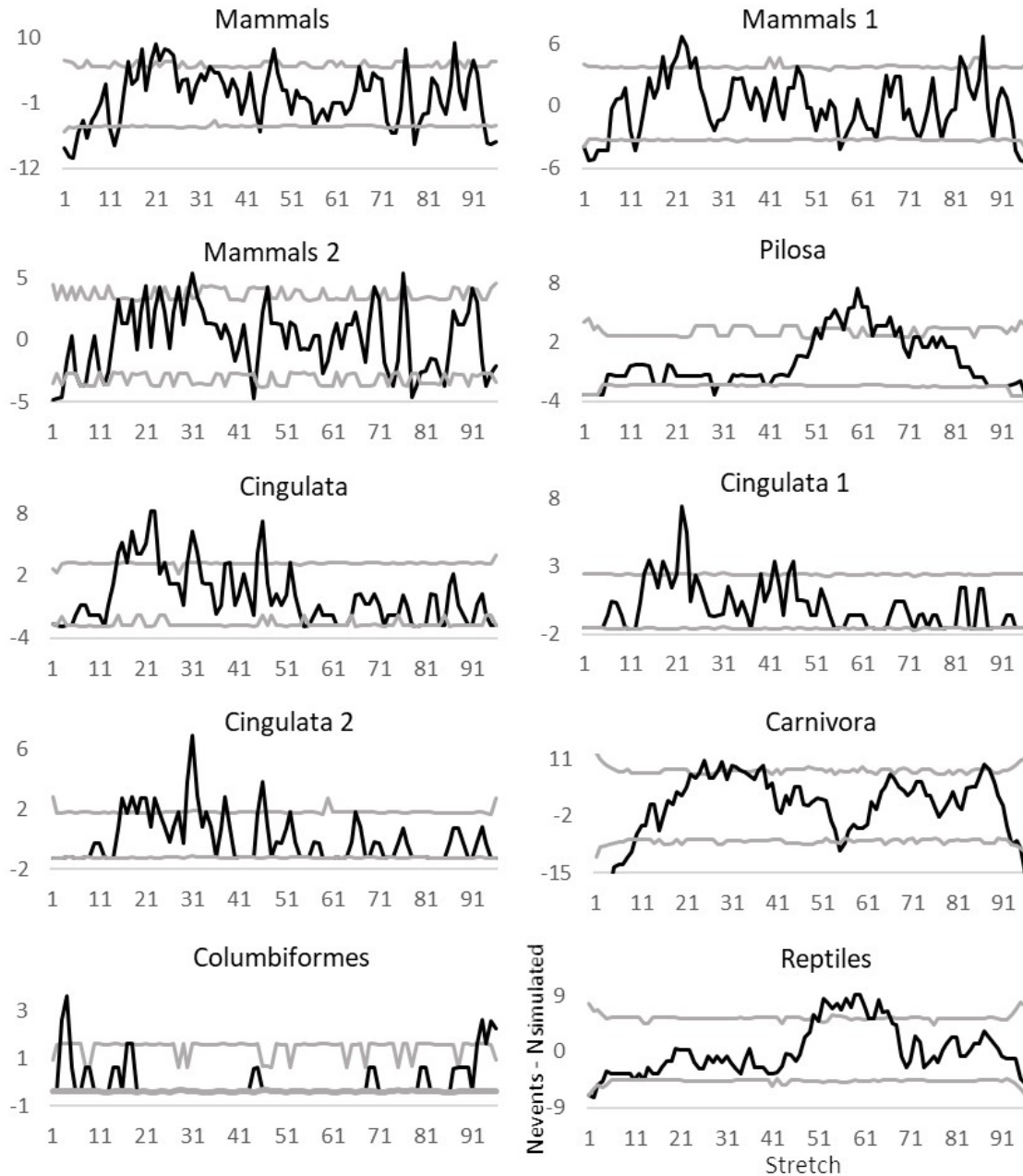


Fig. S2 Roadkill aggregation location on BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014). Black line- HS values; gray lines- upper and lower confidence limits. HS values above confidence limits indicate stretches with significant aggregation intensity (Coelho et al. 2014). The numbers one and two after a class/order/species name means that the results are displayed considering the data of the first or the second year of monitoring, respectively. When no number is after a class/order/species name, it means that the data of both years were analyzed together.

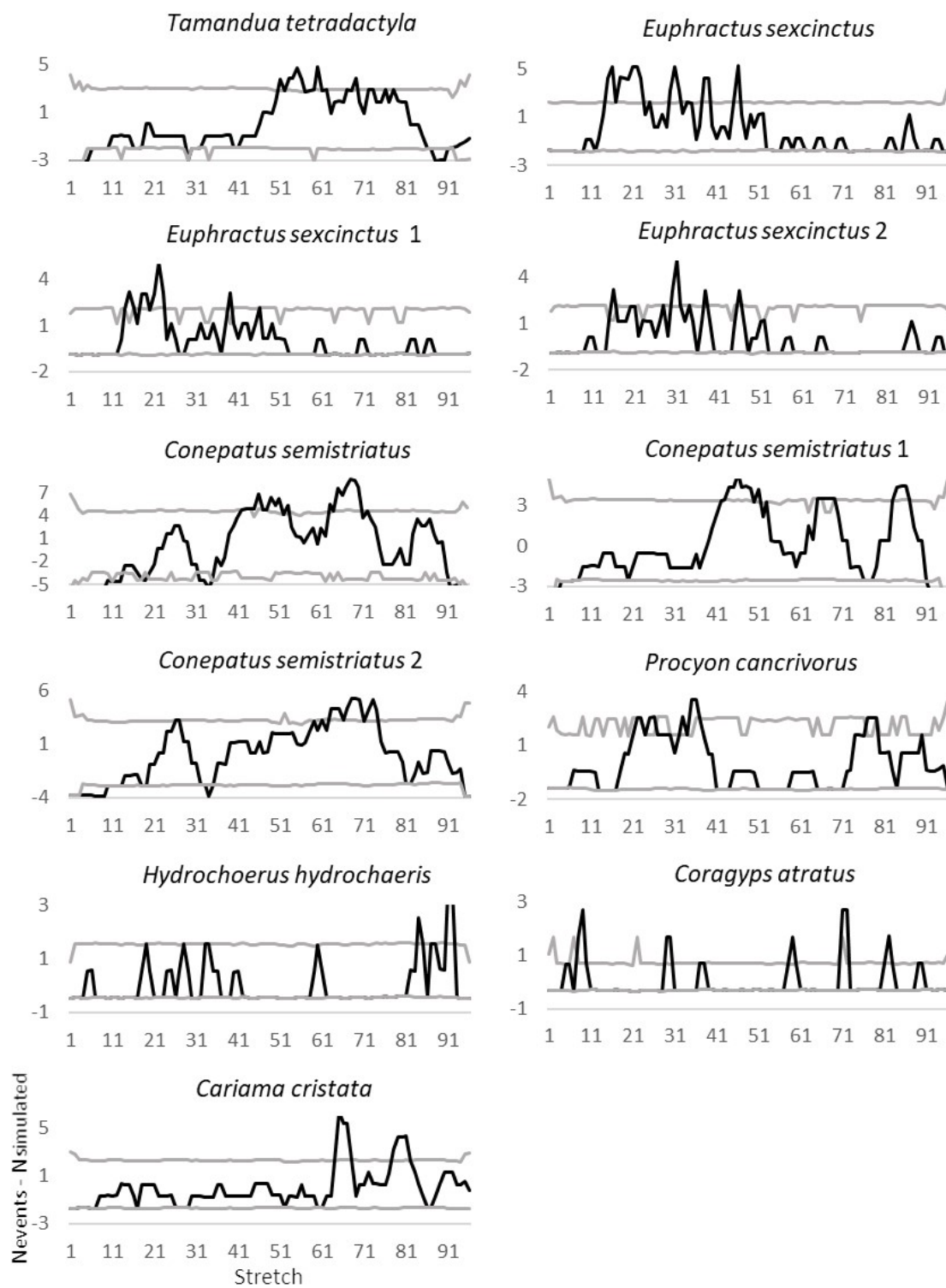


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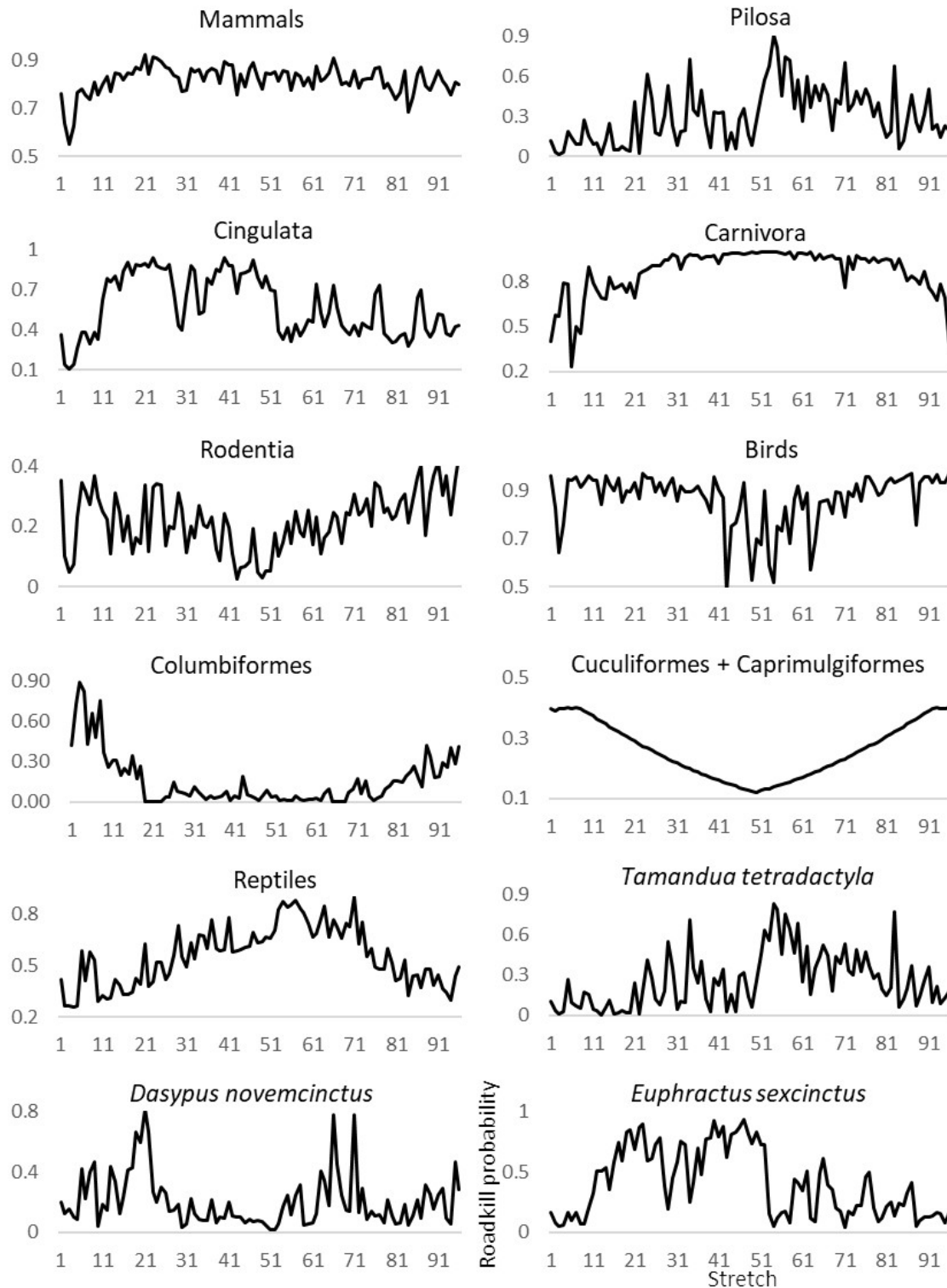


Fig. S3 Roadkill probability according to the stretch analyzed, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

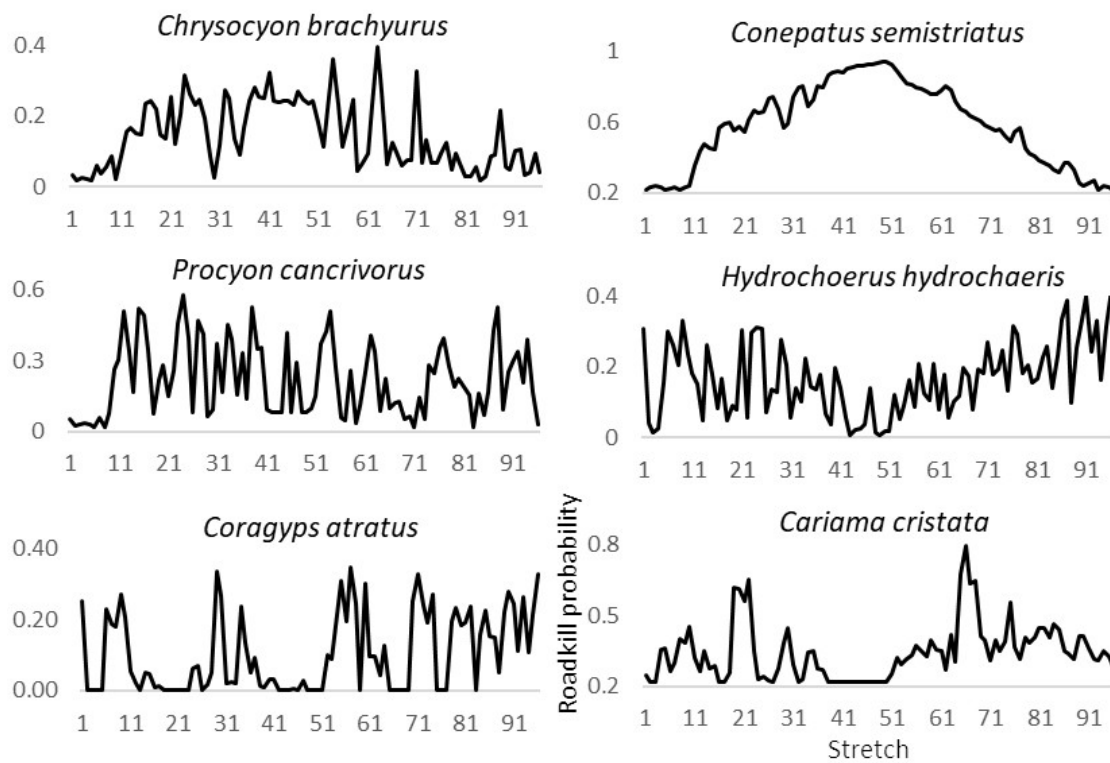


Fig. S3 cont.

