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Inhabiting nearby roads: an analysis of the relationship between the roadkilled mammals and their occurrence close to a highway in Southern Brazil

Vivendo próximo a rodovias: uma análise das relações entre atropelamentos de mamíferos e sua ocorrência no entorno de uma rodovia no Sul do Brasil

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ABSTRACT

The proximity to roads can change the richness, species composition and the abundance of individuals in the biological communities. Similarly, the number of individuals and the roadkilled species are influenced by the dynamics in the community around roads. The main goal of the study was to determine which species of medium and large-size mammals are more susceptible to roadkill and possible relationships with their ecological traits. The study was developed at the southern limit of the distribution of the Atlantic Forest, southern Brazil. Data collection was carried out for one year, from July 2018 to June 2019. We collected data about the richness and abundance of medium and large roadkilled mammals and in the forest fragments around BR153 road. We recorded a total of 15 species of medium and large-size mammals. The number of roadkills seems to reflect the number of records in the surrounding area, although it is not mandatory. The number of roadkills seems to be associated with a set of factors that increase the possibility of collision with vehicles. The ecological traits by themselves do not indicate an elevated chance of roadkill. The main factors that increase the chances of roadkill in the studied region are broad habitat use and the abundance in the surrounding areas. The ecological traits that decrease the likelihood of roadkills are related to the restricted use of forest fragments. Our data indicate that the capacity to move and occupy different environments, mainly associated with high abundance, increases the probability of roadkills.

Keywords: road ecology; forest fragmentation; road-effect zone; conservation biology; Atlantic Forest; linear infrastructure.

RESUMO

A proximidade com rodovias pode alterar a riqueza, composição de espécies e abundância de indivíduos nas comunidades biológicas. De forma semelhante, o número de indivíduos e de espécies atropeladas pode ser influenciado pela dinâmica das espécies nas comunidades no entorno das rodovias. O objetivo principal deste estudo foi identificar quais espécies de mamíferos de médio e grande porte são suscetíveis aos atropelamentos e as possíveis relações com seus atributos ecológicos. O estudo foi desenvolvido no limite sul da distribuição da Mata Atlântica, no sul do Brasil. Os dados foram coletados ao longo de um ano, de julho de 2018 a junho de 2019. Foram recolhidos dados de número de espécies e abundância de indivíduos de mamíferos de médio e grande porte atropelados e ocorrentes em fragmentos florestais no entorno da rodovia BR153, no estado do Rio Grande do Sul. No total foram registradas 15 espécies de mamíferos. O número de atropelamentos reflete parcialmente a abundância de indivíduos de cada espécie nos fragmentos florestais. O número de atropelamentos está associado a um conjunto de fatores que potencializam as chances de colisão com veículos. Os atributos ecológicos, individualmente, não indicam maior chance de atropelamento. Os principais fatores que aumentam as chances de atropelamento na região estudada foram a capacidade de uso amplo do hábitat e a abundância de indivíduos nos fragmentos florestais no entorno da rodovia. Os atributos ecológicos que reduzem as chances de atropelamentos estão relacionados ao uso restrito dos fragmentos florestais. Nossos dados demonstram que a capacidade de se deslocar e ocupar diferentes ambientes, associada à alta abundância, aumenta a probabilidade de atropelamento para mamíferos de médio e grande porte na região sul da Mata Atlântica.

Palavras-chave: ecologia de estradas; fragmentação florestal; zona de efeito da rodovia; conservação biológica; Floresta Atlântica.

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Introduction

One of the main agents promoting landscape fragmentation by anthropic actions is the construction and operation of roads (Van Der Ree et al., 2015). Landscape modifications made by roads can produce several environmental effects besides the direct loss of habitat. The main effects resulting from the implementation of roads are habitat fragmentation and population isolation, mortality from collision with vehicles, degradation of habitat quality, introduction of exotic species, and spread of diseases (Van Der Ree et al., 2015; Barriendos et al., 2021). All these effects can change the dynamics of wildlife populations and modify their movement patterns (Grilo et al., 2021).

