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Comparison between wildlife-vehicle collisions and fauna recorded by camera traps in highways and fragments of Mixed Ombrophilous Forest in Southern Brazil

Comparação entre a fauna atropelada e registrada por armadilhas fotográficas em rodovias e fragmentos de Floresta Ombrófila Mista no Sul do Brasil

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ABSTRACT

Road expansion and the consequent fragmentation of natural habitats pose significant challenges to biodiversity, particularly in endangered biomes such as the Atlantic Forest. This research aimed to inventory the vertebrate species hit along two highways and evaluate the diversity of vertebrate fauna in adjacent forest fragments, recorded by camera traps. It also sought to identify seasonal patterns of wildlife-vehicle collisions and analyze risk factors associated with fauna mortality. The study was conducted on the VRS 873 and ERS 373 highways in the municipalities of Morro Reuter, Santa Maria do Herval, and Gramado, within the Rio Caí Hydrographic Basin, in the state of Rio Grande do Sul, Brazil, between September 2023 and August 2024. Complementary methodologies for monitoring fauna were used, including systematic surveys of carcasses on the roads and records of nine camera traps, installed in adjacent fragments of Mixed Ombrophilous Forest. Photographic records and wildlife-vehicle collisions totaled 58 vertebrate species, belonging to four taxonomic classes, distributed in 19 orders and 41 families. Amphibians were the group most impacted by wildlife-vehicle collisions, followed by reptiles and mammals, while birds had the lowest incidence. Seasonality influenced the frequency of collisions, possibly associated with climate variations and reproductive patterns of the species. The comparison between data from the highways and forest fragments revealed significant differences in the composition of the recorded fauna, indicating that some groups—particularly amphibians and reptiles—are more vulnerable to wildlife-vehicle collisions due to factors such as displacement behavior and habitat availability. The identification of wildlife-vehicle collisions hotspots highlights the need for mitigating strategies, such as wildlife passages and road signs, to reduce the impacts on biodiversity and subsidize conservation policies in the region.

Keywords: highway; Araucaria Forest; vertebrates hit; wild fauna conservation; collisions hotspots.

RESUMO

A expansão rodoviária e a consequente fragmentação dos habitats naturais impõem desafios significativos à biodiversidade, especialmente em biomas ameaçados, como a Mata Atlântica. A pesquisa teve como objetivo inventariar as espécies de vertebrados atropelados ao longo de duas rodovias e avaliar a diversidade da fauna de vertebrados registrada por armadilhas fotográficas em fragmentos florestais adjacentes. Além disso, buscou-se identificar padrões sazonais de atropelamento e analisar fatores de risco associados à mortalidade da fauna. O estudo foi conduzido nas rodovias VRS 873 e ERS 373 nos municípios de Morro Reuter, Santa Maria do Herval e Gramado, inseridos na Bacia Hidrográfica do Rio Caí (BHRC), entre setembro de 2023 e agosto de 2024. Metodologias complementares de monitoramento foram aplicadas, incluindo levantamentos sistemáticos de carcaças nas estradas e registros de nove armadilhas fotográficas instaladas em fragmentos de Floresta Ombrófila Mista adjacentes. Os registros fotográficos e os atropelamentos totalizaram 58 espécies de vertebrados, pertencentes a quatro classes taxonômicas, distribuídas em 19 ordens e 41 famílias. Os anfíbios foram os mais impactados pelos atropelamentos, seguidos por répteis e mamíferos, enquanto as aves apresentaram a menor incidência. A sazonalidade influenciou a frequência dos atropelamentos, possivelmente associada a variações climáticas e padrões reprodutivos das espécies. A comparação entre os dados das rodovias e dos fragmentos florestais revelou diferenças significativas na composição da fauna registrada, indicando que alguns grupos são mais vulneráveis a colisões veiculares em função de fatores como comportamento de deslocamento e disponibilidade de habitat, como no caso de anfíbios e répteis. A identificação de pontos (*hotspots*) de atropelamento destaca a necessidade de estratégias mitigadoras, como passagens de fauna e sinalização viária, para reduzir os impactos sobre a biodiversidade e subsidiar políticas de conservação na região.

Palavras-chave: autoestrada; Floresta com Araucária; vertebrados atropelados; conservação da fauna silvestre; *hotspots* de atropelamentos.

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Introduction

The largest available compilation on collisions involving terrestrial vertebrate species was published by Grilo et al. (2025). The authors analyzed 208,570 wildlife-vehicle collision records from 54 countries on six continents, covering data collected between 1971 and 2024. Collisions increase the risk of local extinction by reducing the effective size of populations and genetic diversity, as well as limiting the mechanisms of demographic recovery. These effects have the potential to decrease the distribution of species and change the spatial and temporal population dynamics, thus compromising long-term conservation efforts.

Urbanization and road expansion are among the main factors of habitat fragmentation, compromising ecological connectivity and isolating populations from wild fauna (Dias et al., 2023). In Brazil, the Atlantic Forest, one of the most threatened biomes in the world, is severely affected by these impacts (Myers et al., 2000). Lion et al. (2016) demonstrated that reptiles in the Atlantic Forest are strongly influenced by the quality of the matrix and the size of the fragments. Likewise, Steinicke et al. (2018) observed that some amphibian species maintain high abundance in fragmented areas surrounded by agricultural matrices, suggesting that local factors, such as the lack of sensitive predators and availability of resources, may favor their persistence.

