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**EMANUEL CAON**

# ANÁLISE RADIOGRÁFICA E CARACTERIZAÇÃO TOPOGRÁFICA DE LESÕES TRAUMÁTICAS EM MAMÍFEROS SILVESTRES ATROPELADOS NO SUDOESTE DO PARANÁ

**REALEZA**
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Dissertação de mestrado apresentada para o Programa de Pós-Graduação em Saúde, Bem-Estar e Produção Animal Sustentável, da Universidade Federal da Fronteira Sul (UFFS), como requisito parcial para obtenção do título de mestre.

Orientador: Prof. Dr. Paulo Henrique Braz

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## RESUMO

O atropelamento constitui o principal fator antrópico associado à mortalidade de animais silvestres, sendo a Mata Atlântica o ecossistema com o maior número de registros no Brasil. A suscetibilidade das espécies aos atropelamentos está diretamente relacionada ao tipo de locomoção, aos padrões ecológicos e comportamentais, bem como às variações sazonais da região. A compreensão da incidência e da morfologia das lesões mais recorrentes nas espécies mais afetadas por atropelamentos possibilita que profissionais envolvidos no resgate e na reabilitação da fauna silvestre adotem condutas mais precisas, otimizando as chances de recuperação e reintegração dos indivíduos ao ambiente natural. Entre os métodos diagnósticos empregados nesse contexto, a radiografia destaca-se como ferramenta fundamental para a detecção e caracterização de fraturas, luxações e demais alterações osteoarticulares, além de subsidiar o planejamento terapêutico e o monitoramento evolutivo dos casos. Diante desse cenário, o presente estudo teve como objetivo quantificar as espécies de mamíferos silvestres encontrados atropelados sob o leito da via, em três rodovias que conectam a cidade de Realeza, Paraná, bem como realizar um estudo radiográfico destes animais visando caracterizar os traumas ósseos. Foram analisadas lesões traumáticas decorrentes de atropelamentos em 51 mamíferos silvestres neotropicais, pertencentes a 12 espécies distintas. As lesões foram classificadas topograficamente em quatro categorias: abdômen e pelve (AP), afetando 36 indivíduos (71%), cabeça e pescoço (HN), também com 36 casos (71%), extremidades (EX) em 31 indivíduos (61%) e na região torácica (TX) em 23 animais (45%). Os achados radiológicos mais prevalentes foram fraturas de pelve (67%; n = 34), seguidas por fraturas em ossos do crânio, incluindo mandíbula (55%; n = 28), osso frontal (45%; n = 23), osso occipital (43%; n = 22), maxilar (43%; n = 22) e osso parietal (41%; n = 21). Também determinamos as frequências de atropelamentos ao longo das estações do ano, sendo a primavera aquela com o maior número de ocorrências. Esses resultados podem auxiliar médicos veterinários que realizam atendimentos de emergência em animais silvestres e serem valiosos em investigações forenses nas quais o atropelamento seja considerado um possível fator contribuinte para a morte.

Palavras-chave: avaliação *postmotem*; diagnóstico por imagem; fauna neotropical; monitoramento de fauna; rodovias brasileiras.

**ABSTRACT**

Roadkill constitutes the main anthropogenic factor associated with wildlife mortality, with the Atlantic Forest being the ecosystem with the highest number of recorded cases in Brazil. The susceptibility of species to road collisions is directly related to their type of locomotion, ecological and behavioral patterns, as well as seasonal variations in the region. Understanding the incidence and morphology of the most frequent injuries in the species most affected by roadkill allows professionals involved in wildlife rescue and rehabilitation to adopt more accurate approaches, optimizing the chances of recovery and reintegration of individuals into their natural environments. Among the diagnostic methods employed in this context, radiography stands out as a fundamental tool for the detection and characterization of fractures, dislocations, and other osteoarticular alterations, in addition to supporting therapeutic planning and case follow-up. In this context, the present study aimed to quantify the species of wild mammals found run over on the road surface along three highways connecting the city of Realeza, Paraná State, as well as to perform a radiographic study of these animals in order to characterize bone traumas. Traumatic injuries resulting from roadkill were analyzed in 51 neotropical wild mammals belonging to 12 different species. The lesions were topographically classified into four categories: abdomen/pelvis (AP), thorax (TX), head/neck (HN), and extremities (EX). The most prevalent radiological findings were pelvic fractures (67%; n = 34), followed by fractures of cranial bones, including the mandible (55%; n = 28), frontal bone (45%; n = 23), occipital bone (43%; n = 22), maxilla (43%; n = 22), and parietal bone (41%; n = 21). We also determined the frequency of roadkills across the seasons, with spring showing the highest number of occurrences. These results may assist veterinarians involved in the emergency care of wild animals and may also be valuable in forensic investigations where roadkill is considered a possible contributing factor to death.

Keywords: brazilian highways; diagnostic imaging; neotropical fauna; Post-mortem evaluation; wildlife monitoring.

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**SUMÁRIO**

# 1 INTRODUÇÃO

Atualmente, estima-se que a extensão total das vias terrestres, incluindo estradas pavimentadas e não pavimentadas, ultrapasse 64 milhões de quilômetros em escala global. (CIA, 2021). As estradas desempenham um papel estratégico no transporte de mercadorias, incluindo matérias-primas e produtos agrícolas, bem como no deslocamento de passageiros, favorecendo a conectividade territorial. (Bager e Alves-Rosa, 2012).

Embora as estradas constituam uma infraestrutura fundamental para o desenvolvimento econômico e social de um país ou região (Amador-Jimenez e Willis, 2012; Weiss *et al*, 2018), também geram impactos negativos sobre a biodiversidade, contribuindo para a degradação e fragmentação de habitats naturais. Entre os principais efeitos nocivos estão a poluição sonora, a iluminação artificial excessiva, a contaminação do solo e da água, além das perturbações visuais que podem afetar o comportamento da fauna. Além disso, as rodovias atuam como barreiras ecológicas, interrompendo rotas migratórias e dificultando a dispersão de espécies, o que pode comprometer a dinâmica populacional de diversas comunidades biológicas. Outro impacto significativo é o aumento da mortalidade de animais silvestres devido a colisões com veículos, o que ameaça ainda mais a conservação da fauna em áreas vulneráveis. (Forman e Alexander, 1998; Forman *et al*. ,2003; Fahrig e Rytwinski, 2009).

Além dos impactos ambientais, a presença de animais domésticos e silvestres nas rodovias representa uma ameaça significativa à segurança viária. A interação entre a fauna e o tráfego pode resultar em acidentes, colocando em risco a vida dos condutores e dos próprios animais. Esses incidentes geram não apenas danos humanos e ambientais, mas também impactos econômicos substanciais, incluindo despesas médicas, custos com reparos de veículos e infraestrutura viária, além de possíveis prejuízos financeiros para setores como o transporte e o turismo (Huijser *et al.*, 2009; Abra *et al.*, 2019; Ascensão *et al.*, 2021).

De acordo com o Ministério do Meio Ambiente (2019), os principais fatores responsáveis pelos impactos sobre a biodiversidade, além de aspectos sociais e culturais, incluem a superexploração de recursos naturais, como plantas, animais e minerais; a introdução de espécies invasoras; o uso de híbridos e monoculturas na agroindústria e em programas de reflorestamento; a contaminação do solo, da água e da atmosfera; e a perda e fragmentação de habitats naturais, intensificadas pela construção de cidades e rodovias. Nesse contexto, a expansão urbana e agrícola, impulsionada pelo crescimento populacional do Brasil, tem sido apontada como um dos principais vetores da devastação da Mata Atlântica.

A Mata Atlântica é considerada o bioma em que possui maior quantidade de registros de atropelamentos de fauna no Brasil, seguido pelo Cerrado, Pantanal, Pampa e Amazônia (Cirino e Freitas, 2017). As estradas são consideradas os principais agentes de fragmentação de habitats de efeito imediato, podendo resultar em significativa alteração na diversidade local, principalmente devido ao efeito de borda e isolamento geográfico de populações (Fahrig e Rytwinski, 2009; Machado-Souza *et al*., 2009). A presença de tráfego de veículos, pode resultar em populações de animais com etiologias diferenciadas, ou seja, animais tendem a evitar regiões com existência de estradas, consequentemente reduzindo o fluxo biológico (Mcgregor; Bender e Fahrig, 2008; Machado-Souza *et al*., 2009).

O atropelamento de fauna terrestre é apontado como um dos principais fatores antrópicos de mortalidade de animais silvestres, superando até mesmo a caça (Forman & Alexander, 1998). Este impacto não se restringe às perdas individuais, pois também compromete a estabilidade populacional, podendo provocar declínios locais em espécies sensíveis. Em regiões fragmentadas e com elevada densidade de rodovias, os efeitos se intensificam, refletindo na redução da abundância e diversidade da fauna, evidenciando a necessidade de estratégias de mitigação e monitoramento contínuo.

A vulnerabilidade dos animais aos atropelamentos está diretamente relacionada ao seu tipo de locomoção, padrões ecológicos e comportamentais. (Laurance *et al*., 2009). Espécies com hábitos terrestres, deslocamento mais lento ou comportamentos exploratórios próximos a rodovias tendem a estar mais expostas ao risco de colisões. Mamíferos de médio e grande porte estão particularmente vulneráveis a atropelamentos devido à ampla área de vida que necessitam para suas atividades diárias. A necessidade de deslocamento para forrageamento e busca de parceiros para reprodução frequentemente os leva a cruzar rodovias, aumentando o risco de colisões com veículos (Laurance *et al.*, 2009). As rodovias representam um fator agravante no risco de extinção de mamíferos de médio e grande porte, especialmente porque essas espécies geralmente apresentam populações reduzidas e vivem em baixas densidades (Grilo *et al*., 2010).