The degree of fragmentation tends to be great in environments next to roads (Cirino et al., 2022). Furthermore, the effects of road use spread to the surrounding area, causing problems such as noise, waste pollution, and luminosity (Parris, 2015; Pinto et al., 2020). This set of factors alters the quality of the surrounding habitats. Thus, the proximity of roads can change the species composition and the abundance of individuals in the biological communities (Rytwinski and Fahrig, 2015). Similarly, the number of individuals and the roadkilled species are linked by the dynamics in the community around roads. These mutual relationships are expressed in the so-called road-effect zone, which can extend from a few to thousands of meters, depending on the taxonomic group and environmental characteristics (Barbosa et al., 2020; Pinto et al., 2020).

Species that do not avoid roads may have high rates of collision (Fahrig and Rytwinski, 2009). The causes of roadkill can vary depending on the structure and the use of roads and can include the number of lanes, traffic volume, speed, vehicle types, presence of mitigating measures, and driver behavior (Collinson et al., 2019). In addition, the ecological traits of the species can lead to different rates of roadkills among species that occur around roads (Hartmann et al., 2011; Cirino et al., 2022). Ecological and behavior traits such as mobility, daily and seasonal activity, population density, habitat, and substrate use can influence the number of roadkills (Rytwinski and Fahrig, 2015; Medrano-Vizcaíno et al., 2022). Consequently, the rates of collisions with vehicles mutually interact with the demographics of populations surrounding roads (Medrano-Vizcaíno et al., 2022). The extent of the road-effect zone and the roadkills are interdependent processes that alter the population dynamics and the structure of communities in roadside habitats.

Mammals are among the species most affected by roadkill, especially in regions with highly fragmented habitats (Grilo et al., 2021; Hill et al., 2021). Habitat reduction limits the size of populations, and the effects of fragmentation alter the structure of mammal communities (Canale et al., 2012). The effects are even more expressive in medium and large mammal species and endemic species (Abra et al., 2021; Cirino et al., 2021). As they occur in lower densities compared to small species and have a low reproduction rate, the population effects of the roadkill tend to be greater in medium and large mammals (Ferreguetti et al., 2020). Larger species commonly need large habitats and move more extensively in the landscape, increasing the probability of finding a road and having to cross it (Rytwinski and Fahrig, 2015; Ferreguetti et al., 2020).

Given this scenario, this study aimed to determine which species of medium and large mammals are more susceptible to roadkill and the possible correlation with their ecological traits. We addressed the following questions: is the number of roadkill events associated with the abundance of individuals of each species in the surrounding areas? Is there a correlation between ecological traits and the likelihood of road collisions? We predict that: a. the proportion of roadkills of medium and large mammals is different from the proportion on the roadside forest fragments; b. the chances of roadkills are influenced by ecological traits like feeding habits, substrate use, and habitat. For this purpose, we compare data on species of medium and large mammals recorded roadkilled and on the roadside forest fragments along a federal road in the Atlantic Forest of southern Brazil.

Material and methods

Study area

The study was developed at the southern limit of the distribution of the Atlantic Forest in the northern region of the State of Rio Grande do Sul, southern Brazil (Figure 1). The landscape in the study area is characterized by Seasonal Deciduous Forest and Mixed Rainforest, specifically called Subtropical Forest of Alto Uruguai (Oliveira-Filho et al., 2015). The climate is Cfa humid subtropical with well-distributed rainfall, hot summers, and an average annual temperature of 18.5°C. The region has rugged relief and altitude varies between 400 and 800 m. The landscape of the study area corresponds to a highly fragmented region with land used predominantly for family farming, whose economic activities importantly rely on small–scale and/or subsistence agriculture (Budke et al., 2010).

The studied region is crossed by the BR153 road (Figure 1). The sampled road is single-lane and paved, with shoulders of about 1.5m, and a speed limit between 80 and 100 km/h. According to the Federal Highway Police, 4,500 vehicles drive on the road per day, characterized by cars, followed by trucks, buses and motorcycles. The mosaic of forest fragments around the road comprises areas in the early, intermediate, and advanced successional stages, as well as fragments of primary forest.

Data collection

Data collection was carried out for one year, from July 2018 to June 2019. We collected data about the species of medium and large mammals (body mass of adults presenting more than 1 kg; see Emmons and Feer, 1997) found dead on roads (roadkilled species) and forest fragments around BR153 road (see below).

Road sample. Data on roadkills were obtained by regular road sampling. The sample was conducted along a 32 km stretch of the BR153 (Figure 1).