Forest fragmentation reduces the availability of quality habitats and increases edge effects, making species more vulnerable to environmental pressures (Dias et al., 2023). Large mammals often adjust their activity patterns to avoid interactions with humans, which can compromise essential ecological functions such as predation and population regulation (Benítez-López, 2018). In addition, the loss of connectivity impairs fundamental processes, such as seed dispersal and migration, impacting species composition and abundance (Dib et al., 2020).

Although essential for human infrastructure, highways significantly increase fauna mortality by wildlife-vehicle collisions and affect animal behavior, influencing the distribution of species (Cavallet et al., 2023). Connectivity between natural areas minimizes the impacts of highways on biodiversity, allowing for the safe displacement of fauna and reducing collision rates (Piotto et al., 2020). Furthermore, wildlife-vehicle collision hotspots usually coincide with areas of greater biodiversity and ecological connectivity, making it essential to adopt conservation strategies in these critical sections (Rocha et al., 2023). Roads also favor the dispersion of exotic species, which compete with native fauna for resources and can act as disease vectors, negatively impacting local populations (Lessa et al., 2016). Thus, understanding the patterns of fauna movement in fragmented landscapes is paramount for effective conservation policies (Abrahms et al., 2023).

According to Pinto et al. (2022), research on highway-related mortality of wild fauna is recent in Brazil, with the first national data described and consolidated by Grilo et al. (2018), who reviewed 71 published scientific papers and accounted for 449 species as victims of wildlife-vehicle collisions: 31 amphibians, 90 reptiles, 229 birds, and 99 mammals. González-Suárez et al. (2018), with data on species occurrence, wildlife-vehicle collision rates, and road network, adjusted models to carry out spatiotemporal forecasting, and estimated that more than eight million birds and more than two million mammals can be killed annually on Brazilian roads.

Cavallet et al. (2023) conducted a study on the patterns of wildlife-vehicle collisions of small vertebrates on two roads in the coastal region of the largest continuous remnant of Brazilian Atlantic Forest, located in the state of Paraná. The authors stated that the most affected groups were birds (33.01% of collisions) and amphibians (30.62%), followed by reptiles (19.13%) and mammals (17.33%), and that warmer months had the highest rates of collisions. In a recent article, Tres et al. (2024) analyzed the impact of the RS 040 highway on vertebrates occurring in the Metropolitan Region of Porto Alegre (state of Rio Grande do Sul). This state highway, which connects the state capital to the coastal region, showed high values of wildlife-vehicle collisions during the study period; 2,371 wild animals were hit and killed, including 1.5% amphibians, 17.2% reptiles, 29.7% birds, and 51.5% mammals.

To better understand the distribution and movement of the fauna, local and regional monitoring and surveys are essential, which provide historical data for further analysis. Biodiversity inventories allow for evaluating environmental impacts and guide more effective conservation measures in the short, medium, and long term. There is no consistent inventory of fauna in forest remnants of the Atlantic Forest in the Encosta da Serra Region, surrounded by streams of the Caí River. Hence, records of wildlife-vehicle collisions and monitoring by camera traps (low invasive) should provide important data for the region.

According to Franceschi et al. (2024), monitoring by camera traps has been consolidated as an essential tool in applied ecology and conservation studies. These devices allow the collection of noninvasive data on the presence, behavior, and population density of wild species, being especially effective in areas of difficult access. In addition, they enable the precise identification of individuals based on visual characteristics, such as color, coat, body patterns, and behavior—fundamental aspects for ecological analysis and taxonomic classification.

The main objective of this research was to inventory the vertebrate species hit along the VRS 873 and ERS 373 highways, located in the municipalities of Morro Reuter, Santa Maria do Herval, and Gramado, in the state of Rio Grande do Sul, Brazil. Specifically, the aim was to i. evaluate the richness and composition of the affected fauna and adjacent forest fragments; ii. identify seasonal patterns and collision hotspots; and iii. analyze risk factors associated with fauna mortality.

Methods

The study area (Figure 1), located on the hillside of the Serra Gaúcha region, is part of the Atlantic Forest domain, with predominance of Mixed Ombrophilous Forest (IBGE, 2012). This unique phytophysiognomy, also known as Araucaria Forest, is found nowhere else in the world. The climate is humid subtropical, with variations between Cfa (hot summer) and Cfb (mild summer) classifications (Alvares et al., 2014).

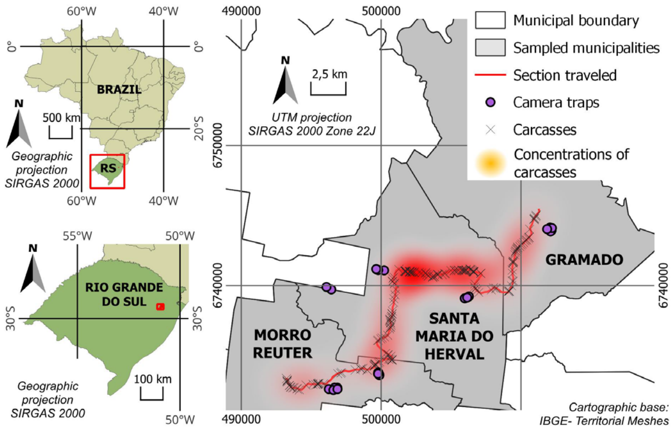

Figure 1 – Maps of the study area in Rio Grande do Sul, Brazil. On the left, the location of the state is highlighted. On the right, the municipalities of Morro Reuter, Santa Maria do Herval, and Gramado are shown, with the stretch traveled on the VRS 873 and ERS 373 highways, underlined in red. Purple dots indicate the location of the installation sites of the camera traps, while "X" symbols mark carcasses of animals hit on the highways. Yellow areas emphasize the highest concentration of wildlife-vehicle collisions recorded between September 2023 and August 2024. Projection: SIRGAS 2000.