O impacto é ainda mais significativo para espécies já classificadas como ameaçadas, uma vez que a mortalidade decorrente de atropelamentos pode comprometer a recuperação populacional e agravar sua vulnerabilidade à extinção (Forman e Alexander, 1998).

Além das características biológicas e comportamentais dos animais, diversos fatores estruturais e operacionais das rodovias influenciam a incidência de atropelamentos. O aumento da velocidade dos veículos e o alto volume de tráfego estão diretamente correlacionados a um maior número de colisões com a fauna. Adicionalmente, rodovias com faixas estreitas tendem a facilitar a travessia de animais, aumentando sua exposição ao risco. Outro fator determinante é a presença de curvas acentuadas, que reduzem a visibilidade e limitam o tempo de resposta tanto dos motoristas quanto dos animais, elevando a probabilidade de acidentes (Forman e Alexander, 1998; Laurance *et al*., 2009).

A incidência de atropelamentos também pode ser influenciada pelas variações sazonais, impactando diferentes grupos de animais de acordo com suas características fisiológicas e comportamentais. Répteis e anfíbios, por serem ectotérmicos, apresentam maior atividade durante períodos mais quentes, o que contribui para um aumento significativo no número de atropelamentos desses grupos em estações de temperaturas elevadas.

Já os carnívoros exibem padrões sazonais de mortalidade viária associados a eventos específicos de seu ciclo de vida, como nascimento, cuidado parental, caça cooperativa entre mãe e filhote, dispersão juvenil e reprodução. Esses períodos críticos, no entanto, variam conforme a espécie, tornando essencial a compreensão dos padrões ecológicos de cada grupo para o desenvolvimento de medidas eficazes de mitigação (Grilo *et al*., 2009).

Na ciência veterinária, os estudos sobre colisões de automóveis envolvendo animais abrangem principalmente abordagens clínicas, protocolos de atendimento emergencial e, em menor escala, achados anatomopatológicos em cães e gatos domésticos vítimas de atropelamento (Kolata *et al*., 1974; Marmarou *et al*., 1994; LaPlaca *et al*., 2007).

Do ponto de vista patológico, as publicações disponíveis descrevem uma ampla variedade de lesões, que vão desde ferimentos leves, como abrasões cutâneas e hematomas subcutâneos, até traumas fatais, incluindo fraturas múltiplas, ruptura de órgãos internos e hemorragias intracavitárias (Fighera *et al*., 2008).

Por outro lado, quando se trata de fauna silvestre, é notável que, apesar de o trauma decorrente de colisões veiculares representar uma causa significativa de morbidade e mortalidade nesse grupo (Brockie *et al*., 2009; Navas-Suárez *et al*., 2018), os estudos focados nas características específicas dessas lesões – incluindo biomecânica, padrões topográficos e fisiopatologia – ainda são escassos (Navas-Suárez *et al*., 2019; Garcês, 2021). As informações disponíveis sobre o tema concentram-se majoritariamente em aspectos ecológicos, como a influência das características da paisagem e a diversidade de espécies afetadas (Coffin, 2007).

A definição de medidas eficazes para a redução de atropelamentos de animais silvestres representa um grande desafio, uma vez que cada região apresenta características ambientais específicas e distintos padrões de colisão (Forman *et al*., 2003; Coffin, 2007; Bueno *et al*., 2015; Schwartz *et al*., 2020). Embora exista uma exigência legal para que concessionárias de rodovias apresentem relatórios sobre colisões entre veículos e animais, tanto em nível federal (Instrução Normativa 13/2013 IBAMA) quanto estadual (Resolução 98/2016 CEMA-PR e Lei Estadual

19939/2019), a literatura aponta problemas significativos relacionados à amostragem e à subnotificação dos dados oficiais (Dornas *et al*., 2012; Balčiauskas *et al*., 2020).

Diante desse cenário, a identificação e análise detalhada dos padrões de atropelamentos de fauna silvestre em cada região são fundamentais para embasar a implementação de estratégias mitigadoras. Medidas como a instalação de passagens subterrâneas, viadutos, cercas e redutores de velocidade têm sido propostas para minimizar esses impactos.

Ainda que o conhecimento demográfico das populações locais seja limitado, compreender quais espécies são afetadas, quantos indivíduos morrem e os pontos críticos onde essas ocorrências se concentram pode representar um passo essencial para prever os efeitos das colisões viárias sobre a biodiversidade e promover ações mais eficazes para a conservação da fauna (Forman *et al*., 2003; Dornas *et al*., 2012).

A radiografia é uma das ferramentas mais utilizadas na avaliação de animais atropelados, sendo essencial para a detecção e análise de fraturas e luxações, além de auxiliar no planejamento e monitoramento do tratamento (Piermattei *et al*., 2006). Para garantir maior precisão na avaliação das lesões, recomenda-se a obtenção de duas vistas ortogonais (90º) da mesma área afetada (Piermattei *et al*., 2006).

Além de seu papel na medicina veterinária de animais domésticos, a radiologia destaca-se como a técnica de imagem mais amplamente empregada na rotina clínica de animais silvestres (Pinto, 2020). Seu uso é justificado pelo custo-benefício vantajoso, pela natureza não invasiva do procedimento e pela capacidade de detectar diversas patologias de forma acessível e eficiente (Thrall, 2014; Pinto, 2020). No entanto, a interpretação dos exames radiográficos e de outros exames diagnósticos complementares deve levar em consideração as particularidades anatômicas específicas de cada espécie, garantindo maior precisão no diagnóstico e tratamento.

Contudo, ainda são escassos os estudos que abordam especificamente as fraturas em animais silvestres vítimas de atropelamento (Arguedas *et al*., 2019). O monitoramento das causas de mortalidade dentro dessas populações representa um grande desafio, tornando a análise de animais feridos e mortos uma ferramenta essencial para obtenção de dados indiretos sobre tendências populacionais e padrões de uso da paisagem (Fajardo, 2001; Wendell *et al*., 2002).

Compreender a incidência e a morfologia das lesões mais frequentes nas espécies mais afetadas por atropelamentos permite que profissionais envolvidos no resgate e na reabilitação de animais silvestres tomem decisões mais assertivas, maximizando as chances de recuperação e reintegração dos indivíduos ao seu habitat natural. Quando a soltura não é viável, a manutenção desses animais em cativeiro também pode desempenhar um papel importante para a conservação, permitindo estudos e ações de manejo.

Além disso, a implementação de medidas eficazes para mitigar os atropelamentos contribui não apenas para a proteção individual dos animais, mas também para a preservação das espécies em nível populacional, reforçando a necessidade de estratégias integradas de conservação.

O número de estudos sobre atropelamento de fauna silvestre no Brasil tem crescido nos últimos anos; contudo, as informações disponíveis permanecem fragmentadas e muitas vezes restritas a localidades específicas. Essa lacuna dificulta o desenvolvimento de estratégias abrangentes e eficazes de mitigação. Nesse contexto, o presente estudo buscou contribuir para o conhecimento sobre o tema por meio da análise radiográfica de mamíferos silvestres vítimas de atropelamento em rodovias do sudoeste do Paraná, considerando um período de um ano.

A pesquisa incluiu a identificação das principais espécies afetadas e a caracterização detalhada das lesões por região topográfica, fornecendo subsídios técnicos para profissionais envolvidos no resgate e na reabilitação da fauna. Dessa forma, os dados obtidos podem contribuir para a formulação de estratégias mais eficazes de conservação das espécies impactadas pela infraestrutura viária.

# 2 OBJETIVOS

## 2.1 OBJETIVO GERAL

Quantificar as espécies de mamíferos silvestres encontrados atropelados sob o leito da via, em três rodovias que conectam a cidade de Realeza, Paraná, bem como realizar um estudo radiográfico destes animais visando caracterizar os traumas ósseos.

## 2.2 OBJETIVOS ESPECÍFICOS

a) Identificar as espécies de mamíferos silvestres vítimas de atropelamento, com base em sua classificação taxonômica;
b) Avaliar, por meio de exame radiográfico, os traumas ósseos decorrentes de atropelamentos, classificando-os topograficamente em quatro regiões corporais: cabeça/pescoço (HN), tórax (TX), abdômen/pelve (AP) e extremidades (EX);
c) Contribuir para a atuação dos médicos-veterinários na identificação de lesões potencialmente fatais em mamíferos silvestres atropelados, especialmente durante o atendimento em centros de triagem de animais silvestres (CETAS);
d) Analisar os registros de atropelamentos de mamíferos silvestres ao longo de um período de um ano, com o objetivo de identificar padrões sazonais e correlacioná-los as quatro estações do ano;
e) Determinar a frequência de ocorrência de lesões traumáticas por região anatômica (HN, TX, AP e EX) em mamíferos silvestres atropelados que levam ao óbito.