Table S1 Results of the Mann–Whitney U test along with its probabilities (p) for the analysis of: A - roadkill probability for Siriema hotspots and non hotspots stretches (Fig. 1); B - number of roadkill for Siriema hotspots and non hotspots stretches (Fig. 2); C - Number of roadkill for Landscape hotspots and non hotspots stretches (Fig. 3).

| | A | | B | | C | |
|----------------------------------|------------------------|------|------------------------|------|------------------------|------|
| | Mann–Whitney U test | p | Mann–Whitney U test | p | Mann–Whitney U test | p |
| Mammals | 131.00 | 0.00 | 85.00 | 0.00 | 214.00 | 0.00 |
| Pilosa | 139.00 | 0.00 | 319.00 | 0.00 | 379.00 | 0.01 |
| Cingulata | 125.00 | 0.00 | 61.50 | 0.00 | 253.00 | 0.00 |
| Carnivora | 139.00 | 0.41 | 98.00 | 0.11 | 235.00 | 0.35 |
| Columbiformes | 37.00 | 0.00 | 53.00 | 0.00 | 113.50 | 0.00 |
| Reptiles | 53.00 | 0.00 | 344.50 | 0.03 | 363.00 | 0.05 |
| <i>Tamandua tetradactyla</i> | 46.00 | 0.00 | 190.00 | 0.03 | 190.00 | 0.03 |
| <i>Euphractus sexcinctus</i> | 180.00 | 0.00 | 47.50 | 0.00 | 322.50 | 0.00 |
| <i>Conepatus semistriatus</i> | 237.00 | 0.30 | 75.00 | 0.00 | 166.00 | 0.03 |
| <i>Procyon cancrivorus</i> | 208.00 | 0.15 | 139.50 | 0.00 | 291.00 | 0.69 |
| <i>Hydrochoerus hydrochaeris</i> | 74.00 | 0.17 | 108.00 | 0.31 | 62.00 | 0.01 |
| <i>Coragyps atratus</i> | 136.00 | 0.00 | 188.00 | 0.00 | 192.50 | 0.00 |
| <i>Cariama cristata</i> | 67.00 | 0.00 | 28.50 | 0.00 | 165.00 | 0.01 |

Table S2 Phi correlation between the hotspots defined by the Siriema program and by landscape models, BR-050 highway, Uberlândia-Uberaba stretch, Cerrado biome, Brazil (2012-2014).

| Group/species | r _{Phi} | p |
|----------------------------------|------------------|--------|
| Mammals | 0.43 | <0.001 |
| Pilosa | 0.41 | <0.001 |
| Cingulata | 0.33 | 0.001 |
| Carnivora | 0.04 | 1.00 |
| Columbiformes | 0.37 | 0.02 |
| Reptiles | 0.64 | <0.001 |
| <i>Tamandua tetradactyla</i> | 0.38 | 0.01 |
| <i>Euphractus excinctus</i> | 0.25 | 0.03 |
| <i>Conepatus semistriatus</i> | 0.08 | 0.42 |
| <i>Procyon cancrivorus</i> | 0.08 | 1.00 |
| <i>Hydrochoerus hydrochaeris</i> | 0.31 | 0.09 |
| <i>Coragyps atratus</i> | 0.32 | 0.02 |
| <i>Cariama cristata</i> | 0.38 | 0.01 |

Capítulo 3

How species-specific characteristics influence mammal roadkill in Cerrado biome, Brazil?⁴

⁴ A formação dessa seção obedece parcialmente às normas do periódico *Perspectives in Ecology and Conservation*.

How species-specific characteristics influence mammal roadkill in Cerrado biome, Brazil?

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Highlights

- How species-specific characteristics influence roadkill are an issue overlooked in Road Ecology.
- We consulted scientific researches to calculate a roadkill rate for the Cerrado species.
- Roadkill rate increases as population density, home range and weaning decrease and body mass increases.
- Scavenger and territorial mammals have a higher roadkill rate, those that prefer forest habitats have a lower one.
- The predicted mammal roadkill rate was 1.35 ind./km/year and 181 909 mammals could die each year.

ABSTRACT

Different factors influence roadkill, as species life history, landscape and climate. Species-specific characteristics that influence roadkill are an issue overlooked in Road Ecology. Thus, this study aimed to determine the species-specific characteristics that influence roadkill and calculate the roadkill rate for each species within its geographical distribution in Cerrado biome. We searched scientific publications to calculate a roadkill rate for the Cerrado species. From the 51 species selected, 32 were killed in car accidents (62.7%) and 19 (37.3%) were not. Eighteen species (35.3%) are endangered in Brazil, from these, half (9, 17.6%) were not identified as roadkill. Roadkill rate increases as population density, home range and weaning decrease and body mass increases. Animals that feed on carcass and territorial have higher roadkill rates. Mammals that prefer forest habitat have lower roadkill rates. The predicted

mammal roadkill rate was 1.35 ind./km/year, 25% higher than the empirical one, the mean roadkill rate per species was 0.03 ind./km/year and 181 909 animals could die each year. We believe a special attention must be taken to the species with a higher roadkill rate even if they are considered common ones and to the endangered species even with small roadkill rates.

Keywords

Life history; Road Ecology; wildlife-vehicle collision; species-level predictions; road mortality risk; species trait.

Introduction

Roads usually negatively affect the environment (Coffin, 2007; Forman and Alexander, 1998; van der Ree et al., 2015) being the wildlife roadkill the effect with a greater number of researches (Ascensão et al., 2017; Clevenger et al., 2003; D'Amico et al., 2015; Grilo et al., 2016). Different factors influence roadkill, as species life history, landscape and climate. While identifying landscape (Ascensão et al., 2017; Bueno et al., 2015; Clevenger et al., 2003; D'Amico et al., 2015) and climate influences (Carvalho et al., 2017; D'Amico et al., 2015; Garriga et al., 2017) on roadkill are an objective in many researches, species-specific characteristics that influence roadkill are an issue overlooked in Road Ecology (D'Amico et al., 2015) with just some researches, most of them performed in the last few years (D'Amico et al., 2015; Ford and Fahrig, 2007; Rytwinski and Fahrig, 2015, 2012), just one in Brazil (González-Suárez et al., 2018).

In general, mammals negatively affected by roads are larger, more mobile species with lower reproductive rates, and species that avoid roads (Rytwinski and Fahrig, 2015). Carnivores are particularly susceptible to the impacts of roads because many species require large areas to sustain their populations, have low reproductive output and occur in low densities (Grilo et al., 2015). In addition, carnivores with large home ranges, long dispersal distances or inability to tolerate human disturbance are particularly vulnerable to the effects of roads and traffic. The bat species most likely to be affected by roads are the small, slow-

flying, forest-adapted ones (Abbott et al., 2015). For arboreal animals, the danger lies in the behavior of crossing the road (Laurance et al., 2009). The previous researchers (Abbott et al., 2015; Grilo et al., 2015; Rytwinski and Fahrig, 2015) investigated general patterns showing that species-specific characteristics can explain roadkill risk, however to build wider models it is necessary to evaluate ecological, behavioral and life-history traits for as many species as possible (González-Suárez et al., 2018).

Besides, many species are not detected during roadkill monitorings, probably because of low densities, small body masses and detectability problems related to methodology (Santos et al., 2011; Teixeira et al., 2013). The solution for this problem would be the understanding of the species-specific characteristics that influence roadkill enabling to calculate a roadkill rate even for the species that were not identified killed during a roadkill monitoring (González-Suárez et al., 2018). Furthermore, it would be possible to have an idea about how roadkill is influencing the survival of rare species.

Additionally, the problem of roadkill seems to be more dangerous on Tropical countries (Laurance et al., 2009). Brazil is one of the countries from South America that is leading Road Ecology researches (Bager et al., 2015). The most recent estimate points that 475 million animals die due to wildlife vehicle collisions in this country (Centro Brasileiro de Ecologia de Estradas, 2017). This number can be aggravated, because road paving and upgrading have received huge investments in the last few years (Bager et al., 2015; Teixeira et al., 2016).

Cerrado biome, a biodiversity hotspot for conservation (Myers et al., 2000) is suffering with this developing process that Brazil is experiencing in the last years. While Brazil was lowering Amazon deforestation, Cerrado has lost 46% of its native vegetation cover, as little as 19.8% remains undisturbed and 31–34% of the remaining Cerrado is likely to be cleared by 2050 (Strassburg et al., 2017). By this same year, if no attitude is made towards preserving Cerrado, 1 140 species of plants and animals will be extinct. Therefore, immediate measures are necessary to preserve what we still have left from Cerrado.

Concerning to Road Ecology, most studies done in Cerrado only monitor the species killed by a vehicle (Cunha et al., 2010; Gomes et al., 2013; Neto et al., 2015; Prado et al., 2006; Santos et al., 2014; Vieira et al., 2012), with few studies aiming to something

more than this (Ascensão et al., 2017; Carvalho et al., 2015; Santos et al., 2017). This study aimed to determine the species-specific characteristics that influence roadkill and calculate the roadkill rate for each species within its geographical distribution in Cerrado biome.

Material and Methods

Study Area

Cerrado biome has more than 2 045 000 km², 21% of Brazil extension, the second biggest Brazilian biome (Klink and Machado, 2005) (Fig. 1). Cerrado comprises 14 443 species of plants and animals, 4 641 (32.2%) of them are endemic and at least 901 of them are in Brazilian Red List (Sawyer et al., 2016). From the 251 species of mammals, 32 are exclusive of Cerrado biome (Paglia et al., 2012), for birds, 29 species are exclusive from 837 (Silva, 1995); for reptiles, 237 species are listed for this biome (Costa et al., 2007). The climate is seasonal, wet and hot from October to March and dry and cold from April to September, with temperatures ranging from 22° to 27° C, average annual rainfall is 1500 mm (Klink and Machado, 2005).

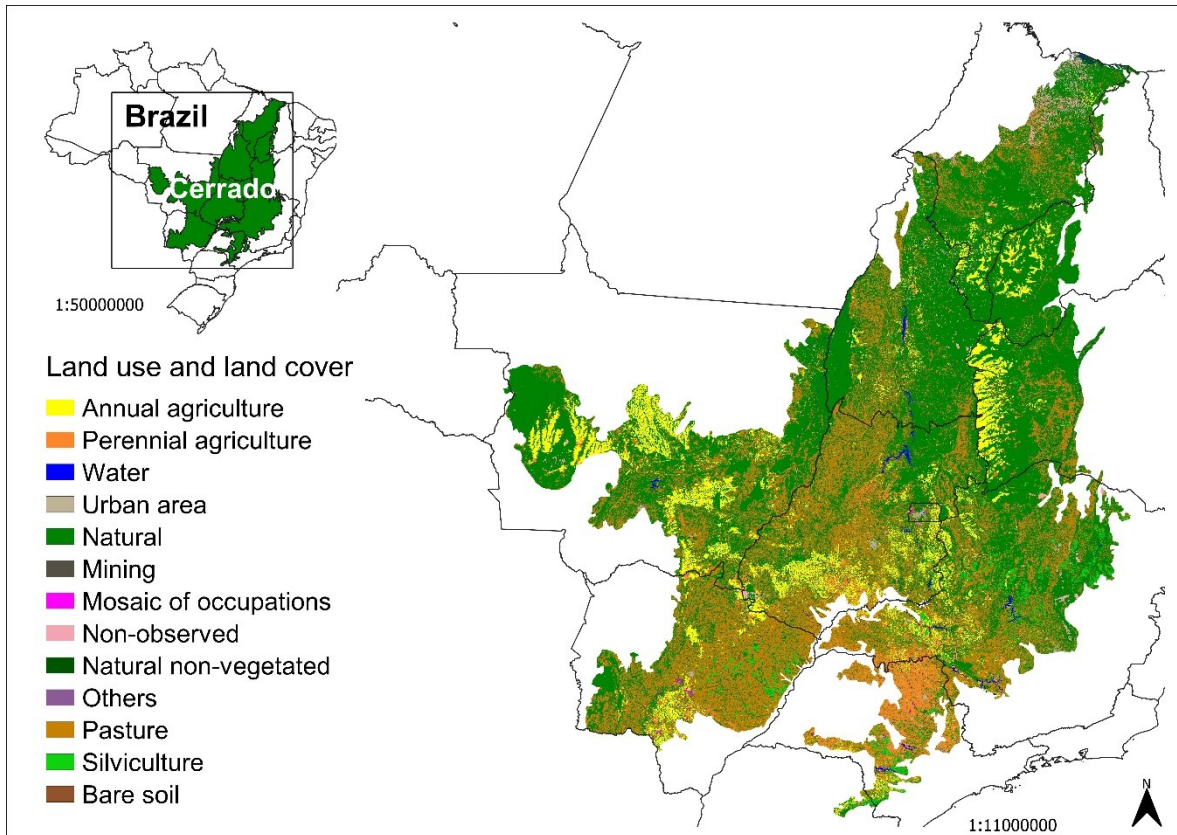


Fig. 1. Cerrado distribution in Brazil highlighting its land cover and land use. Source: Ministério do Meio Ambiente, 2015.