Annual rainfall ranges from 1,700 to 1,900 mm (Rio Grande do Sul, 2020), and altitude varies between 280 to 885 m (Google LLC, 2025). The preserved native vegetation corresponds to 52% of the Gramado area (12,254.56 ha), 43% of Morro Reuter (3,808.30 ha), and 28% of Santa Maria do Herval (3,874.47 ha) (SFB, 2018). The region has abundant water resources and belongs to the sub-basins of the Caí and Sinos rivers. Morro Reuter and Santa Maria do Herval are entirely within the Rio Caí Basin, while Gramado is divided between this basin (69%) and the Rio dos Sinos Basin (31%) (SEMA, 2024). The local economy is driven by tourism in Gramado (PMG, 2024), industry in Morro Reuter (PMMR, 2024), and agriculture in Santa Maria do Herval (PMSMH, 2024).

Sampling was carried out along the highway VRS 873, which starts in Morro Reuter, and RS 373, which crosses Santa Maria do Herval and ends in Gramado, integrating the state road network of Rio Grande do Sul (DAER, 2024). The geographic coordinates of the starting point on VRS 873 are 29°31'46.26"S, 51°4'12.88"W, and those of the end point on ERS 373 are 29°25'11.90"S, 50°53'1.52"W (Figure 1). Along the studied stretch, there are forest fragments, wetlands, streams, agricultural properties (family and extensive), forestry, commercial and industrial establishments, as well as small population clusters. The highway has a simple, predominantly paved track, with a posted speed limit of 60 km/h, due to frequent curves, uphills, and downhills. Electronic speed control and bumps are present along the road to increase safety.

Between September 2023 and August 2024, sampling was carried out according to traveled stretch of road (for recording wildlife-vehicle collisions) and to camera traps (for fauna in adjacent forest fragments). Climatic data were obtained from the Meteorological Station of Canela in Rio Grande do Sul (online) (INMET, 2024), the closest to the study area. Wildlife-vehicle collisions of amphibians, birds, reptiles, and mammals were recorded, while monitoring with camera traps focused on medium - and large-sized species, captured by the sensors. All data were entered into electronic spreadsheets for further analysis.

Data collection on wildlife-vehicle collisions was carried out weekly along 34.32 km on the VRS 873 and ERS 373 highways, always in the morning, using a vehicle at 60 km/h. The route was taken in a single direction, from beginning to end, observing both sides of the highway. For each observed specimen, coordinates, date, and photographic images were recorded, allowing identification at the lowest possible taxonomic level. The carcasses found on the track and on the shoulder were considered and subsequently removed to avoid duplication of records.

Camera traps were installed simultaneously in the three municipalities, based on availability of equipment and landowners' permission to access the areas. In total, 46 spots were monitored in six different areas, corresponding to different properties. The choice of monitoring spots considered proximity to water resources, dense vegetation with canopy and trails, as well as the presence of indirect traces, such as tracks, burrows, scratches, bitten fruits, carcasses, fur, and characteristic odors. Initially, the cameras were installed for two weeks at each location, but with the increase in equipment, the period was extended to one month. Nine Bushnell and Suntek Trail Camera HC802A traps were used, equipped with motion, infrared, and flash sensors not visible for night records. Installations, revisions, and maintenance were performed monthly, replacing memory cards and transferring the images to a laptop. The recordings were analyzed by at least two researchers to identify the fauna.

Collision rates were calculated from the total number of carcasses recorded along the monitored stretch and the number of sampling processes performed. The overall rate was determined considering the relationship between the collision records, the length traveled, and the monitoring period.

For the taxonomic class analysis, the wildlife-vehicle collisions of amphibians, reptiles, birds, and mammals were calculated to compare the frequency of occurrences between the groups. In addition, the density of collisions along the highway was estimated, allowing the visualization of the spatial distribution of events. Moreover, the average distance traveled between each collision for each taxonomic class was estimated, helping to identify patterns potentially related to fauna behavior, landscape structure, and environmental characteristics of the studied area. These data support the understanding of factors that influence fauna mortality and contribute to the development of strategies to mitigate road impacts.

The taxonomic classification of species follows the most up-to-date references for each group: Segalla et al. (2021) for amphibians; Guedes et al. (2022) for reptiles; Abreu et al. (2024) for mammals; and Pacheco et al. (2021) for birds.

Results and Discussions

A total of 58 species was recorded through carcass monitoring on the highways and by camera traps (Table 1). The identified species belong to four taxonomic classes: Amphibia (5); Reptilia (11); Mammalia (26); and Birds (16), distributed in 19 orders and 41 families. The recorded orders are Anura, Squamata, Artiodactyla, Carnivora, Chiroptera, Cingulata, Didelphimorphia, Lagomorpha, Primates, Pilosa, Rodentia, Columbiformes, Cuculiformes, Galliformes, Gruiformes, Hirundinidae, Passeriformes, Strigiformes, and Piciformes.

Among the taxonomic groups recorded, amphibians presented the highest rate of collision, followed by reptiles and mammals, while birds showed the lowest numbers. A total of 42 species were detected, including 5 amphibians, 11 reptiles, 10 mammals, and 16 birds; six of these species were exotic.