## 3 ARTIGO CIENTÍFICO

Os resultados da pesquisa estão apresentados na forma de artigo científico. A formatação do manuscrito está de acordo com as normas do periódico *Animal Conservation.*

*Title page*

**Radiographic analysis and topographic characterization of traumatic lesions in wildlife mammals struck by vehicles in southwestern Paraná**

***Patterns of Trauma in Road-Hit Wildlife***

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*Original Research Article*

# Radiographic analysis and topographic characterization of traumatic lesions in wildlife mammals struck by vehicles in southwestern Paraná


## Abstract

The present study aimed to quantify the species of wild mammals found run over on the road surface along three highways connecting the city of Realeza, Paraná State, as well as to perform a radiographic study of these animals in order to characterize bone traumas. Traumatic injuries resulting from roadkill were analyzed in 51 neotropical wild mammals belonging to 12 different species. The lesions were topographically classified into four categories: abdomen/pelvis (AP), thorax (TX), head/neck (HN), and extremities (EX). The most prevalent radiological findings were pelvic fractures (67%; n = 34), followed by fractures of cranial bones, including the mandible (55%; n = 28), frontal bone (45%; n = 23), occipital bone (43%; n = 22), maxilla (43%; n = 22), and parietal bone (41%; n=21). We also determined the frequency of roadkills across the seasons, with spring showing the highest number of occurrences. These results may assist veterinarians involved in the emergency care of wild animals and may also be valuable in forensic investigations where roadkill is considered a possible contributing factor to death.


Keywords: brazilian highways; diagnostic imaging; neotropical fauna; Post-mortem evaluation; wildlife monitoring.

## Introduction

The global extent of terrestrial road networks, including paved and unpaved roads, currently exceeds 64 million kilometers (CIA, 2021). Highways play a crucial role in territorial connectivity and in the transport of goods, raw materials, and passengers (Bager & Alves-Rosa, 2012). In Brazil, the state of Paraná has a road system comprising approximately 10,473.56 km of paved roads and 1,448.56 km of unpaved roads (Departamento de Estradas de Rodagem – DER, 2021).

Wildlife-vehicle collisions are considered the main anthropogenic cause of mortality among wild animals, surpassing even hunting (Forman & Alexander, 1998). Roads affect the population and genetic dynamics of species through habitat fragmentation, reducing gene flow (barrier effect) and population abundance (depletion effect) (Jackson & Fahrig, 2011). In addition to ecological impacts, the presence of animals on roadways poses a risk to traffic safety and generates substantial economic losses (Huijser et al., 2009; Abra et al., 2019; Ascensão et al., 2021).

Species vulnerability to roadkill events is associated with locomotion type, ecological and behavioral patterns, as well as seasonal variations that influence activity and movement (Laurance et al., 2009). Among the diagnostic tools employed in the assessment of road-killed animals, radiography stands out for its wide availability, low cost, and capacity to detect fractures and dislocations, being extensively used in clinical practice and wildlife medicine (Piermattei et al., 2006; Thrall, 2014; Pinto, 2020). However, the interpretation of radiographic images must take into account the anatomical particularities of each species to ensure diagnostic accuracy.

Although vehicle collisions involving domestic animals are well documented (Kolata et al., 1974; Marmarou et al., 1994; LaPlaca et al., 2007), studies focused on wildlife remain limited. Despite the fact that trauma resulting from vehicle collisions represents a major cause of morbidity and mortality within this group (Brockie et al., 2009; Navas-Suárez et al., 2018), investigations addressing the anatomopathological aspects of these injuries—such as biomechanics and topographic distribution—are still scarce (Navas-Suárez et al., 2019; Garcês et al., 2021). Existing literature primarily emphasizes ecological aspects, including landscape influence and the diversity of affected species (Coffin, 2007).

The present study aimed to identify the main wildlife species affected by vehicle collisions along a roadway segment in the southwestern region of Paraná and to characterize the topographic patterns of traumatic lesions. This research seeks to contribute to the improvement of veterinary care, rehabilitation, and conservation strategies for wildlife impacted by road infrastructure.

## Materials and Methods

Study Area

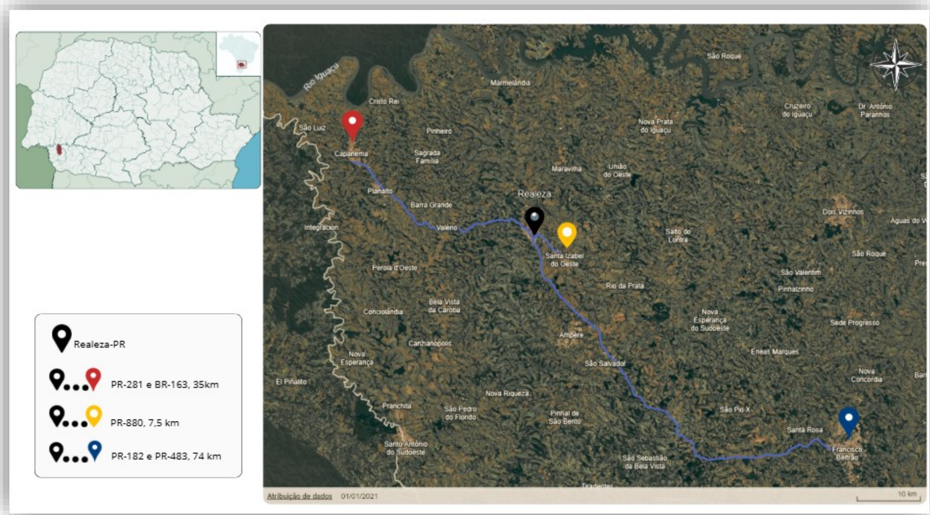
The municipality of Realeza is located in the southwestern region of the state of Paraná, Brazil, at approximate geographic coordinates 25°46'01" S and 53°31'37" W, approximately 515 km from the state capital, Curitiba. It shares borders with the following municipalities: Capitão Leônidas Marques (to the north); Capanema and Planalto (to the west); Ampére (to the south); and Santa Izabel do Oeste and Nova Prata do Iguaçu (to the east). The municipality of Capanema, situated 35 km from Realeza, is the last bordering municipality adjacent to Iguaçu National Park, which encompasses the most significant remnant of the Atlantic Forest worldwide. This park serves as a vital refuge for biodiversity and plays a crucial role in maintaining a complex ecosystem.

The municipal territory lies within the Atlantic Forest biome, specifically within the Mixed Ombrophilous Forest ecosystem, also known as Araucaria Forest, characterized by the prominent presence of *Araucaria angustifolia*. According to the Instituto de Terras, Cartografia e Geociências (ITCG, 2009), the principal phytophysiognomic formations found in the region correspond to the Montane and Submontane Mixed Ombrophilous Forests, reflecting the diversity and structural complexity of the local vegetation.

Located within the area of influence of the Iguaçu River Basin, the municipality of Realeza maintains a direct connection with Iguaçu National Park, recognized as one of Brazil’s largest and most important environmental conservation units. This relationship is grounded not only in geographic proximity but also in environmental, cultural, and economic factors that functionally integrate the region with the park, reflecting an interdependent territorial dynamic.

The research was conducted across three strategic road segments traversing the municipal territory and adjacent areas. The first corresponds to highway PR-880, spanning 7.5 km and connecting Realeza to Santa Izabel do Oeste; the second includes highways PR-182 and PR-483, with a combined length of 74 km, linking Realeza to Francisco Beltrão; and the third encompasses highways PR-281 and BR-163, totaling 35 km, which connect Realeza to Capanema. These routes consist predominantly of state highways characterized by single-lane carriageways, with most segments presenting simple two-way traffic flow and typical rural road features, such as narrow shoulders and variable alignment.The spatial distribution of these road segments and their integration within the regional road network are schematically represented in Figure 1.

Figure 1 – Spatial distribution of the highways included in this study, located in the southwestern region of the state of Paraná, with emphasis on the municipality of Realeza, situated in the western portion of the state.




Note: The map illustrates the monitored road segments connecting Realeza (black dot) to the municipalities of Capanema (PR-281 and BR-163, red dot; 35 km), Santa Izabel do Oeste (PR-880, yellow dot; 7.5 km), and Francisco Beltrão (PR-182 and PR-483, blue dot; 74 km.

Data Collection

The methodological strategy employed for obtaining wild mammal carcasses was based on opportunistic sampling, with no prior systematic monitoring conducted along the selected roadways. Carcasses were found incidentally during transit and immediately collected using appropriate Personal Protective Equipment (PPE) to ensure the biosafety of the research team. After collection, specimens were placed in plastic bags suitable for infectious biological material and transported to the storage site, where they remained frozen in freezers at temperatures below −15°C until radiographic examinations were performed.

Only carcasses of wild mammals found on the roadway surface or along its shoulders were included in the study. Specimens in an advanced state of decomposition (autolysis), those exhibiting signs of post-mortem trauma (e.g., multiple successive collisions), or with any condition that could compromise morphoradiographic analysis were excluded.

For each recorded carcass, essential data were collected, including: collection date and preliminary morphological identification of the animal. These records served as the basis for analyzing collision patterns and monitoring wildlife mortality within road-influenced areas.

Data Analysis

Sampling was non-probabilistic and convenience-based, meaning that the animals included in the study were not selected randomly but rather according to accessibility to the researchers, without employing statistical randomization criteria.