Procedures

We searched for scientific studies, as articles, thesis (doctoral, masters' and graduation ones) and reports approaching mammal roadkill published at any year. Through these publications we calculated a roadkill rate for the Cerrado mammal species. On Google Scholar we searched for the words: roadkill and Cerrado, road ecology and Cerrado, wildlife-vehicle collision and Cerrado, and these terms in Portuguese (atropelamento and Cerrado, ecologia de estradas and Cerrado, colisão de veículos com fauna silvestre and Cerrado). The inclusion criteria were: a weekly monitoring and sufficient data to calculate a roadkill/rate for each species (number of individuals killed for each species and total length of the highway monitored). From the twenty roadkill monitorings performed in Cerrado biome we

had asses, nine reached our criteria (Bagatini, 2006; Brum et al., 2018; Cáceres et al., 2012; Carvalho et al., 2015, 2014; Cunha et al., 2010; Freitas, 2009; Neto et al., 2015; Prada, 2004).

Because the mean speed of the researches analyzed was 50 km/h, it would be possible to detect casualties only above a certain size threshold that is why we opted to analyze just species with a body mass above 1 kg. From 251 Cerrado mammals species, 51 (20.3%) are above the mass threshold (Paglia et al., 2012). We selected life history descriptors that could influence the probability of a species to be killed by a vehicle, including a level of categorical abundance and descriptors of reproduction and behavior (Table 1, Table S1). When there was not information available about a species, we used the information available in the literature for another species from the same genus or family (Table S2).

Table 1

Definition and description of the descriptors used in the models.

| Descriptor name | Description |
|---|--|
| Abundance related descriptors | |
| Abundance | Common or rare |
| Home_range | Home range extension (ha) |
| Density | Population density (individuals/km ²) |
| Reproduction related descriptors | |
| Body_mass | Body mass (kg) |
| Offspring | Average number of offspring per breeding |
| Gestation | Gestation period (months) |
| Lifespan | Lifespan in captivity (years) |
| Sexual_maturity | Age at sexual maturity (months) |
| Weaning | Period that the cub is weaning on its mother (months) |
| Behavior related descriptors | |
| Diet | Carnivorous, insectivorous, herbivorous. omnivorous, frugivorous |
| Diet_breadth | Number of dietary categories eaten by each species: vertebrate; invertebrate; fruit; flowers, nectar, pollen; leaves, branches, bark; seeds; grass, roots, tubers. |
| Scavenger | Scavenger or not |
| Sociability | Social or not |
| Territoriality | Territorial or not |
| Movement | Terrestrial, arboreal, semiaquatic, semifossorial, aquatic |
| Speed | Fast or slow movement |
| Activity | Activity period: Nocturnal, diurnal or nocturnal and diurnal |
| Anthropic | Present in anthropic areas or not |
| Habitat | Habitat preference for: cerrado, forest, water or cerrado and forest |
| Water | Occurrence associated with water presence or not |

Data analysis

In order to understand the species-specific characteristics that influence roadkill and to predict the roadkill rate for the Cerrado species above the group-specific body mass thresholds, we ran GLMM analyses (data available on Table S3). Our response variable was the roadkill rate calculated as an average among the nine consulted researches. As most of the consulted researches performed weekly monitorings and because we calculated a roadkill rate just for species considered as medium to large size mammals, we assumed that their roadkill rate is in the scale of animals/km/week. Therefore, to get annually roadkill rates we multiplied the weekly rate by 52.14 (average number of weeks in a year). We used the MuMIn package in R, testing all the possible relations among the response and the predictor variables inside the group (abundance, reproduction and behavior related predictors; we excluded the variables abundance, stratum, sociability, water and diet.) (Barton, 2015). We used a Gamma distribution and a log link function, the random variable was the taxa family (Bates et al., 2015). Model selection was performed using Akaike Information Criterion (AIC), retaining all models within $\Delta AIC_c < 2$. We calculated AIC weights (wAIC) to compare the relative support of each model. The Relative Importance Weight (RIW) was reckoned for the variables to understand the importance of each one (RIW > 0.9, strong effect; 0.9-0.6, moderate; 0.6-0.5, weak). We used all the predictors that appeared in the best partial models to run a general model. To understand the variance explained by the model we used the function `r.squaredGLMM` from the package MuMIn (Barton, 2015). We selected the best general model based in the predictors that had the higher RIW. With the best general model, we ran a last GLMM to get the species roadkill rate.

To assess how many mammals die as a roadkill victim, we calculated the extension of highways inside each species distribution range for Cerrado and multiplied by its predicted roadkill rate. We used the distribution range available on IUCN (2017), for three species there was no distribution range data available, that is why it was not possible to calculate how many individuals die per year for these species (*Dasyprocta aurea*, *Dasyprocta nigriclunis* and *Myocastor coypus*).

Results

From the 51 species, 32 were killed in car accidents (62.7%) and 19 (37.3%) were not. Eighteen species (35.3%) are endangered in Brazil, from these, half (9, 17.6%) were not identified as roadkill.

Related to abundance models, roadkill rate increases as population density and home range decrease (Table 2, Figure 2). Weaning and body mass were the variables important in the reproduction models, the roadkill rate increases as body mass also increases and weaning decreases. The behavior models were compound by the descriptors carcass, habitat and territoriality. Animals that feed on carcass and territorial have higher roadkill rates. Mammals that prefer forest habitat have lower roadkill rates. Density, habitat, scavenger and territoriality were the variables from the general model chosen to reckon the roadkill rate for the Cerrado mammals species. Fixed effects were responsible for explaining 66% of the variance, the entire model, including fixed and random effects explained 90% of the variance.

Table 2

Species-specific characteristics that influence roadkill rate selected by ΔAIC (<2).

| Model | AIC | ΔAIC | Weight |
|---|--------|--------------|--------|
| Abundance related models | | | |
| Density | -180.5 | 0.00 | 0.50 |
| Density + Home | -179.6 | 0.88 | 0.32 |
| Reproduction related models | | | |
| Weaning | -181.0 | 0.00 | 0.17 |
| Body_mass + Weaning | -180.8 | 0.17 | 0.16 |
| Behavior related models | | | |
| Habitat + Scavenger + Territoriality | -206.4 | 0.00 | 0.33 |
| Habitat + Scavenger | -205.1 | 1.25 | 0.18 |
| Final model | | | |
| Habitat + Scavenger + Territoriality | -206.4 | 0.00 | 0.12 |
| Density + Habitat + Scavenger | -206.3 | 0.08 | 0.12 |
| Density + Habitat + Scavenger + Territoriality | -205.9 | 0.50 | 0.10 |
| Habitat + Home + Scavenger+ Territoriality | -205.8 | 0.61 | 0.09 |
| Habitat + Scavenger | -205.1 | 1.25 | 0.07 |
| Density + Habitat + Home + Scavenger + Territoriality | -205.1 | 1.34 | 0.06 |

AIC = Akaike Information Criterion; ΔAIC = difference between the AIC of a given model and that of the best model.

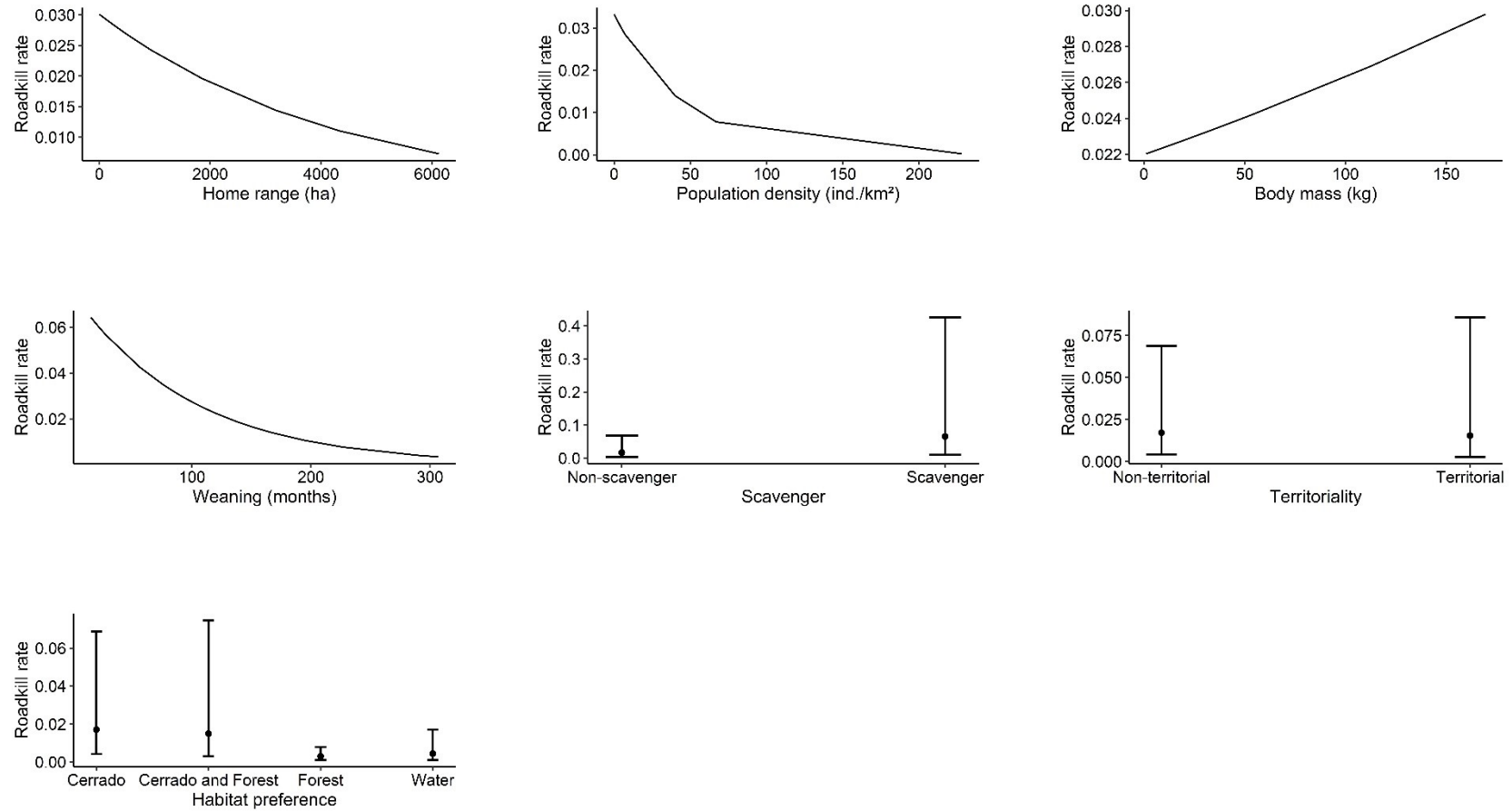


Fig. 2. Relation between the predicted roadkill probability and its predictors.

Eight mammal families had higher roadkill rates than the mean and nine had lower values, the mammal families Procyonidae, Didelphidae and Hydrochoeridae had higher roadkill rates and the families Cuniculidae, Cebidae and Cervidae had lower ones (Figure 3).

The predicted mammal roadkill rate was 1.35 ind./km/year, 25% higher than the empirical one, the mean roadkill rate per species was 0.03 ind./km/year (ranging from 0.37 to 0.0003) and 181 909 animals could die each year. The median endangered species roadkill rate was 0.012 ind./km/year, for the not endangered species this rate was 0.034 ind./km/year, nevertheless this rates were not statistically different ($U=277$, $p=0.70$). Almost half of the roadkill species (15) had a predicted roadkill rate higher than the empirical one.