The presence of exotic species in the survey reflects the anthropic influence in the area and its impacts on native fauna. *Lithobates catesbeianus* (bullfrog), a highly-dispersed invasive amphibian, threatens native populations through predation, competition, and disease transmission, accelerating the decline of local species (Johovic et al., 2020).

Table 1 – Vertebrates recorded in the monitoring of collisions and by camera traps, from September 2023 to August 2024.

TAXON	Family	Species	Common Name	Conservation Status Decree nº 51,797/2014|RS	Record Form	Nº of animals hit
CLASS AMPHIBIA						
Order Anura	*Bufonidae*	*Rhinella henseli*	Cururu Toad	-	WVC	5
		Rhinella icterica	Yellow Cururu Toad	-	WVC	85
	Hylidae	*Boana faber*	Blacksmith Tree Frog	-	WVC	14
	Leptodactylidae	*Leptodactylus luctator*	Wrestler Frog	-	WVC	1
	Ranidae	*Lithobates cataesbianus**	Bullfrog	-*	WVC	2
CLASS REPTILIA						
Order Squamata	*Anguidae*	*Ophiodes striatus*	Striped Worm Lizard	-	WVC	2
	Colubridae	*Oxyrhopus rhombifer*	Amazon False Coral Snake	-	WVC	1
		Oxyrhopus clathratus	Duméril's False Coral Snake	-	WVC	1
		Dipsas ventrimaculata	Boulenger's Tree Snake	-	WVC	4
		Helicops infrataeniatus	Cobra-d'água (in Portuguese)	-	WVC	1
		Boiruna maculata	Mussurana	-	WVC	1
		Phalotris lemniscatus	Duméril's Diadem Snake	-	WVC	1
		Echinanthera cyanopleura	Corredeira-do-mato (in Portuguese)	-	WVC	1
	Leiosauridae	*Anisoleps grilli*	Boulenger's Tree Lizard	-	WVC	3
	Teiidae	*Salvator merianae*	Argentine's Black and White Tegu	-	BF	6
	Viperidae	*Bothrops jararaca*	Jararaca	-	WVC	22
CLASS MAMMALIA						
Order Artiodactyla	*Cervidae*	*Mazama nana*	Pygmy brocket	EN	CT	0
		Subulo gouazoubira	Gray brocket	-	CT	0
Order Carnivora	*Canidae*	*Canis lupus familiaris**	Domestic dog	-*	CT	0
		Cerdocyon thous	Crab-eating fox	-	BF	3
	Felidae	*Felis catus**	Domestic cat	-*	BF	5
		Leopardus guttulus	Southern tiger cat	VU	BF	2
	Mustelidae	*Eira barbara*	Tayra	VU	CT	0
		Galactis cuja	Lesser grison	-	BF	1
	Procyonidae	*Nasua nasua*	Ring-tailed coati	VU	CT	0
		Procyon cancrivorus	Crab-eating raccoon	-	CT	0
Order Chiroptera	*Phyllostomidae*	*Glossophaga* sp.	Bat	-	CT	0

Continue...

Table 1 – Continuation.

TAXON	Family	Species	Common Name	Conservation Status Decree nº 51,797/2014|RS	Record Form	Nº of animals hit
Ordem Cingulata	*Chlamyphoridae*	*Cabassous tatouay*	Greater naked-tailed armadillo	-	CT	0
	Dasypodidae	*Dasypus novemcinctus*	Nine-banded armadillo	-	BF	4
Order Didelphimorphia	*Didelphidae*	*Didelphis albiventris*	Brazilian White-eared Opossum	-	BF	11
		Philander opossum	Gray Four-eyed Opossum	-	CT	0
Order Lagomorpha	*Leporidae*	*Lepus europaeus**	Brown hare	-*	CT	0
Order Primates	*Atelidae*	*Alouatta guariba*	Brown howler	VU	CT	0
	Cebidae	*Sapajus nigritus*	Black capuchin	-	CT	0
Order Pilosa	*Myrmecophagidae*	*Tamandua tetradactyla*	Southern tamandua	VU	CT	0
Order Rodentia	*Caviidae*	*Cavia aperea*	Brazilian guinea pig	-	WVC	5
	Cricetidae	*Oligoryzomys* sp.	Brazilian bush rat	-	CT	0
	Dasyproctidae	*Dasyprocta azarae*	Azara's agouti	VU	CT	0
	Echimyidae	*Myocastor coypus*	Nutria	-	WVC	1
	Erethizontidae	*Coendou spinosus*	Paraguayan hairy dwarf porcupine		BF	3
	Muridae	*Rattus rattus**	House rat	-*	WVC	8
	Sciuridae	*Guerlinguetus aestuans*	Brazilian squirrel	-	CT	0
CLASS BIRDS						
Order Columbiformes	*Columbidae*	*Leptotila verreauxi*	White-tipped dove	-	WVC	1
		Zenaida auriculata	Eared dove	-	WVC	1
Order Cuculiformes	*Cuculidae*	*Guira guiro*	Guira cuckoo	-	WVC	1
Order Galliformes	*Phasianidae*	*Gallus gallus**	Chicken	-*	WVC	2
	Cracidae	*Ortalis squamata*	Scaled chachalaca	-	WVC	1
Order Gruiformes	*Rallidae*	*Gallinula galeata*	Common gallinule	-	WVC	1
Order Hirundinidae	*Hirundinidae*	*Pygochelidon cyanoleuca*	Blue-and-white swallow	-	WVC	1
Order Passeriformes	*Furnariidae*	*Furnarius rufus*	Rufous hornero	-	WVC	1
	Thraupidae	*Coereba flaveola*	Bananaquit	-	WVC	1
		Sicalis flaveola	Saffron finch	-	WVC	10
		Tachyphonus coronatus	Ruby-crowned tanager	-	WVC	2
		Thraupis sayaca	Sayaca tanager	-	WVC	1
	Turdidae	*Turdus rufiventris*	Rufous-bellied thrush	-	WVC	2
	Passerellidae	*Zonotrichia capensis*	Rufous-collared sparrow	-	WVC	2
Order Strigiformes	*Strigidae*	*Strix virgata*	Mottled Owl	-	WVC	5
Order Piciformes	*Ramphastidae*	*Ramphastos dicolorus*	Red-breasted toucan	-	WVC	1
Total specimens hit in the monitoring period						226