Taxonomic identification of wild mammal carcasses was performed in accordance with the criteria established in *Mamíferos do Brasil* (2nd ed.) by Reis et al. (2011), which provides the necessary technical foundation for accurate species classification. The classification of specimens by body size followed the criteria proposed by Navas-Suárez et al. (2022), dividing species into three body mass categories: small (<1 kg), medium (1.1–20 kg), and large (>20 kg).

Data on wildlife-vehicle collisions were analyzed over a 12-month period, from September 2024 to August 2025, with the objective of identifying the temporal distribution of events and the periods of highest incidence. Descriptive analyses were conducted according to month and year of occurrence, as well as seasonal frequency of cases, using the "Calendar Date" platform (https://www.calendardate.com/year2025.php) as a reference tool for defining the seasons of the year.

To enhance understanding of skeletal trauma, whole-body radiological assessments were performed using two orthogonal projections: right lateral-lateral (LLD), ventrodorsal (VD), dorsoventral (DV), mediolateral (ML), craniocaudal (CrCa), and caudocranial (CaCr), depending on the anatomical region evaluated. Radiographic images were obtained using a portable X-ray unit (Magvet® model, 320 mA and 125 kVp) coupled to a digital image acquisition and processing system (Carestream®, DirectView® CR XE model), with compatible software for image digitization and analysis.

Technical exposure parameters were selected based on the animal's body thickness and the anatomical region of interest, following the radiographic technique principles described by Muhlbauer and Kneller (2013), in order to ensure high-quality diagnostic imaging and procedural standardization.

To more precisely characterize the traumatic patterns resulting from vehicle collisions, lesions were categorized according to the anatomical topography of the affected body regions, following the methodology proposed by Kolata et al. (1974), Garcês et al. (2021), and Navas-Suárez et al. (2022). The categories used were: head and neck (HN), thorax (TX), abdomen/pelvis (AP), and extremities (EX).

Data analysis was conducted descriptively and interpretatively to provide a clear and objective overview of the distribution and severity of observed injuries, thereby contributing to the understanding of the impact of vehicle collisions on regional wildlife.

## Results and Discussion

Biological and Epidemiological Characteristics

A total of 51 wild mammals were analyzed, distributed across 12 species, 10 families, and 6 orders. The order *Carnivora* was the most representative, comprising six species (Table 1), including *Cerdocyon thous* (n = 6), *Nasua nasua* (n = 4), *Galictis cuja* (n = 4), *Leopardus wiedii* (n = 2), *Puma concolor* (n = 2), and *Procyon cancrivorus* (n = 1). This diversity highlights the broad susceptibility of Neotropical carnivores to vehicle collisions, likely due to their extensive home ranges and the frequent use of roadways as travel corridors.

Table 1 – Classification and characteristics of wild mammals collected along highways in southwestern Paraná between September 2024 and August 2025.

| Species | Order | nº | Locomotion | Activity | Diet | Social Habits |
|---|---|---|---|---|---|---|
| *Didelphis albiventris* | Didelphimorphia | 8 | Scansorial | Nocturnal | Omnivorous | Solitary |
| *Cerdocyon thous* | Carnivora | 6 | Terrestrial | Nocturnal | Omnivorous | Solitary |
| *Tamandua tetradactyla* | Pilosa | 6 | Scansorial | Nocturnal | Insectivorous | Solitary |
| *Hydrochoerus hydrochaeris* | Rodentia | 6 | Semi-aquatic | Diurnal/Nocturnal | Herbivorous | Gregarious |
| *Dasypus novemcinctus* | Cingulata | 5 | Semi-fossorial | Nocturnal | Insectivorous | Solitary |
| *Coendou prehensilis* | Rodentia | 5 | Arboreal | Nocturnal | Omnivorous | Solitary |
| *Nasua nasua* | Carnivora | 4 | Terrestrial | Diurnal | Omnivorous | Gregarious |
| *Galictis cuja* | Carnivora | 4 | Terrestrial | Diurnal/Nocturnal | Carnivorous | Small Groups |
| *Sapajus nigritus* | Primates | 2 | Arboreal | Diurnal | Omnivorous | Gregarious |
| *Leopardus wiedii* | Carnivora | 2 | Scansorial | Nocturnal | Carnivorous | Solitary |
| *Puma concolor* | Carnivora | 2 | Terrestrial | Diurnal/Nocturnal | Carnivorous | Solitary |
| *Procyon cancrivorus* | Carnivora | 1 | Scansorial | Nocturnal | Omnivorous | Solitary |

Among the recorded species, *Leopardus wiedii* (margay) stands out for being classified as Vulnerable (VU) by the IUCN (International Union for Conservation of Nature). The presence of *Sapajus nigritus* (black capuchin monkey) is also noteworthy, as it is categorized as Near Threatened (NT). Although *Puma concolor* (puma) is considered Least Concern (LC), the most recent assessment of its conservation status in the state of Paraná, conducted in 2024 (State Decree No. 6.040/2024), classified the species as Vulnerable (VU) to extinction. In this context, the Action Plan for the Conservation of Large Felids in the State of Paraná, established by Law No. 21.306/2022, aims to improve the population status of the jaguar (*Panthera onca*) and the puma, as well as to promote coexistence between humans and these large predators.

Regarding activity patterns, seven species were nocturnal, two were diurnal, and three exhibited both diurnal and nocturnal activity. Four locomotion modes were identified: terrestrial (4 species), scansorial (4 species), arboreal (2 species), and semi-aquatic and semi-fossorial (1 species each).

With respect to diet, six species were classified as omnivorous, three as carnivorous, two as insectivorous, and one as herbivorous. Most species exhibited solitary behavior (8 species), while four were gregarious or observed in small groups.

The predominance of nocturnal species observed in this study reflects a typical behavioral pattern among Neotropical wild mammals, which often adjust their activity to nocturnal periods as a strategy to reduce predation risk and intraspecific competition (Milleo et al., 2021). This pattern may also be associated with reduced traffic intensity and noise during nighttime, increasing the likelihood of road crossings (Grilo et al., 2020).

The diversity of locomotion modes recorded—including terrestrial, scansorial, arboreal, semi-aquatic, and semi-fossorial species—indicates a broad occupation of different environmental strata, reflecting landscape heterogeneity and the complex interaction between habitat use and collision risk. Terrestrial and fast-moving species tend to be more vulnerable, especially along road sections that traverse forest fragments or transition areas (Grilo et al., 2020).

The predominance of omnivorous and solitary species corroborates previous findings from roadkill studies in Brazil (Milleo et al., 2024; Grilo et al., 2020). Generalist species with high ecological plasticity tend to be more frequent in collision records, as they exploit a variety of habitats and food resources, increasing their exposure to roads and anthropized environments.

The most frequently recorded species in this study was *Didelphis albiventris* (white-eared opossum), accounting for 15.6% of total occurrences (N = 8). The high frequency of this species in roadkill events may be related to its wide geographic distribution, ecological flexibility, and opportunistic behavior, traits that facilitate the occupation of altered environments and proximity to urban and roadside areas (Prado et al., 2006; Ferreguetti et al., 2020; Milleo et al., 2024). Omnivorous and generalist species such as *D. albiventris* exhibit higher tolerance to anthropogenic disturbances and often exploit food resources along road margins, increasing collision probability.

Of the wild mammals analyzed, 26 (51%) were females, 17 (33%) males, and 8 (16%) of indeterminate sex. Regarding age class, 34 (67%) were juveniles and 17 (33%) adults. In terms of body size, 6 (12%) were small, 37 (73%) medium-sized, and 8 (16%) large. Frequencies related to biological characteristics of the specimens analyzed in this study are presented in Table 2.

Table 2 – Number and frequency of characteristics of wild mammals collected along highways in southwestern Paraná between September 2024 and August 2025.

| **Characteristic** | **Category** | **nº** | **%** |
|---|---|---|---|
| Order | *Didelphimorphia* | 8 | 16 |
| | *Carnivora* | 19 | 37 |
| | *Pilosa* | 6 | 12 |
| | *Rodentia* | 11 | 22 |
| | *Cingulata* | 5 | 10 |
| | *Primates* | 2 | 4 |
| Locomotion | Arboreal | 7 | 14 |
| | Terrestrial | 16 | 31 |
| | Scansorial | 17 | 33 |
| | Semi-fossorial | 5 | 10 |
| | Semi-aquatic | 6 | 12 |
| Activity | Diurnal | 6 | 12 |
| | Nocturnal | 33 | 65 |
| | Diurnal/Nocturnal | 12 | 24 |
| Social Habits | Gregarious | 12 | 24 |
| | Small | 4 | 8 |
| | Solitary | 35 | 69 |
| Diet | Carnivorous | 8 | 16 |
| | Herbivorous | 6 | 12 |
| | Insectivorous | 11 | 22 |
| | Omnivorous | 26 | 51 |
| Sex | Female | 26 | 51 |
| | Male | 17 | 33 |
| | Undetermined | 8 | 16 |
| Age class | Juvenile | 34 | 67 |
| | Adult | 17 | 33 |
| Body size | Small (< 1kg) | 6 | 12 |
| | Medium (1,1 a 20kg) | 37 | 73 |
| | Large ( > 20,1kg) | 8 | 16 |