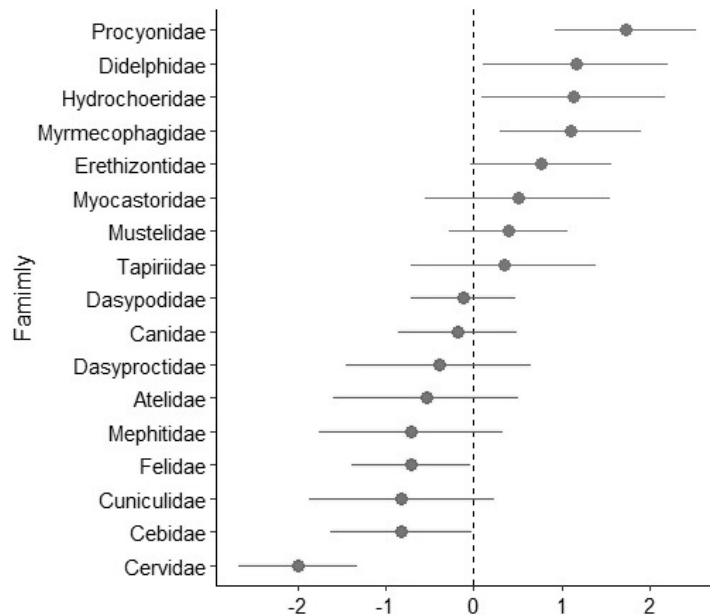


Fig. 3. Relationship between the Family that a species belongs and their roadkill rate. The dotted line represents the neutral effect, families to the left of it have a lower roadkill rate than the mean and those to the right of it, a higher one.

Table 3

Species selected from Cerrado biome highlighting if they were observed as a roadkill or not (R), empirical and predicted roadkill rate (RK), road extension within each species distribution range area, empirical and predicted annual death and their conservation status in Brazil. Species are sorted by their predicted roadkill rate.

| Species | R | Empirical RK/year | Predicted RK/year | Road extension ¹ | Empirical Annual death | Predicted Annual death | Brazil ² |
|----------------------------------|-----|----------------------|----------------------|--------------------------------|------------------------------|------------------------------|---------------------|
| <i>Cerdocyon thous</i> | Yes | 0.2149 | 0.3689 | 170657 | 36668 | 62952 | LC |
| <i>Tolypeutes matacus</i> | No | 0.0000 | 0.1936 | 3251 | 0 | 629 | LC |
| <i>Euphractus sexcinctus</i> | Yes | 0.3008 | 0.1754 | 176369 | 53058 | 30927 | LC |
| <i>Conepatus semistriatus</i> | Yes | 0.0668 | 0.0954 | 107785 | 7198 | 10286 | LC |
| <i>Dasypus novemcinctus</i> | Yes | 0.0507 | 0.0612 | 176369 | 8935 | 10787 | LC |
| <i>Myrmecophaga tridactyla</i> | Yes | 0.0704 | 0.0568 | 172564 | 12144 | 9796 | VU |
| <i>Didelphis albiventris</i> | Yes | 0.0694 | 0.0466 | 168075 | 11659 | 7834 | LC |
| <i>Tamandua tetradactyla</i> | Yes | 0.0547 | 0.0448 | 176369 | 9653 | 7897 | LC |
| <i>Chrysocyon brachyurus</i> | Yes | 0.0214 | 0.0356 | 155065 | 3311 | 5526 | VU |
| <i>Lycalopex vetulus</i> | Yes | 0.0611 | 0.0352 | 129892 | 7942 | 4566 | VU |
| <i>Pecari tajacu</i> | No | 0.0000 | 0.0317 | 176369 | 0 | 5587 | LC |
| <i>Priodontes maximus</i> | No | 0.0000 | 0.0311 | 119163 | 0 | 3702 | VU |
| <i>Dasypus septemcinctus</i> | Yes | 0.0047 | 0.0169 | 176169 | 828 | 2986 | LC |
| <i>Nasua nasua</i> | Yes | 0.0149 | 0.0160 | 165639 | 2468 | 2656 | LC |
| <i>Hydrochoerus hydrochaeris</i> | Yes | 0.0212 | 0.0144 | 176372 | 3741 | 2534 | LC |
| <i>Pteronura brasiliensis</i> | No | 0.0000 | 0.0112 | 43487 | 0 | 486 | VU |
| <i>Procyon cancrivorus</i> | Yes | 0.0195 | 0.0108 | 176369 | 3435 | 1909 | LC |
| <i>Leopardus colocolo</i> | No | 0.0000 | 0.0106 | 61707 | 0 | 655 | VU |
| <i>Conepatus chinga</i> | No | 0.0000 | 0.0098 | 21723 | 0 | 214 | LC |
| <i>Puma yagouaroundi</i> | Yes | 0.0049 | 0.0073 | 176369 | 867 | 1291 | VU |
| <i>Coendou prehensilis</i> | Yes | 0.0085 | 0.0062 | 176369 | 1501 | 1086 | LC |
| <i>Coendou spinosus</i> | Yes | 0.0058 | 0.0062 | 20701 | 120 | 127 | LC |
| <i>Blastocerus dichotomus</i> | Yes | 0.0072 | 0.0058 | 7984 | 58 | 46 | VU |
| <i>Galictis vittata</i> | Yes | 0.0074 | 0.0044 | 80922 | 601 | 360 | LC |
| <i>Eira barbara</i> | Yes | 0.0043 | 0.0044 | 174925 | 758 | 776 | LC |
| <i>Tapirus terrestris</i> | Yes | 0.0048 | 0.0042 | 173347 | 835 | 730 | VU |
| <i>Panthera onca</i> | No | 0.0000 | 0.0037 | 88074 | 0 | 326 | VU |
| <i>Potos flavus</i> | No | 0.0000 | 0.0033 | 168334 | 0 | 561 | LC |
| <i>Puma concolor</i> | Yes | 0.0012 | 0.0033 | 176369 | 214 | 576 | VU |
| <i>Tayassu pecari</i> | No | 0.0000 | 0.0031 | 174822 | 0 | 537 | VU |
| <i>Lontra longicaudis</i> | Yes | 0.0016 | 0.0031 | 176369 | 282 | 542 | LC |
| <i>Cabassous tatouay</i> | No | 0.0000 | 0.0030 | 101727 | 0 | 304 | LC |
| <i>Callicebus nigrifrons</i> | No | 0.0000 | 0.0029 | 29975 | 0 | 88 | LC |
| <i>Sapajus cay</i> | Yes | 0.0042 | 0.0029 | 10045 | 42 | 29 | VU |
| <i>Tolypeutes tricinctus</i> | No | 0.0000 | 0.0029 | 30420 | 0 | 87 | EM |

| | | | | | | | |
|-------------------------------|-----|--------|--------|--------|--------|--------|----|
| <i>Speothos venaticus</i> | No | 0.0000 | 0.0028 | 153600 | 0 | 432 | VU |
| <i>Cabassous unicinctus</i> | Yes | 0.0030 | 0.0026 | 161027 | 478 | 425 | LC |
| <i>Ozotoceros bezoarticus</i> | Yes | 0.0011 | 0.0024 | 11509 | 12 | 28 | VU |
| <i>Alouatta caraya</i> | Yes | 0.0013 | 0.0017 | 137524 | 183 | 237 | LC |
| <i>Leopardus tigrinus</i> | No | 0.0000 | 0.0017 | 101965 | 0 | 169 | EM |
| <i>Leopardus wiedii</i> | No | 0.0000 | 0.0017 | 168963 | 0 | 279 | VU |
| <i>Leopardus pardalis</i> | Yes | 0.0024 | 0.0015 | 176369 | 426 | 257 | LC |
| <i>Dasyprocta azarae</i> | Yes | 0.0011 | 0.0013 | 123388 | 130 | 156 | LC |
| <i>Sapajus libidinosus</i> | Yes | 0.0002 | 0.0012 | 136700 | 33 | 164 | LC |
| <i>Cuniculus paca</i> | Yes | 0.0006 | 0.0009 | 176237 | 107 | 164 | LC |
| <i>Mazama gouazoubira</i> | Yes | 0.0004 | 0.0009 | 125749 | 53 | 109 | LC |
| <i>Dasyprocta aurea</i> | No | 0.0000 | 0.0006 | 0* | - | - | LC |
| <i>Dasyprocta nigriclunis</i> | No | 0.0000 | 0.0006 | 0* | - | - | LC |
| <i>Dasyprocta prymnolopha</i> | No | 0.0000 | 0.0006 | 52666 | 0 | 32 | LC |
| <i>Mazama americana</i> | No | 0.0000 | 0.0005 | 126895 | 0 | 58 | LC |
| <i>Myocastor coypus</i> | Yes | 0.0004 | 0.0003 | 0* | - | - | LC |
| Total | | 1.0310 | 1.3539 | 176372 | 167741 | 181909 | |

¹ Road extension calculated for each species according to its distribution range for Cerrado biome, available in IUCN, 2017.

² Conservation status assessed in ICMBio, 2016.

* Species that no distribution range data was available

Discussion

Many species-specific characteristics influence mammal roadkill rates. González-Suárez et al. (2018), analyzing Brazilian mammals also concluded that higher roadkill rates are associated with smaller home range sizes, bigger body masses and scavenging behavior. In addition, early maturity was also an important descriptor in these authors' research. Although we also added sexual maturity in our model, we identified as an important variable related to reproduction the weaning period, probably because longer parental care during weaning decrease roadkill probability. Another descriptor important in that publication is habitat generalism, variable we could not assess as we focus on one biome.

Other researches also have found larger body mass as an important variable in determining roadkill vulnerability (Ford and Fahrig, 2007; Rytwinski and Fahrig, 2015, 2012). Usually, mammal populations with low density and bigger home ranges are negatively affected by roadkill (Fahrig and Rytwinski, 2009; Rytwinski and Fahrig, 2015, 2012). All the above researches have analyzed just a few descriptors, only González-

Suárez et al. (2018) and our research have assessed more than ten. This may indicate that many species-specific characteristics influence roadkill probability highlighting the importance of more complex analyzes involving a broad range of features.

Some of the descriptors we analyzed that were important, were not investigated by the other researches as weaning period, territoriality and habitat. Territorial animals have a higher roadkill probability possibly because they must move more to revisit territorial boundaries frequently and refresh its own scent marks in order to deter possible intruders (Giuggioli et al., 2011). Forest habitats presumably provide more resources than Cerrado habitat, then mammals move less in this habitat than in Cerrado consequently decreasing their roadkill probability.

Considering just empirical researches, we wouldn't know how 37.3% of the medium and large size mammals are being affected by roadkill. As endangered species are rare and therefore difficult to observe, this paper would help to understand if roadkill is a risk for endangered species. The addition of these species was responsible to raise the predicted roadkill rate in 25%, what demonstrate how empirical researches are underestimated. Anyway, we must consider that our predicted roadkill rate is also underestimated, because the publications we consulted were performed weekly, by car at about 50 km/h (Santos et al., 2011; Teixeira et al., 2013). González-Suárez et al. (2018) in an attempt to correct this bias applied a correction index to the roadkill rate and predicted values among 0.02 to 1.08 ind./km/year and 2 225 101 mammals could die on Brazilian roads. Considering that González-Suárez et al. (2018) analyzed 12 times more species and the whole country instead of just Cerrado biome, the number of 181 909 we predicted can be considered similar to that of those authors. On the other hand, the number of mammals that dies on Brazilian Cerrado highways are overestimated, because we considered that there are wildlife populations spread continuously through the whole Cerrado, which we know is far away from the true. Thus, a more realistic number would have to consider where there is still a population and the highway extension inside it.

The difference among the families with higher and lower roadkill rates reflect on the conservation status of them: just one species from the families with higher roadkill rates is endangered, on the other hand, most of the species from families with lower roadkill rates are endangered. *Cerdocyon thous* (crab-eating fox) was the species with higher roadkill rates. Fortunately, this species is not endangered in Brazil. However, it was found killed in all nine consulted researches, other researches also verified *C. thous*

as the most killed one in Brazil (Dornas et al., 2012; González-Suárez et al., 2018; Grilo et al., 2018). All these indicates that more attention should be driven to this species, since in a single year 62 952 individuals could possibly die. The second species with a higher roadkill rate was the *Tolypeutes matacus* (Southern three-banded armadillo), species not found killed in any of the nine researches we had assessed. Although, we must consider that a small part of its distribution range encompasses the Cerrado biome (Reis et al., 2016) and just two publications were performed in this area (Brum et al., 2018; Carvalho et al., 2014). *Euphractus sexcinctus* (yellow armadillo) was the third species with higher roadkill rate, not being listed in only one consulted research. Even though this species is not in the Brazilian Red List, the 30 927 annual deaths can represent a huge loss of individuals. *Myrmecophaga tridactyla* (giant anteater) was observed killed in eight researches and from all the endangered species from Brazil, this is the one with a higher roadkill rate. Diniz & Brito (2013) concluded that with just 0.05 of a population affected (eight individuals) by roadkill within 30 years a population would go extinct, when this number is 0.15 (25 individuals) the population would persist during not even ten years. Therefore, it seems that the conservation of *Myrmecophaga tridactyla* can be in great risk due to roadkill.

Unfortunately, we still do not know how roadkill is affecting species because in Brazil it lacks basic information about many species. We identified species that possibly have a higher roadkill rate, however, a question still remains: can roads and/or traffic reduce or even eliminate a population, and how? (Rytwinski and Fahrig, 2015). Another important step is identify where within their geographical ranges species are expected to be affected by roads and also which regions have more species vulnerable to roads (Ceia-Hasse et al., 2017). This kind of knowledge will enable to build mitigation measures that protect as much species and individuals as possible (Lesbarrères and Fahrig, 2012).