CE: critically endangered; EN: endangered; VU: vulnerable; WVC: wildlife-vehicle collision; CT: camera trap; BF: both forms. (*): exotic species; (-) no data.

Among mammals, *Lepus europaeus* is already established in South America (Konzen et al., 2024). *Canis lupus* represents a threat to biodiversity by competing for territory, predating native species, and transmitting pathogens, thereby compromising conservation (Lessa et al., 2016). *Felis catus* reduces populations of small mammals, changing ecological dynamics in forest areas (Lazenby et al., 2021). Furthermore, *Rattus rattus,* in addition to predating eggs and small vertebrates, serves as a reservoir of parasites, impacting biodiversity and public health (Lima et al., 2024).

These factors represent challenges for the conservation of native mammals, including species registered as vulnerable, such *as Leopardus guttulus, Eira barbara, Nasua nasua, Alouatta guariba, Tamandua* *tetradactyla,* and *Dasyprocta azarae,* as well as *Mazama nana,* classified as endangered according to State Decree nº 51,797/2014 (Rio Grande do Sul, 2014). A relevant scientific advancement was the revalidation of the species *L. guttulus* (Southern tigrina) as occurring in Rio Grande do Sul (Trigo et al., 2013). This taxonomic refinement reinforces the need for periodic reviews of conservation lists, considering the increasing threats of habitat fragmentation and the presence of invasive species in the region.

During the study, 39 sampling events were conducted over a 34.32 km stretch, traveled only in one direction, totaling 1,367.89 km. In this period, 226 identifiable carcasses were registered, resulting in an average of 5.79 wildlife-vehicle collisions per sampling. Carcass density was estimated at 0.165 individuals/km, reflecting the frequency of occurrences along the monitored stretch.

Table 2 presents the distribution of wildlife-vehicle collisions between taxonomic classes, indicating the absolute number of records, percentage of total collisions, collision rate expressed in individuals/km/day, and the average distance traveled until the occurrence of a new collision. Among the analyzed groups, amphibians showed the highest incidence, corresponding to 47.35% of the records (107 individuals), with a rate of 0.080 individuals/km/day. Reptiles and mammals had the same number of records (43 occurrences each, 19.03% of the total), with a rate of 0.032 individuals/km/day and an average of 0.798 km between events. Birds recorded the lowest number of occurrences (33 individuals, 14.6% of the total), with a rate of 0.025 individuals/km/day and the highest average distance between collisions (1.04 km).

The overall rate of wildlife-vehicle collisions observed throughout the study was 0.169 individuals/km/day, evidencing the significant pressure of highways on local fauna. The average distance to the next collisions, considering all records, was 6.59 km per animal, which reinforces the frequency with which events occur along the road network.

About 11.95% of collisions (n=27) involved animals not identified in terms of species level, due to the condition of the carcasses after successive collisions. Among these records, 4.87% were amphibians (n=11); 0.44% were snakes (n=1); and 6.64% were birds (n=15). Despite the impossibility of specific identification, one of the bird records could be classified in terms of the genus, belonging to the group *Turdus* sp. (thrushes). The prominent fragmentation of the carcasses may indicate a higher frequency of collisions at certain points on the highway, suggesting that some individuals were hit several times before collection.

The collisions did not occur in a homogeneous way along the sampled stretch. According to the spatial analysis, there were areas of higher concentration of carcasses, characterizing hotspots of wildlife-vehicle collisions, especially close to forest fragments, water resources, and planting areas. Figure 1 illustrates the map of the study area, highlighting the points of higher density of wildlife-vehicle collisions and suggesting a non-uniform distribution of mortality events of the fauna. Considering the patterns of wildlife-vehicle collisions recorded in this study, similarities and differences were verified in relation to research conducted in other biomes. Authors of studies conducted in the Amazon revealed that amphibians and reptiles are the most affected groups, representing 47% of the records (Rocha et al., 2023), which corroborates the findings of this study. This vulnerability is associated with the dependence of these animals on bodies of water and limited locomotion (Cavallet et al., 2023). Conversely, mammals accounted for 19.3% of the records in the present study, while authors of surveys conducted in the Atlantic Forest and Cerrado indicate higher rates due to landscape connectivity and habitat availability (Pessanha et al., 2023).