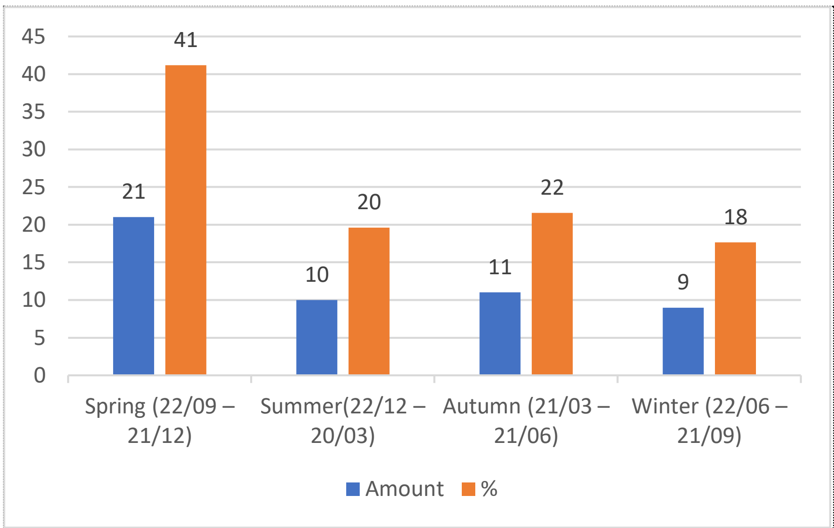
The predominance of juvenile individuals (67%) among road-killed mammals suggests that behavioral inexperience and post-weaning dispersal phases may increase susceptibility in this group. In many mammal species, juveniles initiate independent movements during dispersal in search of new territories, often requiring them to cross open areas and roads (Raymond et al., 2021). Additionally, juveniles generally have lower physical strength and slower escape responses, reducing their ability to evade oncoming vehicles (Cáceres et al., 2011).

Regarding sex, the predominance of females (51%) aligns with findings from other studies reporting female-biased road mortality among wild mammals, particularly during reproductive periods, when increased mobility occurs due to food-seeking or parental care (Moore et al., 2023). However, variation in this pattern across species and locations suggests that ecological and behavioral factors—such as seasonality, landscape type, and reproductive behavior—significantly influence sex-based mortality rates (Ascensão et al., 2022).

## Seasonality

Seasonal analysis revealed that most collisions occurred in spring (41%), followed by autumn (22%), summer (20%), and winter (18%) (Figure 2). This pattern may reflect a combination of ecological and behavioral factors, such as greater foraging activity and mobility during mild climatic periods, and increased availability of food resources, thereby elevating the likelihood of road encounters.

Figure 2 – Frequency of wildlife-vehicle collisions involving wild mammals by season of the year.



The higher number of collisions recorded in spring may be associated with the reproductive period of several wild mammal species. During this season, individuals become more active and expand their home ranges in search of mates and food, thus increasing the likelihood of road crossings. Species such as armadillos and opossums have been reported as frequent roadkill victims during this period (Smith-Patten & Patten, 2008). In this study, the absence of containment structures along monitored stretches likely facilitated animal access to the roadways.

Still, spring in southern Brazil coincides with the harvest and soil-preparation period for new crops, especially corn, wheat, and soybeans. The intensification of agricultural activities increases machinery and vehicle traffic while also altering habitat use and temporarily reducing vegetation cover, prompting animals to move in search of shelter and food. The combination of these factors, which includes increased reproductive activity, greater resource availability, and intensified human activities, promotes increased wildlife movement and, consequently, raises the incidence of roadkills during this season.

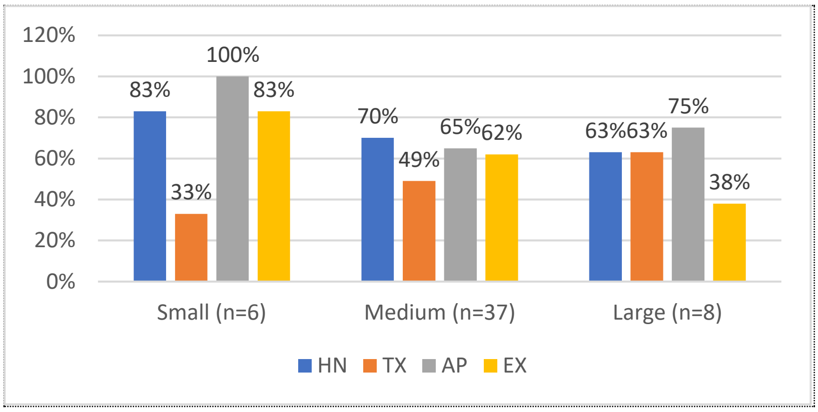
Seasonal variations in roadkill frequency can differ among regions, reflecting local environmental, ecological, and behavioral characteristics. For instance, Milleo et al. (2024) reported higher occurrence rates during autumn in northern Paraná, reinforcing the influence of regional factors on temporal distribution. Elements such as latitude, rainfall regime, fauna composition, food resource availability, and traffic intensity can alter activity and movement patterns throughout the year. Thus, although seasonality may vary across locations, the findings of this study confirm that biological and environmental factors play a decisive role in the occurrence of wildlife-vehicle collisions.

## Topographic Classification

Among the 51 mammals analyzed, topographic classification of collision-related injuries revealed the highest incidence in the abdominal/pelvic (AP) and head/neck (HN) regions, each affecting 36 individuals (71%). Lesions in the extremities (EX) were recorded in 31 individuals (61%), and thoracic (TX) injuries in 23 (45%).

Regarding the distribution of affected body segments, 15 animals presented injuries in all four regions, 10 in three, and 13 in one or two regions, indicating that a considerable proportion of collisions result in multiple and diffuse traumas consistent with high-energy impacts.

Figure 3 – Frequency of traumatic injuries by anatomical segment and body size class in wild mammals struck by vehicles.




The results of this study show that the frequency and distribution of bodily injuries resulting from roadkills vary according to mammal body size (Figure 3). A higher incidence of injuries in the abdomen/pelvis (AP) segment was recorded in small- and large-bodied individuals, whereas head/neck (HN) injuries were more prevalent in medium-sized animals. In other contexts, thoracic and abdominal injuries have been reported as the most common, followed by injuries to the head and neck (Garcês et al., 2021), indicating a general trend of greater vulnerability in these regions during vehicle collisions. Variation among the observed patterns may be associated with body size, the species involved, and road characteristics, but overall, the findings confirm that abdominal and cranial regions concentrate most fatal impacts in wild mammals.

Expectedly, small mammals exhibited a higher incidence of compressive lesions resulting from direct wheel impact (Klainbart et al., 2018). In this study, these species showed a high frequency of trauma (>80%), primarily affecting the abdominal/pelvic (AP), head/neck (HN), and extremity (EX) regions. This pattern suggests that smaller-bodied individuals are more susceptible to multi-segment trauma due to a combination of anatomical and biomechanical factors. Because of their low stature and center of mass close to the ground, these animals are often struck directly by vehicle wheels, increasing the likelihood of complete body compression. Their fast and erratic locomotion, common among small terrestrial mammals, also reduces reaction time to approaching vehicles, favoring frontal or lateral high-energy collisions.

In medium-sized mammals, a relatively balanced distribution of lesions across body regions was observed (70% in head/neck (HN), 65% in abdomen/pelvis (AP), 62% in extremities (EX), and 49% in thorax (TX)). This distribution suggests partial dissipation of impact energy across multiple anatomical regions, resulting in generalized trauma. The intermediate body mass provides some resistance to direct impact yet allows broad propagation of kinetic energy throughout the body (Cross, 2012; Taili et al., 2024). Additionally, the height of medium-sized animals often aligns with the front of light vehicles and utility trucks, making them prone to simultaneous head, trunk, and limb injuries.

In large-bodied species, a high frequency of abdominal/pelvic (AP) injuries (75%) was recorded, followed by head/neck (HN) and thoracic (TX) lesions (63%), with a marked reduction in extremity (EX) involvement (38%). This pattern indicates that as body size increases, the primary impact point shifts toward the central body regions, with reduced limb involvement. This configuration can be explained by collision dynamics: larger animals, due to greater mass and height, have a center of gravity aligned with the front of medium and large vehicles, favoring direct trunk impacts. Moreover, their higher inertia reduces the likelihood of being thrown or sustaining multiple subsequent impacts, concentrating kinetic energy in a single contact point.

These findings contribute to understanding the dynamics of wildlife-vehicle collisions and underscore the importance of mitigation strategies tailored to species-specific morphological and behavioral traits. Measures such as wildlife underpasses or overpasses and fencing systems should be planned according to animal body size and movement patterns. In areas with a predominance of small-mammal collisions, localized interventions, such as speed-reduction devices and warning signage in critical segments, may represent more effective prevention alternatives.

## Radiographic Findings

The main radiographic findings in wild mammals struck by vehicles were pelvic fractures (67%; n = 34), followed by fractures of cranial bones, including the mandible (55%; n = 28), frontal bone (45%; n = 23), occipital bone (43%; n = 22), maxilla (43%; n = 22), and parietal bone (41%; n = 21). The high frequency of pelvic fractures may be related to the anatomical positioning of this structure, located near the body's center of mass and therefore often in the direct line of vehicle impact.

In quadrupedal mammals, the pelvis acts as a transitional structure between the hind limbs and trunk, responsible for absorbing and redistributing forces during locomotion. Upon collision, this region tends to receive a significant portion of the kinetic energy generated by impact, especially when the animal is struck laterally or while attempting to cross the road.