We believe a special attention must be taken to the species with a higher roadkill rate even if they are considered common species as *Cerdocyon thous*, *Euphractus sexcinctus* and *Conepatus semistriatus*. Obviously, endangered species are of great concern because the loss of some individuals can represent a big loss for the whole community, therefore even species with small roadkill rates could be in risk due to roadkill (Rytwinski and Fahrig, 2015). For example, it is estimated that the Brazilian population of *Chrysocyon brachyurus* was composed of 21 746 individuals (Paula et al.,

2008) that would represent a loss of 25% of its population in a single year even with a roadkill rate of 0.04 ind./km/year. Finally, as we used actual roadkill monitorings, these data are subject to a series of bias and must be explored and interpret carefully (González-Suárez et al., 2018), more specific studies must be taken specially for species with a small body mass.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES, Finance Code 001). We acknowledge the Institute of Biology from the Federal University of Uberlândia for providing our transport to collect the data. We thank the Climatological Station of the Federal University of Uberlândia (UFU), Brazil, for providing the climate data. We especially thank the field surveyors who collected the field data and to the reviewers.

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Table S1

Bibliography used to asses species-specific characteristics. For all species we consulted Myers et al., (2018), Tacutu et al., (2018) and Reis et al. (2010).

| Species | Bibliography used |
|----------------------------------|--|
| <i>Alouatta caraya</i> | Ludwig et al., 2015 |
| <i>Blastocerus dichotomus</i> | Duarte et al., 2012a |
| <i>Cabassous tatouay</i> | Anacleto et al., 2015b |
| <i>Cabassous unicinctus</i> | Anacleto et al., 2015a |
| <i>Callicebus nigrifrons</i> | Melo et al., 2015 |
| <i>Cerdocyon thous</i> | Beisiegel et al., 2013; Trovati, Brito, and Duarte, 2007 |
| <i>Chrysocyon brachyurus</i> | Paula et al. (2013) |
| <i>Coendou prehensilis</i> | Faria and Giné, 2010 |
| <i>Coendou spinosus</i> | Faria and Giné, 2010 |
| <i>Conepatus chinga</i> | Kasper et al., 2013b, 2012 |
| <i>Conepatus semistriatus</i> | Cavalcanti et al., 2013; Kasper et al. 2012 |
| <i>Cuniculus paca</i> | Beck-king et al., (1999) |
| <i>Dasyprocta aurea</i> | - |
| <i>Dasyprocta azarae</i> | - |
| <i>Dasyprocta nigrichunis</i> | - |
| <i>Dasyprocta prymnolopha</i> | Sousa, 2010 |
| <i>Dasypus novemcinctus</i> | Silva et al., 2015 |
| <i>Dasypus septemcinctus</i> | Faria-Corrêa et al., 2015 |
| <i>Didelphis albiventris</i> | Sanches et al., 2012 |
| <i>Eira barbara</i> | Rodrigues, Pontes, and Rocha-Campos, 2013 |
| <i>Euphractus sexcinctus</i> | Silva, Jociel Ferrira Costa, et al., 2015 |
| <i>Galictis vittata</i> | Kasper et al., 2013a |
| <i>Hydrochoerus hydrochaeris</i> | Herrera and Macdonald, 1989; Vargas et al., 2007 |
| <i>Leopardus colocolo</i> | Queirolo et al., 2013 |
| <i>Leopardus pardalis</i> | Oliveira, Almeida, and Campos, 2013 |
| <i>Leopardus tigrinus</i> | Oliveira et al., 2013a |
| <i>Leopardus wiedii</i> | Tortato et al., 2013 |
| <i>Lontra longicaudis</i> | Rodrigues et al., 2013 |
| <i>Lycalopex vetulus</i> | Lemos et al., 2013 |
| <i>Mazama americana</i> | Duarte et al., 2012b |
| <i>Mazama gouazoubira</i> | Duarte et al., 2012c |
| <i>Myocastor coypus</i> | - |
| <i>Myrmecophaga tridactyla</i> | Miranda et al., 2015 |
| <i>Nasua nasua</i> | Beisiegel and Campos, 2013; Trovati, Brito, and Duarte, 2010 |
| <i>Ozotoceros bezoarticus</i> | Duarte et al., 2012d; Tomas et al., 2012; Versiani, 2011 |
| <i>Panthera onca</i> | Morato et al., 2013 |

| | |
|-------------------------------|--|
| <i>Pecari tajacu</i> | Desbiez et al., 2012 |
| <i>Potos flavus</i> | Sampaio et al., 2013 |
| <i>Prionomys maximus</i> | Aya-Cuero et al., 2017; Chiarello et al., 2015 |
| <i>Procyon cancrivorus</i> | Cheida, Guimarães, and Beisiegel, 2013 |
| <i>Pteronura brasiliensis</i> | Rodrigues et al., 2013 |
| <i>Puma concolor</i> | Azevedo et al., 2013 |
| <i>Puma yagouaroundi</i> | Almeida et al., 2013 |
| <i>Sapajus cay</i> | Rímoli et al., 2015 |
| <i>Sapajus libidinosus</i> | Fialho et al., 2015 |
| <i>Speothos venaticus</i> | Jorge et al., 2013 |
| <i>Tamandua tetradactyla</i> | Ohana et al., 2015 |
| <i>Tapirus terrestris</i> | Medici et al., 2012 |
| <i>Tayassu pecari</i> | Desbiez et al., 2012 |
| <i>Tolypeutes matacus</i> | Reis et al., 2016 |
| <i>Tolypeutes tricinctus</i> | Reis et al., 2015 |

Table S2

List descriptors that no values were found for the analyzed species and the species from which these values were taken

| Species | Descriptor(s) | Species from which the values were taken |
|---|--------------------------------------|---|
| <i>Blastocerus dichotomus</i> | Weaning | Average of Cerrado deers |
| <i>Cabassous tatouay</i> | Lifespan and home range | <i>Cabassous unicinctus</i> |
| <i>Cabassous tatouay</i> and <i>Cabassous unicinctus</i> | Gestation, weaning, sexual maturity | <i>Euphractus sexcinctus</i> |
| <i>Callicebus nigrifrons</i> | Weaning and sexual maturity | <i>Callicebus moloch</i> |
| <i>Coendou spinosus</i> | Weaning, sexual maturity and density | <i>Coendou prehensilis</i> |
| <i>Dasyprocta aurea</i> and <i>Dasyprocta nigriclunis</i> | Offspring and gestation | <i>Dasyprocta</i> sp. |
| <i>Dasyprocta aurea</i> and <i>Dasyprocta nigriclunis</i> | Sexual maturity | <i>Dasyprocta leporine</i> |
| <i>Dasyprocta aurea</i> and <i>Dasyprocta nigriclunis</i> | Weaning, home range and density | <i>Dasyprocta azarae</i> |
| <i>Dasyprocta azarae</i> | Sexual maturity | <i>Dasyprocta leporina</i> |
| <i>Dasyprocta prymnolopha</i> | Density | <i>Dasyprocta aurea</i> |
| <i>Dasypus septemcinctus</i> | Weaning | <i>Dasypus novemcinctus</i> |
| <i>Leopardus braccatus</i> | Weaning and sexual maturity | <i>Leopardus tigrinus</i> and <i>Leopardus wiedii</i> |
| <i>Lycalopex vetulus</i> | Sexual maturity | <i>Lycalopex gymnocercus</i> |
| <i>Sapajus cay</i> | Weaning | <i>Sapajus apella</i> |
| <i>Sapajus cay</i> | Sexual maturity | <i>Sapajus libidinosus</i> |
| <i>Sapajus libidinosus</i> | Weaning | <i>Sapajus apella</i> |

*Tolypeutes tricinctus*Offspring, gestation,
weaning and sexual
maturity*Tolypeutes matacus***Table S3** is an excel file**References**

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Capítulo 4

Patterns of animal and human traffic accidents on federal Brazilian highways, from 2007 to 2017: an overview ⁵

⁵ A formatação dessa seção obedece parcialmente às normas do periódico *Tropical Conservation Science*.

Patterns of animal and human traffic accidents on federal Brazilian highways, from 2007 to 2017: an overview

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Abstract

Traffic accidents are the 9th main cause of deaths in the world. This study evaluated general patterns of animal/human accidents, from 2007 to 2017, on federal Brazilian highways in an attempt to understand how these accidents are impacting human lives and Brazil economy. We tried to answer the following questions: 1) when it happens more animal/human accidents? 2) the road design affects accidents? 3) who is more involved in this kind of accidents: men or women, what age are they, what kind of vehicle do they drive? 4) where the highest frequency of animal/human accidents occurs in Brazil? The data source was the official registers of the Brazilian Federal Highway Police. The 44 444 accidents comprised 68 775 people, including 66.1% unharmed, 23.2% with minor injuries, 7.7% with serious injuries and 1.6% died. The accidents occurred mainly from April to August (9% each), on Sundays (16%), with clear sky (61.3%), at night (68.4%), in rural zones (73.5%), and on straight stretches (88.8%). Usually the animal/human accidents involved just one vehicle, especially a car (48%). People affected by accidents were mostly drivers, adults and men. Most of the animal/human accidents happened in Northeast Brazilian Coast. In eleven years, the monetary costs of traffic accidents in Brazil were R\$ 4 667 809 223.03. Only animal/human accidents costed R\$ 1 400 342 766.91, amount of money enough to install fences and one wildlife crossing structure each two kilometers through 517 km of four-lane roads.

Keywords

Road Ecology, roadkill, road accidents, security, domestic fauna, wildlife.

Introduction

In Brazil, about 61% of cargos and 95% of passengers are transported through highways (Confederação Nacional de Transporte., 2017), indicating that the transport sector is moving high amounts of financial resources. In the year 2014, this sector, as well as auxiliary services to transport and mail, had revenues of more than R\$ 400 billion (Brazilian Institute of Geography and Statistics., 2014). Due to its importance, our country has 212 866 km of paved highways and 1 365 426 of unpaved, presenting a density of approximately 24.8 km of paved roads for each 1 000 km² of area (Confederação Nacional de Transporte., 2017).

Brazil is a huge country, with 8 515 767.049 km² and 27 states distributed among five regions. Although important, highways are not homogenously distributed across the country. Concerning federal paved highways, the Northeast is the region with the largest extension of this type of infrastructure, with 30.6% of the total national road network, followed by the Southeast and South regions, with 19.4% and 18.6% (Confederação Nacional de Transporte, 2017). The Midwest and North regions present only 17.6% and 13.8%, respectively. However, when the density of highways is analyzed by region, it is observed that, though the largest extension is in the Northeast region, the highest concentration is located in the South region (20.9%), followed by the Southeast (13.6%), Northeast (12.8%), Midwest (7.1%) and North (2.3%) regions.

Regardless its importance, highways are the 9th main cause of deaths in the world and the 10th in Brazil, being able to move to the 7th by 2030 (AMBEV, 2017; World Health Organization, 2015). Among young people (15-29) traffic fatalities are the number one cause of deaths (World Health Organization, 2015). Road traffic crashes cost countries an average of 3% of their gross domestic product (GDP). Besides, there was a 48.7% increase in the number of deaths from 2001 to 2012, from 2013 this number started to decrease, achieving the best result in 2015 with 19.2 deaths per 100 thousand inhabitants (AMBEV, 2017). On the other hand, the number of injured victims has increased 29.2% from 2010 to 2015, representing 203 thousand people.

According to IPEA (2015), the average cost of accidents on Brazilian federal highways with fatal victims is R\$ 646 762.94, for victims with injuries this value is R\$ 90 182.71 and for those without injuries it is R\$ 23 062.97. In 2016, accidents costed almost R\$ 11 billion to Brazil, 0.17% of its GDP (Confederação Nacional de Transporte,

2017). In contrast, Brazil has invested just 0.14% from its GDP on public federal highways. To further aggravate this scenario, we can mention the growth of the road network and the vehicle fleet in the country. In the last ten years, the paved federal road network increased 11.3% while the vehicle fleet grew 102,4%.

Traffic accidents can be caused by: frontal, lateral, rear-end or transverse collision; track output; rollover; collision with fixed object; tipping; multiple-vehicle collision; running over pedestrians or animals (Confederação Nacional de Transporte., 2017). Besides directly affecting human lives, wild animals roadkill also have negative environmental impacts (Coffin, 2007; Forman & Alexander, 1998; Laurance, Goosem, & Laurance, 2009; van der Ree, Smith, & Grilo, 2015). It is estimated that 475 million wild animals are killed every year on Brazilian highways, 90% of them are small vertebrates, 9% are medium-sized and 1% are large ones (Centro Brasileiro de Ecologia de Estradas, 2017).

The problem of wildlife vehicle collisions should be considered critical if we take into account that, in addition to the direct death of the animals, local animal populations may suffer a decline if roadkill rates exceed breeding and immigration rates (Forman, 1998). Thus, the risk of local extinction is very high when the impact of linear structures is very strong, stopping gene flow between populations separated by a highway (Laurance et al., 2009).

Considering the threat to biodiversity conservation, material, economic and human lives losses caused by roadkill, there is an urgent need for measures to mitigate it (van der Grift et al., 2013). Some of these measures are: warning signs and electronic barriers; speed reducers; investment in driver awareness through educational campaigns; olfactory, luminous and sonorous repellents; modification of the environment; fences and wildlife crossing structures (Glista, DeVault, & DeWoody, 2009; Grilo, Bissonette, & Cramer, 2010; Lesbarrères & Fahrig, 2012). Wildlife crossing structures and fences have been widely proposed and implemented worldwide and are recognized as the most effective mitigation measure for wildlife (Rytwinski et al., 2016). An important step at a mitigation measure program is to identify correctly the sites with a greater number of roadkill (Clevenger, Chruszcz, & Gunson, 2003), the period of the year (Garriga, Franch, Santos, Montori, & Llorente, 2017; Gonçalves et al., 2018; Santos et al., 2017), the species (González-Suárez, Zanchetta Ferreira, & Grilo, 2018) and people who can be target of educational campaigns.