Corrêa et al. (2017) recorded 318 vertebrates hit over 45 km in the Pampa biome, with a predominance of species with high mobility and nocturnal habits, such as *Didelphis albiventris* (white-eared opossum); this pattern was similar to that found for *Dasypus novemcinctus* (nine-banded armadillo). The two species were recorded both by camera traps and collisions, reinforcing the hypothesis of Assis et al. (2022), according to whom low terrestrial locomotion and low visual perception increase road vulnerability.

The collisions involved 209 native and 17 exotic specimens, suggesting less exposure of exotic species to road risk, possibly because they inhabit urban areas. *F. catus* and *R. rattus* are exotic species commonly associated with anthropized environments due to their high capacity to adapt to modified urban and rural areas (Lazenby et al., 2021; Lima et al., 2024). The collisions observed in this study occurred mainly near forest fragments. For *L. catesbeianus*, the records were reduced, indicating a lower road displacement compared to native amphibians.

Table 2 – Distribution of wildlife-vehicle collisions by taxonomic class, including number of records, total percentage, collision rate, and average distance traveled to a new event.

Class	Collisions (n)	Collisions (%)	Collision rate (individuals/km/day)	Km per animal hit
Class Amphibia	107	47.35	0.080	0.321
Class Reptilia	43	19.03	0.032	0.798
Class Mammalia	43	19.03	0.032	0.798
Class Birds	33	14.60	0.025	1.040
General values of wildlife-vehicle collisions	226	100%	0.169	6.59 (individuals/km)

These data reinforce the greater vulnerability of native fauna, influenced by its ecology and habitat use. Nevertheless, even in smaller numbers, exotic species can impact local fauna through competition and other ecological factors.

The variations in the records between this study and previous researches evidence the influence of environmental and behavioral factors on the distribution of collisions. Researchers indicate that periods of higher rainfall increase the displacement activity of the fauna, increasing the risk of collisions, especially for amphibians and reptiles (Pessanha et al., 2023; Rocha et al., 2023). According to the present study, 89.38% of wildlife-vehicle collisions occurred between September 2023 and March 2024. The highest rainfall incidence was recorded in May, which may have influenced both the detection of carcasses and the displacement of the fauna (Figure 2).

The heat maps, designed based on the geographical coordinates of the collisions, show critical points along the highway where the fauna faces a high risk of mortality. Figure 3 shows the general distribution of collisions—that is, the sum of all sampled groups—demonstrating areas of higher incidence throughout the studied stretch. The regions marked in deep red indicate alarming concentrations of occurrences, especially close to forest fragments, bodies of water, and cropland, reflecting the significant impact of highways on local biodiversity.

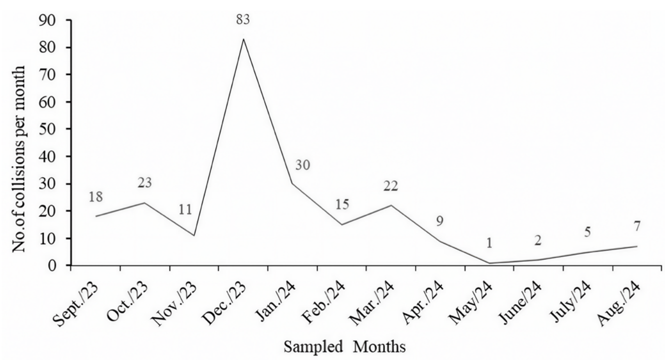

Figure 2 – Monthly distribution of collisions over the study period. Most records occurred between September 2023 and March 2024, while May 2025 presented the lowest incidence.

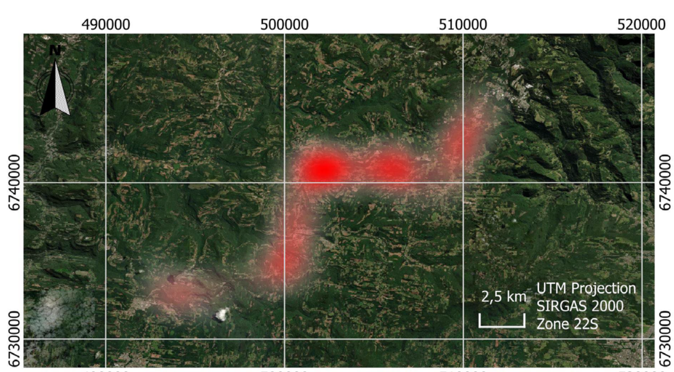

Figure 3 – Spatial distribution of wildlife-vehicle collisions recorded along the highway, showing fauna mortality hotspots (sum of amphibians, reptiles, birds, and mammals). Areas highlighted in red show stretches with higher concentration of occurrences, indicating critical zones for biodiversity.

Figure 4 details the collisions by taxonomic groups and shows distinct patterns of distribution and vulnerability. Amphibians and reptiles presented records widely distributed along the highways, with greater concentrations in areas close to forest fragments and stretches with dense vegetation on the edges. Mammals, in turn, recorded collisions more concentrated at specific spots, suggesting the use of recurrent routes for displacement. Conversely, birds were mainly recorded in a single stretch of the highways with higher speed, flat terrain and with the presence of grain crops — factors that can attract species adapted to open environments and, at the same time, increase the risk of collision.

In addition, the observations showed that species with low mobility were often recorded in sections with sharp curves and dense vegetation along the road edges. These conditions reduce the visibility of both animals and drivers, hindering rapid reactions and increasing the likelihood of collisions, even when there is no direct intention of causing damage to the fauna. These patterns suggest that collision hotspots result not only from the presence of fauna or forest fragments but also from structural characteristics of the highway that intensify the risk. Hence, the identification of these critical stretches of road is fundamental to subsidize mitigation strategies that consider both animal behavior and road design.