Furthermore, the structural rigidity of the pelvis and its direct articulation with the vertebral column limit force dissipation, often resulting in complex or multiple fractures. Additionally, the flight behavior exhibited by many wild species—characterized by moving away from the stimulus in the opposite direction of the vehicle—favors injury to the posterior body, particularly the pelvis and sacrum (Intarapanich et al., 2016). The frequency and distribution of these lesions are presented in Table 3.

Table 3 – Main radiological findings in Brazilian wild mammals presenting traumatic injuries resulting from vehicle collisions.

| **Radiological Findings** | **Total (n=51)** | **Carnivora (n=19)** | **Didelphimorphia (n=8)** | **Pilosa (n=6)** | **Rodentia (n=11)** | **Cingulata (n=5)** | **Primates (n=2)** |
|---|---|---|---|---|---|---|---|
| *HN* | | | | | | | |
| Frontal bone fracture | 23 (45%) | 6 (32%) | 4 (50%) | 6 (100%) | 4 (36%) | 2 (40%) | 1 (50%) |
| Occipital bone fracture | 22 (43%) | 9 (47%) | 1 (13%) | 4 (67%) | 5 (45%) | 2 (40%) | 1 (50%) |
| Temporal bone fractur | 19 (37%) | 7 (37%) | 2 (25%) | 4 (67%) | 4 (36%) | 1 (20%) | 1 (50%) |
| Parietal bone fracture | 21 (41%) | 6 (32%) | 3 (38%) | 4 (67%) | 5 (45%) | 2 (40%) | 1 (50%) |
| Mandibular fracture | 28 (54%) | 8 (42%) | 5 (63%) | 6 (100%) | 6 (55%) | 2 (40%) | 1 (50%) |
| Maxillary fracture | 22 (43%) | 7 (37%) | 3 (38%) | 5 (83%) | 4 (36%) | 2 (40%) | 1 (50%) |
| Nasal bone fracture | 14 (27%) | 4 (21%) | 3 (38%) | 1 (17%) | 4 (36%) | 1 (20%) | 1 (50%) |
| Cervical vertebra fracture | 7 (14%) | 2 (11%) | 0 (0%) | 3 (50%) | 1 (9%) | 1 (20%) | 0 (0%) |
| Zygomatic bone fracture | 15 (29%) | 6 (32%) | 2 (25%) | 1 (17%) | 3 (27%) | 2 (40%) | 1 (50%) |
| *TX* | | | | | | | |
| Rib fracture | 20 (39%) | 5 (26%) | 1 (13%) | 5 (83%) | 6 (55%) | 3 (60%) | 0 (0%) |
| Toracic vertebra fracture | 11 (22%) | 4 (21%) | 2 (25%) | 1 (17%) | 4 (36%) | 0 (0%) | 0 (0%) |
| Sternum fracture | 1 (2%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (9%) | 0 (0%) | 0 (0%) |
| *AP* | | | | | | | |
| Pelvic fracture | 34 (67%) | 10 (53%) | 6 (75%) | 5 (83%) | 10 (91%) | 2 (40%) | 1 (50%) |
| Lumbar bvertebra fracture | 14 (27%) | 4 (21%) | 2 (25%) | 2 (33%) | 5 (45%) | 1 (20%) | 0 (0%) |
| Coxofemoral joint luxation | 8 (16%) | 1 (5%) | 2 (25%) | 0 (0%) | 5 (45%) | 0 (0%) | 0 (0%) |
| Coccygeal vertebra fracture | 1 (2%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (9%) | 0 (0%) | 0 (0%) |
| Sacral fracture | 6 (12%) | 4 (21%) | 1 (13%) | 1 (17%) | 0 (0%) | 0 (0%) | 0 (0%) |
| *EX* | | | | | | | |
| Tibial fracture | 10 (20%) | 3 (16%) | 0 (0%) | 4 (67%) | 3 (27%) | 0 (0%) | 0 (0%) |
| Scapular fracture | 13 (25%) | 5 (26%) | 2 (25%) | 3 (50%) | 1 (9%) | 1 (20%) | 1 (50%) |
| Fibular fracture | 6 (12%) | 1 (5%) | 0 (0%) | 2 (33%) | 3 (27%) | 0 (0%) | 0 (0%) |
| Radial fracture | 8 (16%) | 1 (5%) | 3 (38%) | 2 (33%) | 1 (9%) | 1 (20%) | 0 (0%) |
| Ulnar fracture | 6 (12%) | 2 (11%) | 2 (25%) | 1 (17%) | 0 (0%) | 1 (20%) | 0 (0%) |
| Femoral fracture | 18 (35%) | 5 (26%) | 2 (25%) | 3 (50%) | 5 (45%) | 3 (60%) | 0 (0%) |
| Humeral fracture | 13 (25%) | 5 (26%) | 1 (13%) | 4 (67%) | 1 (9%) | 2 (40%) | 0 (0%) |
| Humeralradial join luxation | 1 (2%) | 0 (0%) | 1 (13%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |

In addition to pelvic fractures, a high frequency of cranial bone injuries, including the mandible, frontal, occipital, maxillary, and parietal bones, was observed. Similar findings have been reported in other studies (Simpson et al., 2009; Taili et al., 2024), suggesting that high-energy frontal or lateral impacts frequently result in cranial fractures in roadkill victims. This pattern is closely related to the impact kinematics, since the vehicle's kinetic energy is transferred unevenly to the animal's body, creating multiple focal points of force concentration.

In many cases, the instinctive flight response causes animals to alter their posture, by raising the head, turning the trunk, or accelerating across the road, exposing the cranial region to first contact with the vehicle or surrounding hard surfaces such as the pavement or the vehicle itself. Moreover, anatomical characteristics shared among mammals, such as the relative fragility of facial bones and reduced muscular coverage of the head, further increase vulnerability to fractures, even during secondary impacts.

In contrast to the predominance of cranial injuries observed in other species, the individuals of *Cerdocyon thous* analyzed in this study exhibited a higher frequency of pelvic fractures (67%), followed by involvement of lumbar vertebrae (50%), appendicular skeleton (33%), and cranial bones (33%). The concentration of lesions in the posterior region of the body supports the hypothesis that medium- to large-sized carnivores tend to orient their bodies with their backs facing the oncoming vehicle at the moment of impact (Argyros & Roth, 2016). Similar anatomical patterns, characterized by greater involvement of the appendicular skeleton in mammals struck by vehicles, have also been reported in previous studies (Minar et al., 2013; Jang et al., 2019), reinforcing the influence of body size and species-specific behavior on fracture distribution.

Among the long bones evaluated, the femur showed the highest frequency of fractures (35%), followed by the humerus (25%), tibia (20%), and radius (16%). The greater susceptibility of the femur to fractures in vehicular collisions may be associated with its anatomical position and its structural role in weight-bearing. This pattern has likewise been reported in other studies (Jang et al., 2019), emphasizing the importance of this bone in trauma resulting from high-energy impacts.

In *Tamandua tetradactyla*, all radiographed individuals exhibited some degree of cranial involvement, with a 100% incidence of fractures in the frontal bone and mandible, 83% in the maxilla, 67% in the occipital, temporal, and parietal bones, and 17% in the nasal and zygomatic bones. The predominance of fractures in this region may be associated with anatomical and behavioral traits typical of xenarthrans, such as plantigrade locomotion, short limbs, and slow movement, which reduce the capacity for evasive responses in the presence of approaching vehicles (Arguedas et al., 2019; Ribeiro et al., 2017). Limited visual acuity may further contribute to the increased vulnerability of this species to frontal impacts during collisions.

In tapirs (*Tapirus terrestris*), large-bodied animals with short limbs and robust trunks, fractures are most frequently observed in the thoracic and abdominal/pelvic regions, followed by the head/neck and extremities (Navas-Suárez et al., 2019). Considering similar anatomical features, capybaras (*Hydrochoerus hydrochaeris*) also exhibited a fracture pattern concentrated in these regions, with notable involvement of lumbar vertebrae (83% of cases) and thoracic fractures, including ribs (83%), among the six radiographed individuals in this study.