Besides, the problem of roadkill is not restricted to wildlife, domestic mammals also die on roads (Carvalho-Roel, Iannini Custódio, & Marçal Júnior, in press). Omena Junior et al. (2012) found 16% of domestic mammals among mammal roadkills, Freitas (2009) raised a total of 47%, Esperandio (2011) recorded 28% and Bagatini (2006) 52%. Freitas & Barszcz (2015), analyzing news on the internet about wildlife vehicle accidents, concluded that 70% involved domestic animals.

The Brazilian Federal Highway Police is responsible to answer and record accidents that happen on federal highways and make all this data available (Brazilian Federal Highway Police, 2018). Although corresponding to just 30.5% of Brazilian highways (Confederação Nacional de Transporte., 2017) it is through federal highways that most of the people travel. Therefore, we believe these data can help road managers understand when, where, how and who is affected by human/animal accidents; providing information to support more effective mitigation measures. That is why we analyzed general patterns of animal/human accidents from 2007 to 2017 on federal Brazilian highways. First, we bring general data about how human/animal accidents are impacting human lives and Brazil economy. Second, we try to answer the following questions: 1) when it happens more animal/human accidents? 2) the road design affects accidents? 3) who is more involved in this kind of accidents: men or women, what age are them, what kind of vehicle do they drive? 4) where the highest frequency of animal/human accidents occurs in Brazil?

Material and Methods

We analyzed the public data registered by the Brazilian Federal Highway Police from 2007 to 2017 (Brazilian Federal Highway Police, 2018). These data are available by the type of accident or by people involved on it. We selected just accidents that the cause was animal roadkill. Unfortunately, they do not discriminate if animals involved on accidents are wild or not. They provide a range set of variables, we chose some of our interest: kind of victim (no victim, injured and died), number of victims (no victim, minor or serious injured and death), day of the week, month of the year, year, phase of the day (night, daytime, dawn and nightfall), weather conditions (clear sky, cloudy, rainy and others), number of lanes (two, four or multi-lane), road layout (straight or curve stretches),

land use (urban or rural area), number and kind of vehicles (cars, trucks, pickups, motorcycles and others), kind of person involved (driver or passenger), age, sex (man or woman), Brazil state and geographical coordinates. Descriptive statistics were employed to the data.

The Brazilian Institute of Applied Economic Research (IPEA) has published a report on which they calculate how much Brazil spends with car accidents according to the severity of the accident (no victims, minor or serious injured and fatal ones). In order to get this number, they took into account the costs associated to people, to vehicles, to propriety (damage to public and private property) and to institutions (like the federal police, emergency and judicial services) (IPEA, DENATRAN, & ANTP, 2006). To assess how much Brazil has spent just with animal/human accidents, we used the values provided by the Institute of Applied Economic Research, (2015) for each kind of accident (no victims, minor or serious injured and fatal ones). Finally, we corrected this value according to the Extended Consumer Price Index (Índice de Preço ao Consumidor Amplo - IPCA in Portuguese) of August 2018. We considered 30% of the accidents as evolving wildlife animals (S. R. de Freitas & Barszcz, 2015). Finally, we used the data provided by Huijser, Abra, & Duffield (2013) to calculate how many wildlife crossing structures and fences it would be possible to build with the money Brazil has spent with wildlife/human accidents. Huijser et al. (2013) have calculated the cost of the construction of a 3x3 meters wildlife crossing structure with fence and jump-outs (R\$84,624.74 – structure along 4-lane roads (35 m culvert length), value corrected for August 2018). They also calculated the cost of a fence along one km (R\$203,612.08 - value corrected for August 2018).

Two-lane roads encompass 93.8% of federal highways, in order to avoid bias, we divided the total number of accidents by the total length of two and four-lane roads (48 760.5 and 2 376.6, respectively) (National Transport Infrastructure Department, 2017). Because highways are not homogenously distributed across Brazil states, for example, while Amazonas state has just 6 170 km of federal roads, Minas Gerais state has 18 111.3. That is why, we divided the number of accidents in each state by the length of roads inside this state, this way we got an index of accidents/km for each state.

From 2017, the Brazilian Federal Highway Police started to register the geographical position of the animal/human accidents. We used these data to create kernel

density maps showing the density of all accidents and accidents according to their gravity with fatal, injured and no victims. We identified as animal/human hotspots those stretches with medium to high density of accidents with fatal and injured victims. We calculated the total length of highways inside animal/human hotspots and their location in Brazil. We used the free software QGIS v.3.2.2 (QGIS Development Team, 2018).

Results

More than 1 600 000 road accidents were recorded in the analyzed period, representing an accident every 3.5 minutes. Animal roadkill represents only 2.7% of the causes of accidents, totaling 44 444 accidents, on average one vehicle accident involving animals and humans every two hours. Between 2013 and 2016, traffic accidents had a drop of 4 768 to 2 605 records (-45%), remaining stable in 2017 (Figure 1).

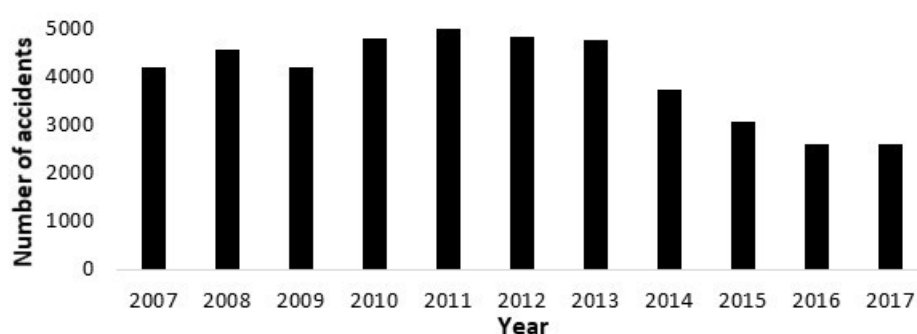


Figure 1. Number of accidents caused by collisions with animals from 2007 to 2017 on Brazilian federal highways. Data registered by the Brazilian Federal Highway Police.

Most of the accidents involving animals had no human victims (66.7%, 29 641), 30% (13 638) had people injured and 2.2% (974) caused death. From 2014, there was a drastic decrease in the number of accidents with no human victims (-63%), while for accidents with human victims we can observe a small increase from 2007 to 2017 (25% for injured victims and 14% for fatal ones) (Figure 2). The 44 444 accidents comprised 68 775 people, 66.1% (45 443) unharmed, 23.2% (15 941) with minor injuries, 7.7% (5 291) with serious injuries and 1.6% died (1 129). Every 3.6 days a person dies in an animal vehicle accident and a person gets injured every 4.5 hours. The number of people involved in these accidents as the number of victims from 2013 to 2016 decreased (-40.5% people involved, -51.8% people with no injury and -16.2% people with minor

injuries). The number of serious and fatal victims had small fluctuations during the 11-years period. Brazil has spent R\$ 4 667 809 223.03 with animal/human accidents during the 11-years period, R\$ 1 000 each 1.2 minutes.

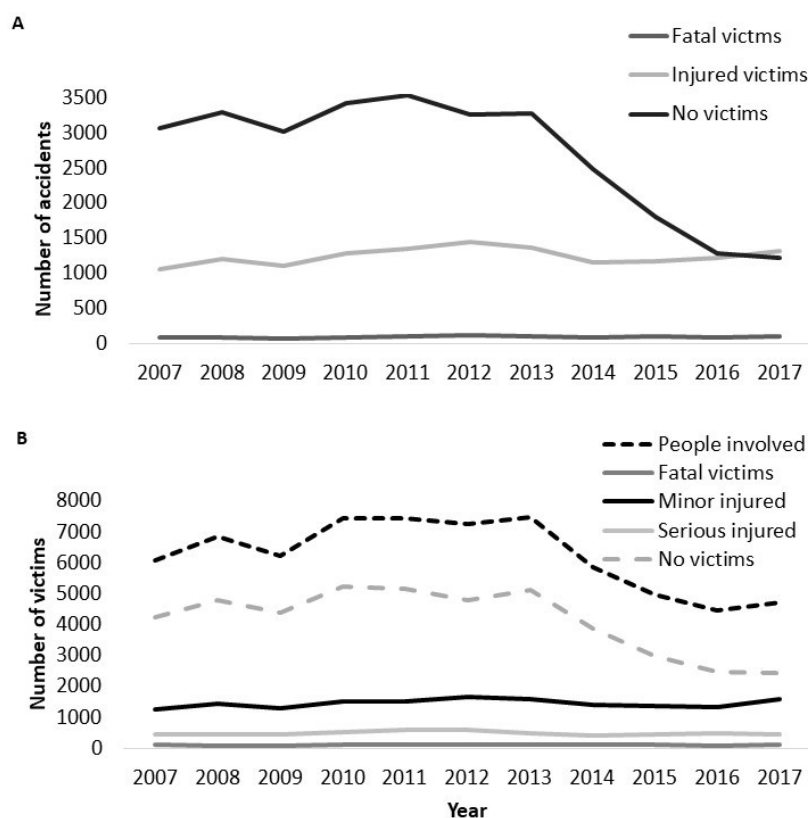


Figure 2. A) Number of accidents caused by collisions with animals from 2007 to 2017 on Brazilian federal highways according to its severity: fatal, injured or no victims. B) Number of human victims caused by collisions with animals from 2007 to 2017 on Brazilian federal highways according to its severity: fatal, minor and serious injured or no victims. Data registered by the Brazilian Federal Highway Police.

The months with more accidents were those from April to August (9% each), November had the lowest number of accidents (7%, -986 accidents comparing to the month with the highest number of accidents) (Table 1). Tuesday, Wednesday and Thursday were the days with lower animal/human accidents (13%, on average 5 887 for each month), Sunday was the day with more accidents (16%, 6 874). More accidents happened during the night (68,4%, 30 388), when the sky was clear (61.3%, 27 262) and on two-lane highways (77%, 34 228). Although, when we correct for the extension of federal roads of each type (two-lane and four-lane), on two-lane highways it happened

0.7 accidents per km and on four-lane highways 4.1. There was a higher frequency of accidents on straight stretches (88.8%, 39 225) and in rural areas (73.5%, 32 679).

Usually the animal/human accidents involved just one vehicle (maximum 7), most of the them were cars (48%, 32 800). A great amount of the drivers did not get hurt in the accident (72%, 36 150), 18% (9 169) had minor injuries, 6% (3 237) serious injuries and 1% died (723). Regarding the passengers, 50% (9 026) were unharmed, 37% (6 651) had minor injuries, 11% (1 952) serious injuries and 2% (367) died. In relation to age, the majority were between 25-44 years old (49%, 33 638) (Table 1). Men were involved in more accidents (80%, 55 057) than women (18%, 12 389) (2%, 1 333, not identified). Drivers were composed mostly by men (93%, 45 785), on the other hand passengers were equally distributed between men (49%, 8 778) and women (51%, 8 985). While 71% (36 743) of the men did not get hurt, this number was 51% (6 290) for women; 37% (4 607) of women had minor injuries while for men it was 20% (10 279); 10% (1 234) of women had serious injuries for men this number was 7% (3 662); 2% of men (848) and women (187) died.

Minas Gerais state had the highest frequency of animal/human accidents (13%) amongst Brazilian states (Table 2). Correcting this number for the extension of federal roads for each state, it was possible to see a change. Sergipe, Paraíba and Pernambuco presented more accidents per km of road, all states of the Northeast region. The states with less accidents per km did not change a lot: Amazonas, Amapá, Roráima and Pará, all states of the North region.