Environmental factors influenced the records, as observed in May 2024, when heavy rains limited the collections to a single sampling, in which only one carcass was found, suggesting a possible reduction in the movement of the fauna. These data reinforce the vulnerability of certain groups, particularly amphibians, which accounted for almost half of the recorded collisions, evidencing the influence of climatic and seasonal variables on the occurrence of these events.

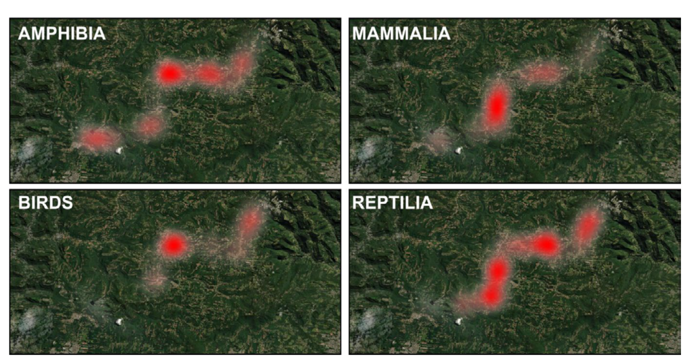

Figure 4 – Detailed mapping of collisions by taxonomic group (amphibians, birds, mammals, and reptiles). The different shades of red reflect the frequency of occurrences for each group, evidencing distinct patterns of vulnerability and allowing the identification of critical points for mitigating measures.

The spatial analysis allowed for the identification of collision hotspots, indicating a non-homogeneous distribution of events along the VRS 873 and ERS 373 highways. This pattern reinforces the influence of environmental and structural factors, such as the presence of forest fragments, proximity to water resources, and winding stretches with sharp curves. Authors of previous studies conducted in the Amazon (Rocha et al., 2023) and the Atlantic Forest (Pessanha et al., 2023) demonstrated that seasonal variation directly influences collision hotspots, being more frequent in rainy periods. The results indicate a similar pattern, with a higher concentration of collisions between September 2023 and March 2024, suggesting that climatic conditions increase the risks for amphibians and reptiles, which represented a large part of the records.

Regarding the camera traps, the sampling effort totaled 37,632 hours of recording, with videos averaging 22.05 seconds in duration, over 603 days of exposure in the three municipalities. A total of 24 species were recorded, including three exotic species.

The camera traps made it possible to document social and reproductive behaviors, especially in spring and summer, when food availability and climate conditions favor the development of young animals. This pattern was observed for *Cerdocyon thous* (crab-eating fox), *N. nasua* (ring-tailed coati), *and Subulo gouazoubira* (gray brocket). In turn, *Cabassous tatouay* (greater naked-tailed armadillo), *Coendou spinosus* (Paraguayan hairy dwarf porcupine), *Galactis cuja* (lesser grison), *Philander opossum* (gray four-eyed opossum), and *T. tetradactyla* (Southern tamandua) were recorded only once, and *T. tetradactyla*, *C. spinosus*, *C. tatouay,* and *G. cuja* occurred in winter, while *P. opossum* was exclusively recorded in summer.

The records reinforced patterns of activity described in the literature. *C. thous,* commonly classified as crepuscular/nocturnal (Trigo et al., 2014), was in fact recorded at night at several monitoring moments, confirming this pattern. However, it also exhibited significant daytime activity, especially in the morning (6:00 am to 11:59 am), possibly due to low rates of human disturbance. On several occasions, adults were observed accompanied by puppies, suggesting that daytime activity is related to parental care and foraging. The species was recorded in 19 of the 46 sampling points, demonstrating high plasticity of time and habitat.

Likewise, *E. barbara* (tayra), typically diurnal or cathemeral in tropical forests (Lima et al., 2020), maintained predominantly daytime activity in the studied fragments, reinforcing its preference for less impacted environments. According to the data, both species adjust their activity periods based on resource availability and local anthropic pressure, with *C. thous* showing greater tolerance to human presence and anthropized environments (Silva et al., 2020), while *E. barbara* persists in modified forest mosaics, provided that there is tree structure and adequate prey supply.

In addition, *S. gouazoubira*, a solitary and territorial species, used specific routes for displacement, guided by its own chemical markers (Srbek-Araujo and Alzuguir, 2024). This behavior was confirmed in the footage, where individuals repeatedly traveled the same tracks. Similarly, *D. azarae* and *N. nasua* were recorded during the day, corroborating researchers who indicate diurnal habits for these species (Assis et al., 2022).

Native species represented the largest portion of species richness recorded in the areas monitored with cameras. Among reptiles, only *Salvator merianae* (Argentine black and white tegu) was identified. Among mammals, three exotic species were verified: *C. lupus*, *F. catus*, and *L. europaeus*. The presence of these species shows their high environmental plasticity. On the one hand, *C. lupus familiaris* and *F. catus* were recorded at different times of the day and night, evidencing wide adaptation to anthropized environments and potential impact on native fauna—whether as predators, competitors, or disease vectors (Lessa et al., 2016; Lazenby et al., 2021). On the other hand*, L. europaeus* had a single night record, suggesting a lower population density or a specific use of the sampling sites. Its occurrence may be associated with the presence of natural predators, which influence its patterns of movement and activity.