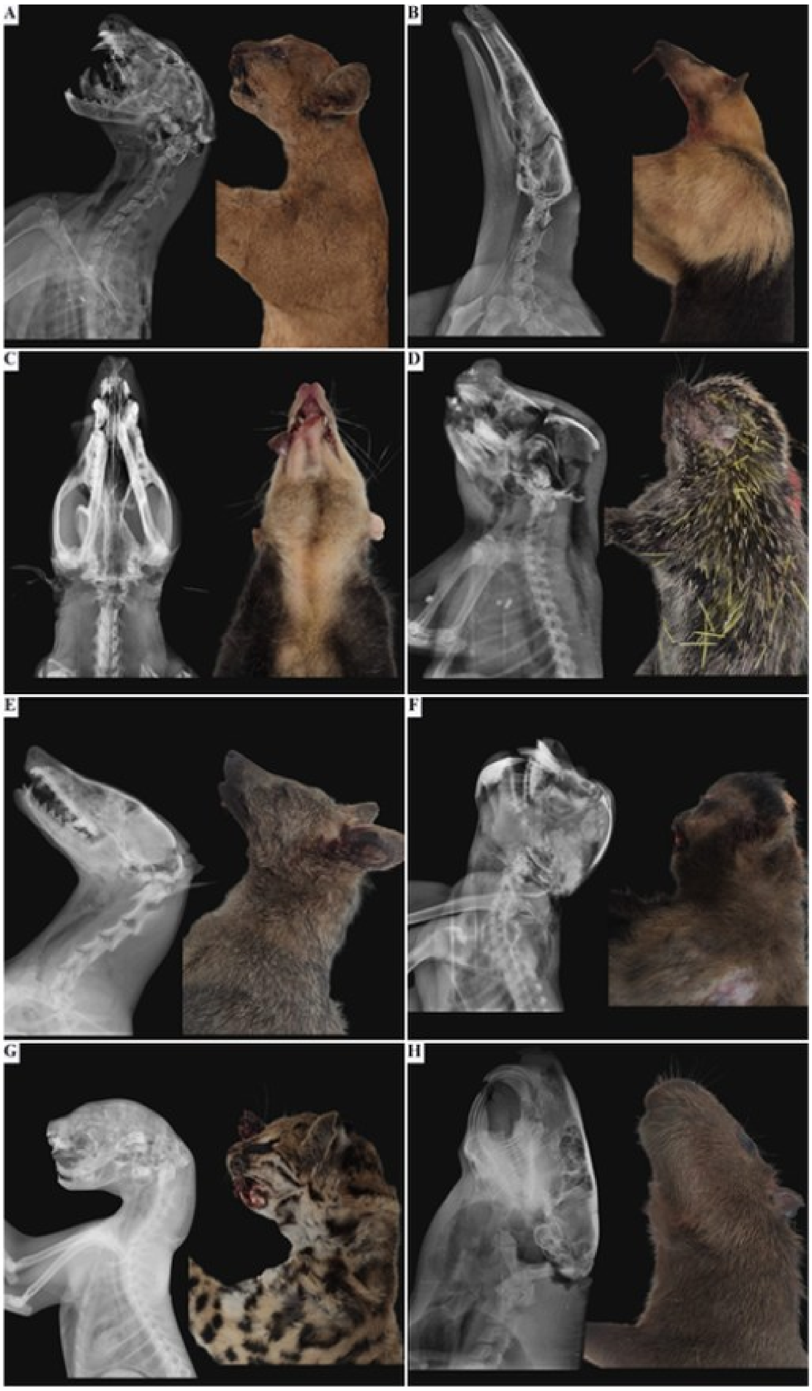
The predominance of thoracic and abdominal fractures may be explained by the height of these animals' center of gravity relative to the front of vehicles, which favors direct impacts on the trunk during collisions. Moreover, their compact body conformation combined with high body mass reduces the ability to dissipate kinetic energy at the moment of impact, concentrating forces in the thoracoabdominal cavity.

In the present study, all eight specimens of white-eared opossums (*Didelphis albiventris*) exhibited at least one bone fracture. The most frequently affected regions were the pelvis (75%), mandible (63%), and frontal bone (50%), while among the extremities, the radius was the most commonly fractured bone (38%). In contrast, Ribas (2016), who analyzed a road-killed *D. albiventris* specimen through radiography and forensic necropsy, reported no evidence of fractures or dislocations.

Two cases of roadkill involving black-horned capuchin monkeys (*Sapajus nigritus*) were identified. One individual presented multiple cranial fractures, whereas the other exhibited pelvic fractures. Although such occurrences were documented in this study, Hetman et al. (2019) note that roadkill involving non-human primates is considered relatively rare on a global scale, likely due to the lower population density of these species in high-traffic areas and their more cautious behavior when confronted with approaching vehicles.

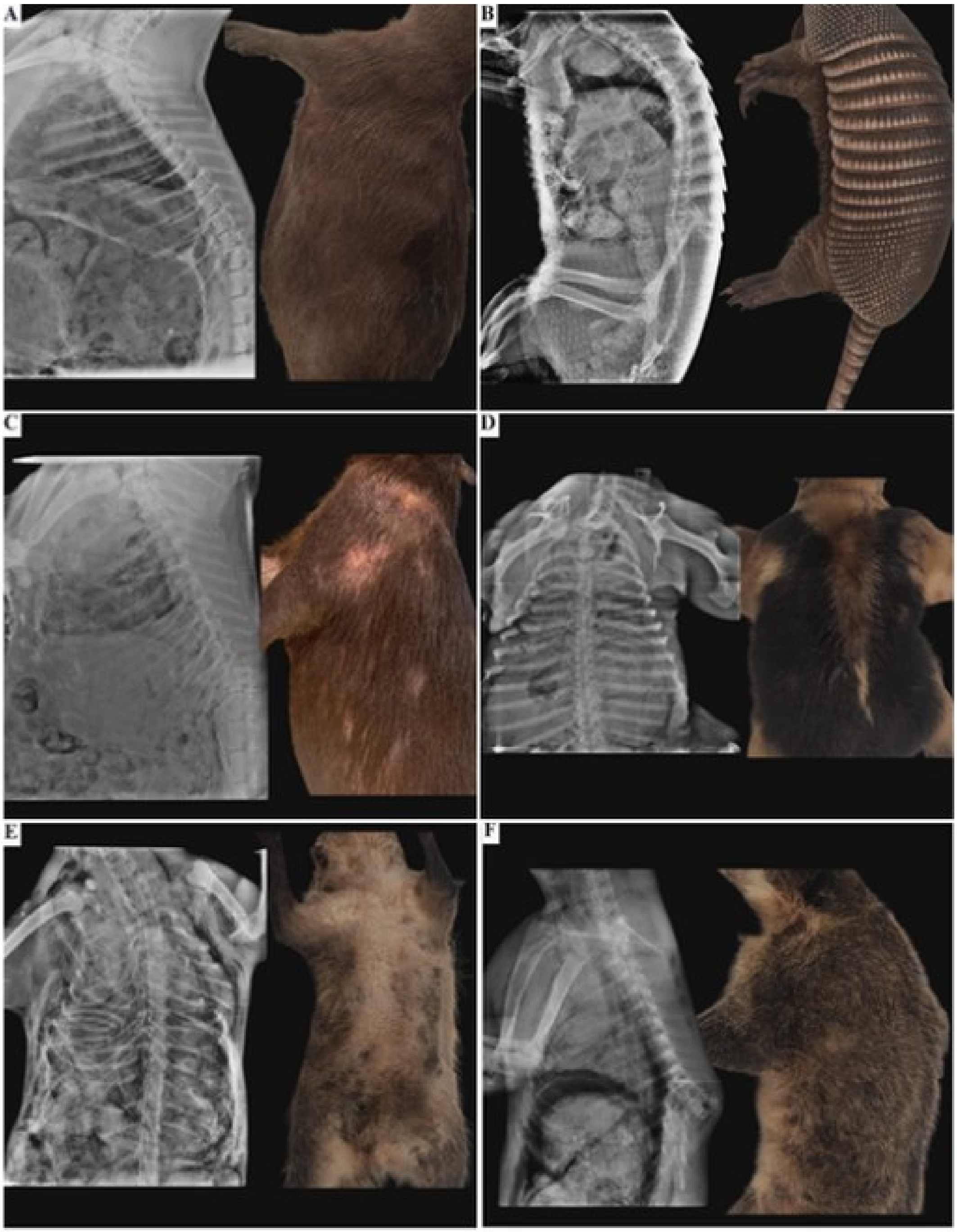
Postmortem imaging modalities, such as radiography, computed tomography, and magnetic resonance imaging, are widely used in patients involved in vehicular collisions, allowing for the detection of injuries that may not be evident upon gross examination and enabling reconstruction of impact dynamics through computational tools (Chatzaraki et al., 2018). In the present study, radiographs allowed the identification of pelvic, craniofacial, and other skeletal fractures that could have gone unnoticed during necropsy, highlighting the importance of advanced diagnostic imaging techniques for animals involved in vehicular trauma.

Figure 4 – Vehicle collision injuries in wild mammals involving the head and neck region (NH), radiograph (left) showing bone fractures and structural alterations, compared to photograph (right) of the specimen.