Table 1. Total and percentage (%) of animal/human accidents for: months of the year, day of the week, day period, weather, kind of lane, lane design, kind of vehicle and age of the victim. Data registered by the Brazilian Federal Highway Police (2007-2017).

| | | | | | | | | | | | | |
|-----------------|-----------|-----------|------------|------------|----------|----------------|----------|--------|-----------|---------|----------|----------|
| Month | January | February | March | April | May | June | July | August | September | October | November | December |
| Total | 3454 | 3279 | 3661 | 3868 | 4116 | 4041 | 4143 | 3940 | 3687 | 3650 | 3157 | 3448 |
| % | 7.8 | 7.4 | 8.2 | 8.7 | 9.3 | 9.1 | 9.3 | 8.9 | 8.3 | 8.2 | 7.1 | 7.8 |
| Day of the week | Monday | Sunday | Tuesday | Wednesday | Thursday | Friday | Saturday | | | | | |
| Total | 6874 | 6530 | 5896 | | 5868 | 5896 | 6683 | 6697 | | | | |
| % | 15.5 | 14.7 | 13.3 | | 13.2 | 13.3 | 15.0 | 15.1 | | | | |
| Day period | Dawn | Daytime | Nightfall | Night | | | | | | | | |
| Total | 3415 | 8451 | 2187 | 30388 | | | | | | | | |
| % | 7.7 | 19.0 | 4.9 | 68.4 | | | | | | | | |
| Weather | Clear sky | Cloddy | Rainy | Ignored | Sunny | Foggy | Windy | Snowy | Hailstorm | | | |
| Total | 27262 | 8784 | 3211 | 1988 | 1903 | 1010 | | 271 | 8 | 4 | | |
| % | 61.3 | 19.8 | 7.2 | 4.5 | 4.3 | 2.3 | | 0.6 | 0.0 | 0.0 | | |
| Kind of lane | Two-lane | Four-lane | Multi-lane | | | | | | | | | |
| Total | 34228 | 9648 | 568 | | | | | | | | | |
| % | 77.0 | 21.7 | 1.3 | | | | | | | | | |
| Lane design | Straight | Curve | Crossroad | | | | | | | | | |
| Total | 39225 | 4707 | 248 | | | | | | | | | |
| % | 88.8 | 10.7 | 0.6 | | | | | | | | | |
| Kind of vehicle | Car | Truck | Pickup | Motorcycle | Bus | Other | | | | | | |
| Total | 32800 | 10412 | 10070 | 8507 | 4904 | 2012 | | | | | | |
| % | 47.7 | 15.2 | 14.7 | 12.4 | 7.1 | 2.9 | | | | | | |
| Age | 0 a 12 | 13 a 24 | 25 a 44 | 45 a 64 | 65 | Not identified | | | | | | |
| Total | 1.8 | 12.6 | 48.8 | 22.5 | 2.2 | 12.0 | | | | | | |
| % | 1.8 | 12.6 | 48.8 | 22.5 | 2.2 | 12.0 | | | | | | |

Table 2. Number of animal/human accidents for each Brazil state, the extension of federal highways and the number of accidents per km of highway. Data registered by the Brazilian Federal Highway Police (2007-2017).

| Brazil State | Number of accidents | % of accidents | Km of highways | Accidents/km |
|--------------------------|---------------------|----------------|----------------|--------------|
| North region | | | | |
| Acre (AC) | 329 | 0.7 | 1652.5 | 0.2 |
| Amapá (AP) | 65 | 0.1 | 1214.4 | 0.1 |
| Amazonas (AM) | 95 | 0.2 | 6170 | 0.02 |
| Pará (PA) | 638 | 1.4 | 7680.6 | 0.1 |
| Rondônia (RO) | 770 | 1.7 | 2283.9 | 0.3 |
| Roraima (RR) | 150 | 0.3 | 1858.6 | 0.1 |
| Tocantins (TO) | 415 | 0.9 | 2739.7 | 0.2 |
| Northeast region | | | | |
| Alagoas (AL) | 819 | 1.8 | 901.7 | 0.9 |
| Bahia (BA) | 3420 | 7.7 | 11300.4 | 0.3 |
| Ceará (CE) | 1930 | 4.3 | 3648.2 | 0.5 |
| Maranhão (MA) | 1745 | 3.9 | 4326.8 | 0.4 |
| Paraíba (PB) | 1993 | 4.5 | 1689.3 | 1.2 |
| Pernambuco (PE) | 3384 | 7.6 | 2931.7 | 1.2 |
| Piauí (PI) | 2515 | 5.7 | 4508.9 | 0.6 |
| Rio Grande do Norte (RN) | 1622 | 3.6 | 1802.8 | 0.9 |
| Sergipe (SE) | 691 | 1.6 | 419.2 | 1.6 |
| Midwest region | | | | |
| Distrito Federal (DF) | 67 | 0.2 | 377.46 | 0.2 |
| Goiás (GO) | 1701 | 3.8 | 6322.9 | 0.3 |
| Mato Grosso (MT) | 1326 | 3 | 6625.3 | 0.2 |
| Mato Grosso do Sul (MS) | 2532 | 5.7 | 4603.9 | 0.5 |
| Southeast region | | | | |
| Espírito Santo (ES) | 570 | 1.3 | 1695 | 0.3 |
| Minas Gerais (MG) | 5775 | 13 | 18111.3 | 0.3 |
| São Paulo (SP) | 1631 | 3.7 | 6539.1 | 0.2 |
| Rio de Janeiro (RJ) | 2107 | 4.7 | 2549.05 | 0.8 |
| South region | | | | |
| Paraná (PR) | 2044 | 4.6 | 6373.7 | 0.3 |
| Rio Grande do Sul (RS) | 4332 | 9.7 | 8644 | 0.5 |
| Santa Catarina (SC) | 1777 | 4 | 3569 | 0.5 |

In 2017, there was a higher concentration of animal/human accidents in the Northeast region (in the states BA, AL, PE, PB, RN and CE) and in Rio de Janeiro (RJ) state, all regions close to the sea (Figure 3). Accidents with no victims happened in a

higher frequency in the Northeast region, South Rio de Janeiro (RJ) and East São Paulo (SP). The fatalities with injured people were more intense in the Northeast region, but also in Southeast Minas Gerais (MG), South Rio de Janeiro (RJ) and East Paraná (PR). The accidents with fatal victims were concentrated in the Northeast region. Twelve states presented hotspots of animal/human accidents with human victims, totaling 7790 km and 374 victims (Figure 4). Rio Grande do Norte, Ceará, Paraíba e Pernambuco were the states with more accidents regarding the extension of highways (Table 3).

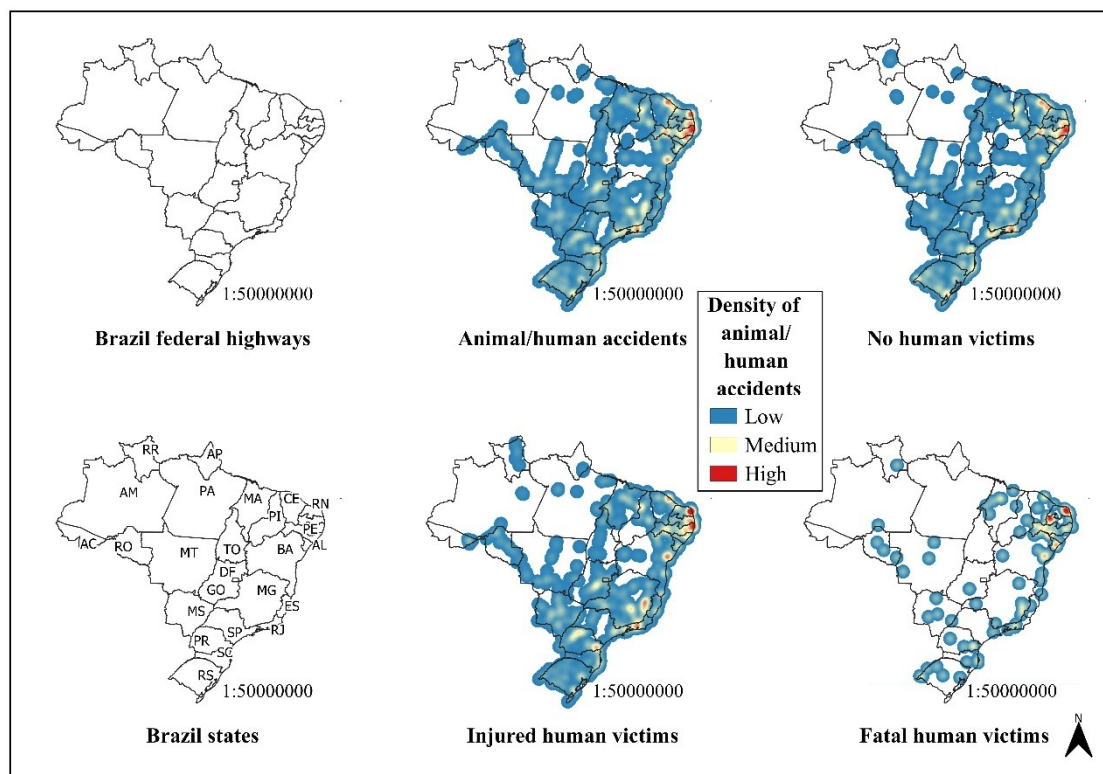


Figure 3. Kernel density maps, showing the sites with lower to higher density of animal/human accidents according to the type of victim: fatal, injured and no victim in Brazil for 2017. We also show Brazil federal highways and Brazil states with their names abbreviated. Data source: Brazilian Federal Highway Police.

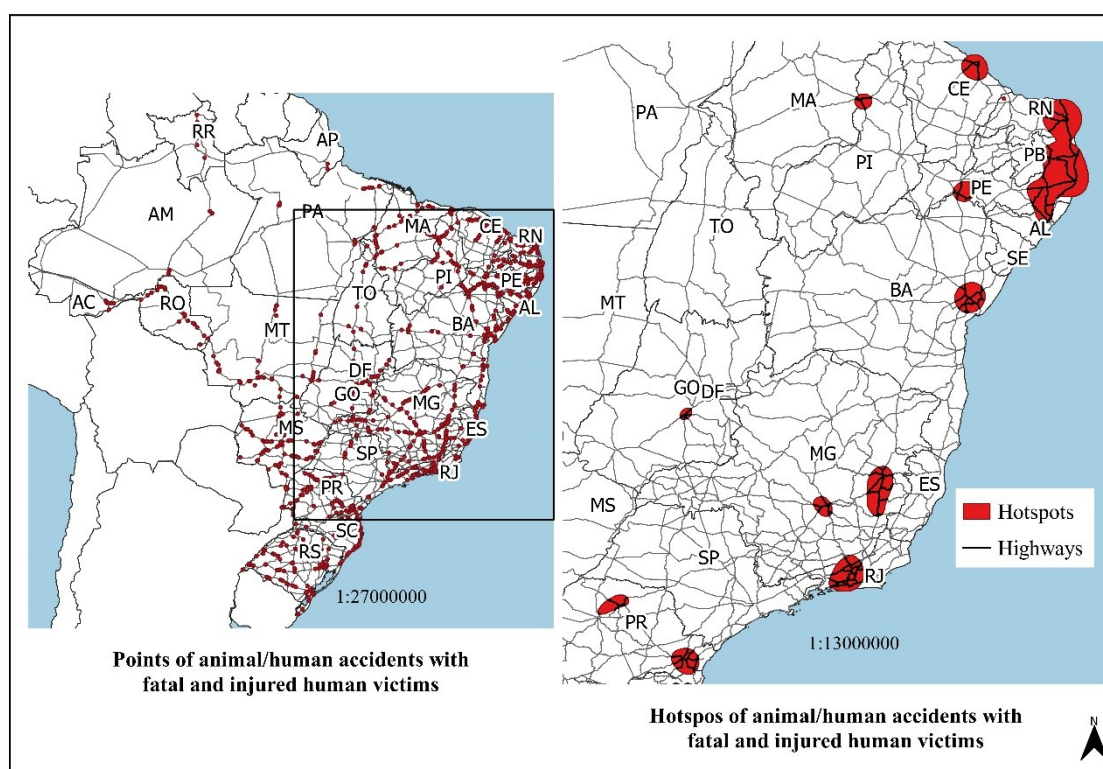


Figure 4. Points and hotspots of animal/human accidents with fatal and injured human victims for Brazil (2017), highlighting the highways within the hotspots. We also show Brazil federal highways and Brazil states with their names abbreviated. Data source: Brazilian Federal Highway Police.

Table 3. States where hotspots of animal/human accidents with injured or fatal human victims were identified, the extension of highways within the hotspots, number of victims and accidents per km.

| State with an accident hotspot | Km of highways within the hotspot | Number of injured and fatal victims | Accidents/km |
|--------------------------------|-----------------------------------|-------------------------------------|--------------|
| Alagoas (AL) | 372.4 | 11 | 0.03 |
| Bahia (BA) | 828.5 | 31 | 0.04 |
| Ceará (CE) | 287.2 | 26 | 0.09 |
| Goiás (GO) | 208.6 | 5 | 0.02 |
| Maranhão (MA) | 125.6 | 2 | 0.02 |
| Minas Gerais (MG) | 1400.2 | 57 | 0.04 |
| Paraíba (PB) | 593 | 38 | 0.06 |
| Pernambuco (PE) | 1140.3 | 68 | 0.06 |
| Piauí (PI) | 268.4 | 13 | 0.05 |
| Paraná (PR) | 950.1 | 36 | 0.04 |
| Rio de Janeiro (RJ) | 1084.1 | 33 | 0.03 |
| Rio Grande do Norte (RN) | 532.2 | 54 | 0.10 |

Discussion

The results reveal a clear pattern for traffic accidents caused by collisions with animals on federal Brazilian highways: a decrease in the number of accidents, but an increase of fatalities. In general, these results follow the Brazilian tendency of road accidents involving animals and human in the last years (AMBEV, 2017), as well as the evolution of casualty accidents (Institute of Applied Economic Research, 2015). Probably this is a result of a more effective enforcement of the law by the Brazilian Federal Highway Police after the implementation of the Dry Law, prohibiting drink driving (Freitas & Barszcz, 2015). Even with this reduction, Brazil is far away of achieving the goals of the 2030 Agenda from the UN to reduce mortalities by half by 2020 (United Nations General Assembly, 2015). Not even mentioning the goal of offering a better public transportation system by 2030. The World Health Organization (2017) has already stated some means to decrease the number of accidents like: speed management, infrastructure design and management, enforcement of traffic laws, leadership on road safety, vehicle safety stands and survival after a crash. In order to achieve European patterns investment in transport infrastructure (Confederação Nacional de Transporte, 2017) that in 2014 was 0.78% of its GDP, 0.41 just in roads (European Environment Agency, 2016), Brazil would have to triplicate its values.