The expressive number of small- and medium-sized mammal species recorded is relevant, considering that these animals have varied habits and occupy different ecological niches, which reflects the diversity present in the sampled areas. The occurrence of these species in environments under strong anthropic pressure shows the resilience of some populations but also points to the vulnerability of these groups to human activities.

In an analysis by taxonomic groups, establishing relationships between wildlife-vehicle collisions and photographic records, some comparisons are noteworthy. None of the five amphibian species were recorded by the camera trap method, as the small size of the specimens, their behavior, and their organisms with lower temperature are not detected by the infrared sensors of the equipment. This also occurred for reptiles, considering that, of the 11 species recorded, only the Argentine black and white tegu, also known as Argentine giant tegu (*S. merianae*), was recorded by camera traps, due to its size (which exceeds 50 cm) and its diurnal and crepuscular habits. Nonetheless, all species of amphibians and reptiles were victims of collisions; in particular, two species stand out: *Rhinella icterica* (yellow cururu toad) and *Bothrops jararaca* (jararaca), which are animals of wide distribution and very common in the region. Respectively, with 85 and 22 specimens hit, the two species account for 51% of the total number of individuals of wild fauna hit. Considering the classes, amphibians and reptiles totaled 150 collisions, 72% of all animals, indicating that the highway is a significant barrier for small terrestrial vertebrates in the region.

The mammals were represented by 22 wild species in the study area—the greatest richness—and presented some interesting peculiarities. *Cavia aperea* (Brazilian guinea pig) and *Myocastor coypus* (nutria) were recorded only by collisions; they are cursorial rats, unusual in forested areas, inhabitants of wetlands and grasslands, frequent users of the right-of-way of highways. Six species, namely *C. thous* (crab-eating fox), *L. guttulus* (Southern tigrina), *D. novemcinctus* (nine-banded armadillo), *G. cuja* (lesser grison), *D. albiventris* (white-eared opossum), and *C. spinosus* (Paraguayan hairy dwarf porcupine), were recorded by collisions and adjacent areas. Therefore, for eight species of wild mammals, the highways are an imminent danger, as they become a physical barrier in areas explored by them.

All birds were recorded by collisions. The 15 native species are of common occurrence in the territory of Rio Grande do Sul, and the numbers of collisions probably represent their abundance in the adjacent areas. The presence of five collisions of *Strix virgata* (mottled owl) is associated with its behavior, as it can be found in forest fragments inserted in the urban matrix, having the habit of hunting small amphibians, reptiles, and mammals, mainly mice.

Conclusions

The combination between collision monitoring and camera traps not only enabled the evaluation of the highway's direct impact but also provided an updated view of the fauna, especially mammals, present in the nearby forest fragments. Some species were recorded by both methodologies, while others appeared only in one of them, evidencing the complementarity between the employed methods. The higher frequency of collisions compared to photographic records may indicate greater vulnerability to the road network or low detection by camera traps, especially in the case of small species or those with more discreet habits. These findings highlight the importance of complementary approaches to understand the presence and the risks faced by fauna in anthropized landscapes.

Although statistical tests were not applied, the spatial analysis of the records allowed the observation of different patterns between the taxonomic groups, with the identification of critical zones (hotspots) and factors associated with mortality. Amphibians and reptiles showed a wider distribution of collisions along the highways, with a higher incidence in stretches close to native vegetation and edges with dense vegetation. Mammals presented records in different stretches along the highways, with two main areas of concentration, but in a spatial arrangement more spaced than the other groups, while birds were concentrated mainly on a single straight and agricultural stretch, which may be related to the presence of grain crops and the higher vehicle speed, attracting species adapted to open environments.

Furthermore, it was observed that sharp curves with dense vegetation on the edges were places of higher risk for low-mobility species, such as some amphibians and reptiles, due to low visibility for both animals and drivers. In turn, plain stretches favored accelerated traffic, increasing the chance of wildlife-vehicle collisions. Such patterns show that hotspots result from the interaction between fauna behavior, landscape structure, physical characteristics of the road, and drivers' behavior.

The results reveal the complex interaction between wild fauna and road infrastructure in the Encosta da Serra Gaúcha region, emphasizing the challenges faced for biodiversity conservation. The detailed survey of collisions and monitoring by camera traps demonstrated distinct patterns of vulnerability among taxonomic groups, evidencing the importance of considering ecological and structural factors in the formulation of mitigation strategies. The identification of hotspots in forest connectivity areas and in structurally critical sections reinforces the need for more effective preventive actions.

The implementation of wildlife corridors, underground passages, and adequate signaling are key solutions to minimize habitat fragmentation and increase fauna safety. In addition, continuous monitoring of critical points and the integration of technologies, such as presence sensors, can assist in risk management and targeting of more effective actions. These efforts must be followed by environmental education programs aimed at drivers and local communities in order to increase awareness of the importance of biodiversity conservation. It is worth highlighting the lack of protected areas in the region.

Thus, this study contributes to understanding the impacts of highways on the biodiversity of the Atlantic Forest at the regional level and highlights the need for road planning that is more integrated with conservation strategies. The continuity of research in the region is essential to improve environmental management measures and ensure the preservation of local ecosystems, ensuring a balance between human development and the maintenance of biological diversity.

Authors' Contributions

Noschang, C.: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, validation, visualization, writing – original draft, writing – review & editing. **Petry**, K.: methodology, supervision, resources, software, validation, visualization, writing – original draft, writing review & editing. **Barros**, M.P.: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, supervision, project administration, resources, validation, visualization, writing – original draft, writing – review & editing.

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