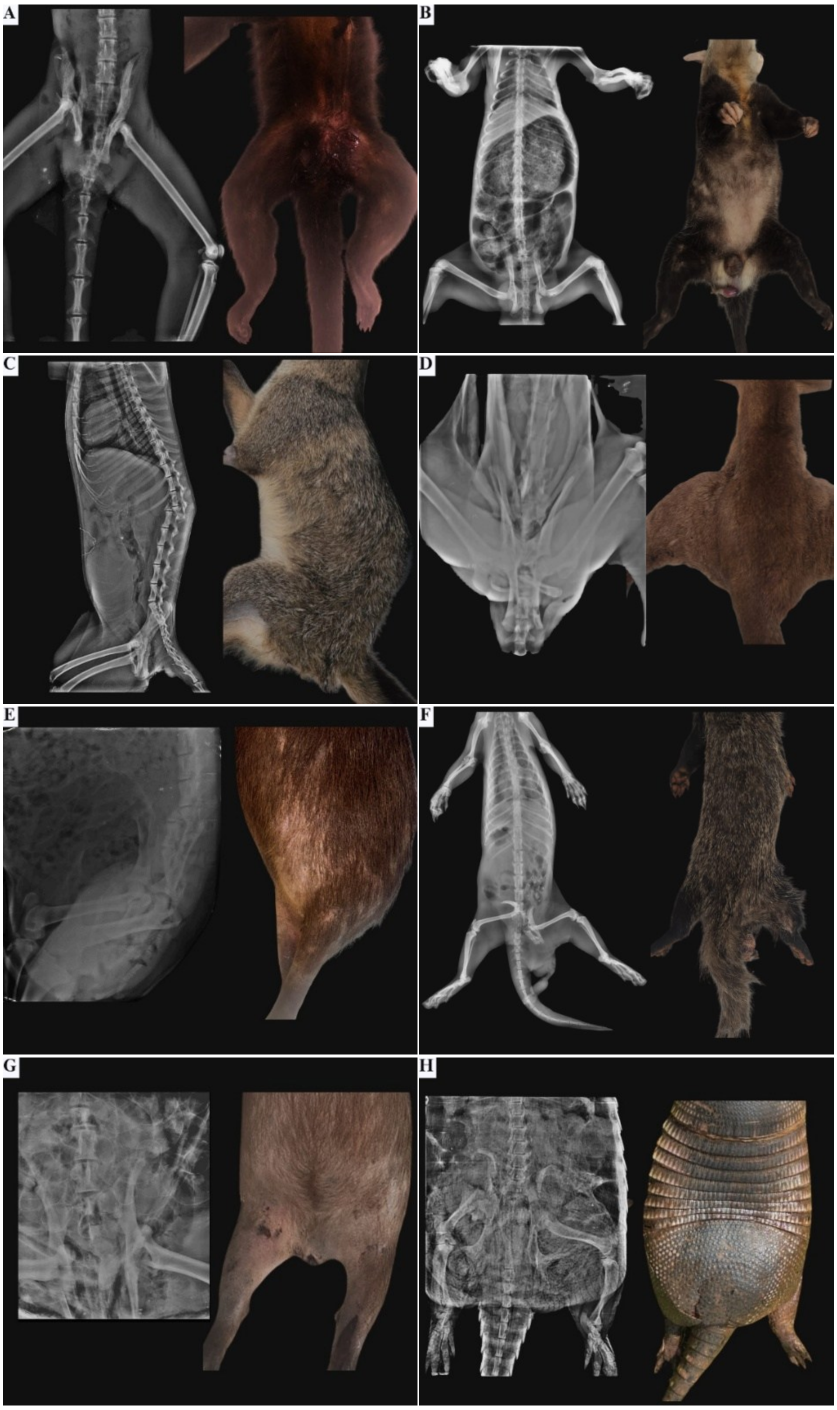
Note: (A) *Puma concolor.* Cranial trauma with fractures in the nasal, frontal, parietal, temporal, occipital, zygomatic, mandible, and maxilla bones, and fracture of cervical vertebra C3. (B) *Tamandua tetradactyla.* Fracture in the frontal bone. (C) *Didelphis albiventris.* Mandibular fracture. (D) *Coendou prehensilis.* Cranial trauma with fractures in the nasal, frontal, parietal, temporal, occipital, zygomatic, mandible, and maxilla bones. (E) *Cerdocyon thous.* Fractures in the parietal, temporal, and occipital bones. (F) *Sapajus nigritus.* Cranial trauma with fractures in the nasal, parietal, temporal, occipital, zygomatic, mandible, and maxilla bones. (G) *Leopardus wiedii.* Cranial trauma with fractures in the nasal, frontal, parietal, temporal, occipital, zygomatic, mandible, and maxilla bones. (H) *Hydrochoerus hydrochaeris.* Fracture in the occipital bone.

Figure 5 – Vehicle collision injuries in wild mammals involving the thoracic region (TX): radiograph (left) showing bone fractures and structural alterations, compared to photograph (right) of the specimen.




Note: (A) *Hydrochoerus hydrochaeris*. Rib fractures and fracture of thoracic vertebra T12. (B) *Dasypus novemcinctus*. Rib fractures. (C) *Hydrochoerus hydrochaeris*. Rib fractures and fractures of thoracic vertebrae T12. (D) *Tamandua tetradactyla*. Rib fractures. (E) *Procyon cancrivorus*. Rib fractures. (F) *Nasua nasua*. Fracture of thoracic vertebra T12.

Figure 6 – Vehicle collision injuries in wild mammals involving the abdominal/pelvic region (AP): radiograph (left) showing bone fractures and structural alterations, compared to photograph (right) of the specimen.




Note: (A) *Sapajus nigritus.* Pelvic fracture involving the ilium, ischium, and pubis. (B) *Didelphis albiventris.* Pelvic fracture involving the ilium. (C) *Cerdocyon thous.* Fracture of lumbar vertebra L2. (D) *Puma concolor.* Pelvic fracture involving the ilium. (E) *Hydrochoerus hydrochaeris.* Fracture of lumbar vertebra L6. (F) *Galictis cuja.* Pelvic fracture involving the ilium, ischium, and pubis. (G) *Hydrochoerus hydrochaeris.* Pelvic fracture involving the ilium, pubis, and ischium, with coxofemoral luxation. (H) *Dasypus novemcinctus.* Pelvic fracture involving the ilium and pubis.

Figure 7 – Vehicle collision injuries in wild mammals involving the limb region (EX): radiograph (left) showing bone fractures and structural alterations, compared to photograph (right) of the specimen.


Note: (A) *Galictis cuja.* Tibial fracture. (B) *Coendou prehensilis.* Tibia and fibula fractures. (C) *Coendou prehensilis.* Femoral fracture. (D) *Puma concolor.* Humeral fracture. (E) *Hydrochoerus hydrochaeris.* Tibia and fibula fractures. (F) *Didelphis albiventris.* Radius and ulna fractures. (G) *Nasua nasua.* Tibia and fibula fractures. (H) *Tamandua tetradactyla.* Radius and ulna fractures.

Future research should prioritize direct behavioral observations of animals in areas with varying traffic intensities, employing technologies such as GPS tracking, camera traps, and motion sensors to identify behavioral patterns associated with collision risk. The findings of such studies could inform more effective mitigation strategies, including the implementation of wildlife crossings, directional fencing, and adaptive signage, thereby promoting wildlife conservation in high-traffic regions.

Specifically, research on giant anteaters indicates that individuals inhabiting areas near roads do not actively use existing crossing structures, suggesting the need for fencing to direct animals toward these safe passages (Noonan et al., 2021). Although the data from this study do not allow direct assessment of such behavior, they confirm that fatal vehicle collisions represent one of the principal causes of mortality among Neotropical fauna.

## Conclusions

The present study described the topographic pattern of traumatic lesions in Neotropical wild mammals resulting from vehicle collisions, providing relevant information for understanding the mechanisms of fatal trauma across different body regions. A higher occurrence of injuries was observed in the abdominal/pelvic and cranial regions compared to the thoracic region and extremities. Bone fractures, whether isolated or multiple, were frequently identified radiographically in one or more body segments, underscoring the severity of the impacts and offering valuable insights for diagnosing deaths associated with roadkill events.

Additionally, seasonal variation was observed in the occurrence of these events, with a higher number of cases recorded during spring, indicating that temporal factors may influence species vulnerability. The results contribute to improving clinical and veterinary emergency responses and serve as a valuable scientific reference for forensic investigations and wildlife conservation actions aimed at mitigating the impacts of road infrastructure on native fauna.

## Statements and Declarations

All authors have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors

*Competing Interests:* None.

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# 4 CONSIDERAÇÕES FINAIS

O presente estudo permitiu caracterizar o padrão topográfico das lesões traumáticas em mamíferos silvestres neotropicais vítimas de colisões com veículos, evidenciando que as regiões de abdômen/pelve e crânio são as mais acometidas, em comparação ao tórax e às extremidades. A alta frequência de fraturas ósseas, isoladas ou múltiplas, identificadas radiologicamente em diferentes segmentos corporais, demonstra a gravidade dos impactos e reforça a importância do exame por imagem como ferramenta auxiliar no diagnóstico de mortes por atropelamento.

A análise temporal revelou ainda uma variação sazonal na ocorrência desses eventos, com maior número de registros durante a primavera, o que sugere influência de fatores biológicos e ambientais, como períodos reprodutivos e aumento da atividade de deslocamento de determinadas espécies. Esse padrão indica que a vulnerabilidade à colisão com veículos não é uniforme ao longo do ano, mas reflete dinâmicas ecológicas específicas de cada grupo.

Os resultados obtidos fornecem subsídios relevantes à prática médico-veterinária, especialmente no atendimento emergencial e no manejo clínico de fauna silvestre, contribuindo para o reconhecimento e a interpretação das lesões compatíveis com atropelamentos. Além disso, oferecem base científica para o desenvolvimento de protocolos forenses que permitam identificar com maior precisão a causa mortis em casos suspeitos de trauma veicular.

Do ponto de vista da conservação, os achados reforçam a urgência da implementação de medidas de mitigação direcionadas, considerando as particularidades de cada grupo taxonômico e os períodos de maior vulnerabilidade. A integração entre monitoramento viário, diagnóstico veterinário e políticas públicas de conservação é essencial para reduzir a mortalidade de fauna silvestre e mitigar os impactos das rodovias sobre os ecossistemas neotropicais.

Por fim, esta pesquisa contribui para o avanço do conhecimento sobre a interação entre fauna e infraestrutura viária no Brasil, destacando a importância de abordagens interdisciplinares que unam a medicina veterinária, a ecologia e a gestão ambiental no enfrentamento desse relevante problema de conservação.

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