Let's mention the scary result of this research. Brazil has spent R\$ 4 667 809 223.03 with animal/human accidents from 2007 to 2017. Of course that a great amount of these accidents were caused by domestic animals. Freitas & Barszcz (2015) analyzing news published online concluded that 30% of the accidents involved wild animals. Considering this number, Brazil has spent RS 1 400 342 766.91 in accidents of wild animals with vehicles, R\$ 127 303 887.90 per year. With the money that is spent every year with wildlife/human accidents, it would be possible to install fences and one wildlife crossing structure each two kilometers through 517 km of four-lane roads. The lifetime of this structures is about 75 years for wildlife crossing structures and 25 for fences (Huijser et al., 2013).

More accidents happened from April to August, on Sundays, at night and with a clear sky. The months with more accidents were those from the dry season. In the dry season due the scarcity of food, animals have to move more, increasing their roadkill probability (Bueno & Almeida, 2010; Cunha, Moreira, & Silva, 2010). Usually people

enjoy the weekend to travel and come back home on Sunday, that is why there were higher animal/human accidents on this day and less from Tuesday to Thursday. Although, usually there is a lower frequency of vehicles at night, its precisely during this period that happened more accidents (Freitas & Barszcz, 2015), probably because of sleepiness (Åkerstedt, Kecklund, & Hörte, 2001). Mammals, that are the most involved in this kind of accidents, are usually nocturnal and move more during this period (Reis, Peracchi, Fragonezi, & Rossaneis, 2010) increasing their roadkill probability (Caceres, 2011; González-Suárez et al., 2018). In addition, the lack of visibility also difficulties their visualization (Laurance et al., 2009). However, most of the accidents happened at night, the sky was clear, maybe because when it is cloudy or rainy, drivers travel slowly and carefully (Billot, El Faouzi, & De Vuyst, 2009), decreasing the roadkill probability. In addition, animals move less on rainy days.

We identified higher values of animal/human accidents on four-lane roads and straight stretches, opposing to the prediction that narrow road widths would encourage road-crossing movements (Laurance et al., 2009). However, we must take into account that four-lane roads have large traffic volumes, which increase roadkill. Straight stretches provide a quitter environment for drives, in these sites drivers usually increase the speed (Ben-Bassat & Shinar, 2011), what decrease their response time to the presence of an animal. Meanwhile, on curve stretches they drive slowly (Van Winsum & Godthelp, 1996). In addition, many drivers can fall asleep in straight stretches. Still, roads usually have more stretches with straight lines than with curves. Most of the roads are inside rural areas (Lee, 2005) and also animals.

Adult men driving a car were involved in more accidents. Because the animals are the main cause of the accidents, just one vehicle was involved on it (Freitas & Barszcz, 2015). Our results are a little discrepant of the Brazilian fleet of vehicles where cars are the group with more representativeness (55%) followed by motorcycles (22%), pickups (10%) and trucks (3%) (Confederação Nacional de Transporte, 2017). In relation to the Brazilian fleet of vehicles, trucks were more involved in animal/human accidents and motorcycle less, presumably because trucks are more present in Brazilian roads since about 61% of cargos are transported through highways (Confederação Nacional de Transporte, 2017) and motorcycles are more used in cities than on roads.

As drivers suffered more accidents than passengers we can deduce that at least 2/3 of the people travel alone. Passengers involved in accidents as fatal or injured victims

were almost twice the percentage of drivers, probably because an innate act of the driver is to reduce the impact for him, what causes more damages to the passengers. Adults were the main victims in animal/human accidents as they are the drivers and represent a big amount of Brazilian population (25-44 years old, 32%; 45-64 years old 25%; projection for 2017 of the Instituto Brasileiro de Geografia e Estatística (2018)). Because men get more involved in accidents, four times more, usually three men die for every one woman (World Health Organization, 2015). This difference is just a result of the biggest number of men as drivers, that frequently travel alone. Anyhow, when we look at percentage data, women and men die in the same frequency.

The most of the animal/human accidents with serious or fatal human victims happened in Northeast Brazil. We believe that this is due to the following facts: larger extension of federal highways, greatest increase on vehicles fleet, poor condition of roads and tourism on coastal zones. Of the amount of the paved federal road network, the Northeast is the region with the greatest extension of this type of infrastructure, 30.6% (Institute of Applied Economic Research, 2015). On the other hand, when the density of highways is analyzed by region, the highest concentration is in the South region (20.9 km/1000 km²), followed by the Southeast (13.6) and finally by the Northeast (12.8) (Confederação Nacional de Transporte, 2017). In addition, the Northeast region was the region with the greatest increase of the road fleet between 2007-2017 (168%). The highways of the Northeast region are in second place regarding poor and bad general condition (30.9% of the highways, just the North region has more poor and bad highways, 43.9%) (Confederação Nacional de Transporte, 2017). Finally, The Northeast is a privileged region in what concerns the investment of tourism in the coastal zone (Becker, 2001), half of the Brazilian people intended to travel to the Northeast region in 2017 (Ministry of Tourism, 2017).

The opposite is observed for the North region with few accidents. We cannot forget that huge areas of Brazil still do not have paved highways, like Amazonas state with just 631 km (1 559 148.9 km² of area) while other states are the opposite, as São Paulo with 1 119 km of paved federal highways (248 222.4 km² of area, six times smaller than Amazonas state) (Confederação Nacional de Transporte, 2017). The North region is also sparsely populated with just 4.12 inhabitants/km², while this value is 8 times bigger for the Northeast region (34.15) and 21 for the Southeast (86.92). Another important thing to consider, is that in the North region the fluvial transportation is very important, 60%

of the cargo transportation in Amazonas state is through rivers (Miranda, 2017). Therefore, we believe our results are a partial picture from how people and roads are distributed through Brazil, with more animal/human accidents in populated, high road network, poor road conditions and great movement of people and goods.

In general, these results can work as tool to the Federal Highway Police. They should focus their awareness and law enforcement efforts on Sundays from April to August, since during this period it happens 1.2% and 1% more accidents than the average, respectively. The Federal Highway Police should target men, since the chance of men being involved in an accident is almost 75% and trucks because in spite of representing just 3% of the Brazilian fleet of vehicles they are involved in 15% of the accidents. Additionally, drivers should avoid travelling at night since the chance of an animal/human accident is 3.6 times greater at night than during daytime.

Unfortunately, the Brazilian Federal Highway Police only registers if animals are the cause of an accident without discriminating if they are wild or not, this differentiation is important, since there are clear differences in the location of hotspots of domestic and wild animals as well as in the mitigation measures that could be implemented to minimize the risk of accidents (Carvalho-Roel et al., in press). Anyway, we think that these data can help Road Ecologists to have a better understand about animal/human accidents on Brazilian highways and support general mitigation measures. Many researches have been done in Brazil identifying wildlife roadkill (Ascensão, Desbiez, Medici, & Bager, 2017; Carvalho, Bordignon, & Shapiro, 2014; Coelho, Kindel, & Coelho, 2008; Gonçalves et al., 2018; Saranholi et al., 2016; Teixeira et al., 2013) and such data would improve Road Ecology researches in the country. Furthermore, the Brazilian Federal Highway Police should start using the app Sistema Urubu, that was specially designed to send photos of wildlife roadkill to specialists who identify the species correctly (Morais & Bager, 2016).

About mitigation measures, for domestic fauna, the responsibility should lie on its owner (Freitas & Barszcz, 2015). Carvalho-Roel et al. (in press) has proposed the following mitigation measures: (i) education campaigns, (ii) adequate containment of animals to prevent them from going to the road, (iii) sterilization, (iv) creation of a rescue program, people could call when they see an animal near the road and it would be rescued (this measure can be used for wild animals too), (v) the correct enforcement of the law. The Federal Law 9.605/98 declare as a crime the cruelty towards animals and specifies a

penalty (Cardoso, 1998). Then, Brazil already have a law aiming to protect fauna, the big step now is its fully enforcement.

About wildlife/human accidents, the solutions have been extensively proposed but not executed. Brazil has a bill that is in the pipeline since 2015 (Izar, 2015) that states the following mitigation measures: (i) application of a national public registry of accidents with wild animals, (ii) inspection and continuous monitoring in the areas of higher incidence of wild animals roadkill, (iii) implementation of actions that aid the wild fauna to cross the road, such as signaling and speed reducers, arboreal or underground passages, fences and reflectors, (iv) environmental education.

Acknowledgements

We acknowledge the Institute of Biology from the Federal University of Uberlândia for providing our transport to collect the data. We thank the Climatological Station of the Federal University of Uberlândia (UFU), Brazil, for providing the climate data. We especially thank the field surveyors who collected the field data and to the reviewers.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

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Considerações finais

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O padrão de uso do solo influencia a localização dos atropelamentos de animais silvestres. A proximidade a corpos d'água se mostrou como uma das variáveis mais importantes na determinação dos atropelamentos. Quanto menor a distância até o perímetro urbano, maior é a frequência de atropelamento de mamíferos e aves e menor a de répteis. Além dessas variáveis, o atropelamento de mamíferos aumenta com o aumento das áreas naturais de Cerrado, bem como daquelas de agricultura e silvicultura. Para aves, silvicultura e pastagem são variáveis importantes associadas ao atropelamento de indivíduos desse grupo. Assim, a preservação de áreas ripárias e instalação de medidas de mitigação próximas a estas, são importantes para a diminuição das taxas de atropelamento. Além disso, as áreas naturais de Cerrado também devem ser alvos de tais medidas.

O clima também influencia a localização temporal dos atropelamentos. Répteis foi o grupo que apresentou claros padrões temporais, com maiores valores de temperatura mínima, umidade e temperatura média influenciando os atropelamentos desse grupo, que ocorreram com maior frequência na estação chuvosa. Maiores valores de temperatura mínima e precipitação acumulada aumentaram a frequência de atropelamento de mamíferos silvestres, apontando também a temperatura média como uma variável importante para esse táxon. Para aves, insolação, umidade e temperatura mínima são variáveis importantes, sendo que este grupo apresentou maiores taxas de atropelamento durante a estação seca. Conhecendo os padrões temporais, é possível planejar medidas a serem aplicadas em um curto espaço de tempo que possibilitem a proteção de um grande número de indivíduos.

Medidas de mitigação devem proteger o maior número de espécies possível, contudo, a localização destas, para a classe mamíferos apresentou baixa correlação entre suas respectivas ordens e espécies. Porém, as ordens Cingulata, Pilosa e Rodentia parecem representar bem esses locais em relação às espécies que compõem esses *taxa*. Já a ordem Carnivora não apresentou o mesmo resultado, sugerindo a necessidade de uma análise mais fina, talvez em nível de família. Para aves, nenhum dos dois métodos utilizados foi bom o suficiente para identificar esses locais para um número satisfatório de espécies/grupos. Ainda, monitoramentos mais longos se fazem necessários, já que a localização das medidas de mitigação mudou de um ano para o outro para os grupos analisados. Todavia, os dados agrupados dos dois anos representaram bem os anos separadamente.

De forma geral, o melhor método para a identificação de locais prioritários para implementação de medidas de mitigação é aquele que considera as características da paisagem, já que este foi capaz de localizar estas áreas para 1,4 mais espécies/grupos do que o programa Siriema. Além disso, estes resultados podem ser aplicados para outras rodovias do Cerrado brasileiro, sem a necessidade prévia de dados de atropelamento. Por outro lado, o programa Siriema mostrou-se melhor em relação ao custo benefício, mitigando 9% da rodovia, essa metodologia protegeria 31% dos indivíduos contra 22% para o outro método. Infelizmente, os dois métodos não identificaram os mesmos locais prioritários para a implementação de medidas de mitigação, já que o primeiro identifica onde os animais atravessaram e o segundo onde eles possivelmente atravessariam.

Os monitoramentos de animais atropelados podem não estar sendo eficientes na identificação das espécies de mamíferos de médio e grande porte atropeladas no Cerrado, já que 37,3% destas não foram identificadas em nenhum dos nove trabalhos consultados. Os resultados mostraram que as características específicas de cada espécie

influenciam a taxa de atropelamento, sendo que esta aumenta com o aumento da densidade populacional, área de vida e diminuição do período de amamentação e massa corpórea. Mamíferos carniceiros e territoriais apresentam maior taxa de atropelamento, já aqueles que preferem áreas florestais, menor taxa. Note-se ainda que a taxa de atropelamento de mamíferos de médio e grande porte no Cerrado é de 1,35 indivíduos/km/ano, sendo 25% maior do que a taxa observada, indicando que 181.909 mamíferos podem estar morrendo atropelados todos os anos.

Os acidentes entre animais e veículos levaram 1.129 pessoas à morte no período de 2007 a 2017, gasto este de R\$ 1.400.334.766,91, quantia suficiente para instalar cercas e uma estrutura de travessia de vida selvagem a cada dois quilômetros, passando por 517 km de estradas duplicadas. Tais medidas deveriam ser implantadas preferencialmente na região Nordeste, onde ocorre maior frequência de acidentes.

Por fim, sugerimos que a Polícia Rodoviária Federal concentre seus esforços na abordagem de motoristas do sexo masculino, nos finais de semana e à noite, no sentido de conscientizá-los sobre os riscos de atropelamentos de animais silvestres. Um melhor planejamento poderá ser realizado, por parte de engenheiros de tráfego e biólogos, se a Polícia Rodoviária passar a discriminar se o animal envolvido no acidente é doméstico ou silvestre. Acreditamos que medidas relativamente simples como essas poderão auxiliar nos esforços de proteção da vida selvagem e diminuir os riscos de acidentes para os motoristas que trafeguem por rodovias federais em todo país.