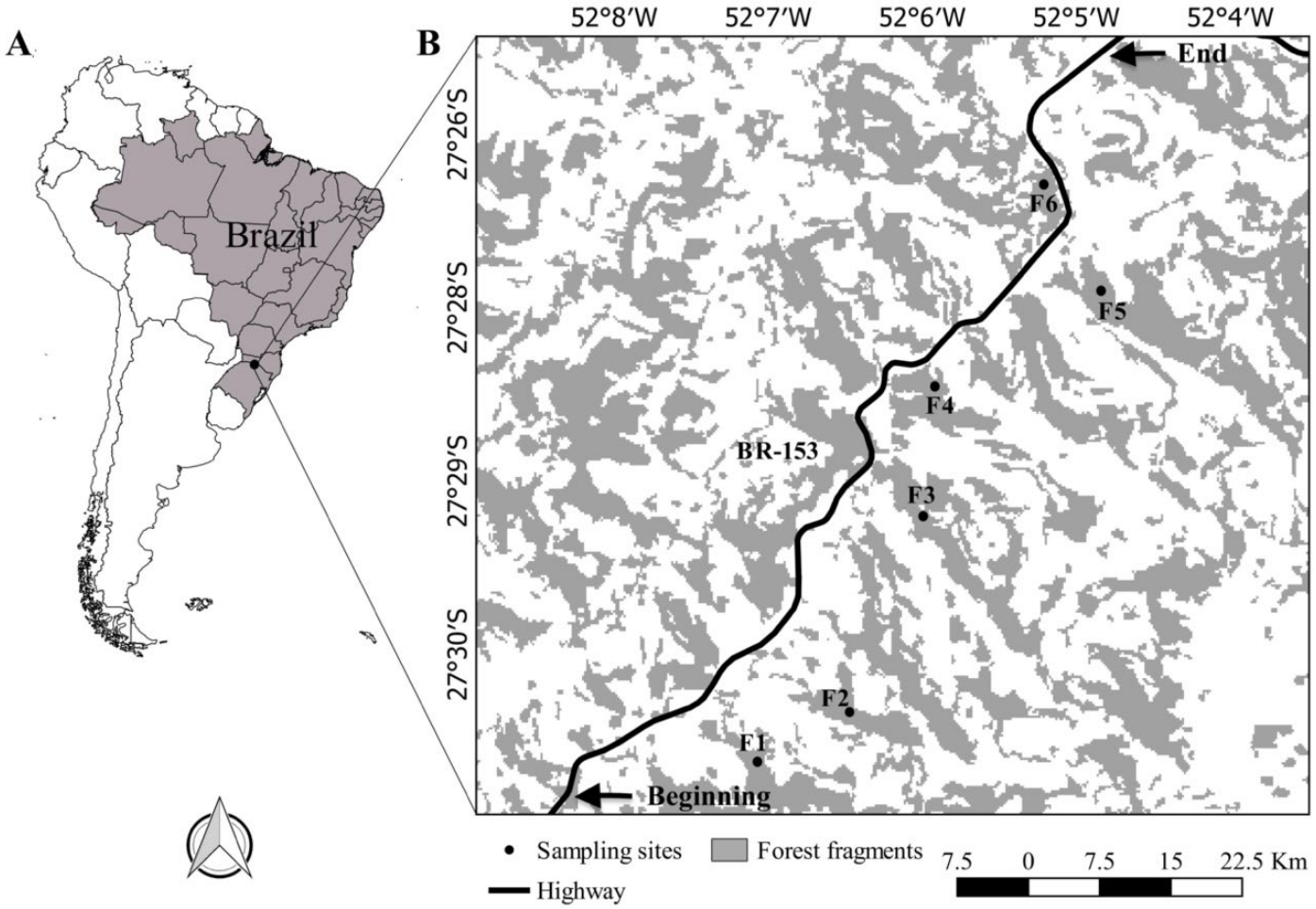

Figure 1 – Location of the study area, road (BR153) and the six sampled fragments F1-F6 in the northern State of Rio Grande do Sul, southern Brazil. White areas represent areas with predominantly agricultural land use.
Source: adapted from Rodrigues et al. (2022).

During the samplings we drove slowly, about 50 km/h, searching for mammal roadkills. The road was sampled 10 consecutive days per month, always in the morning, with an interval of at least 10 days between samplings. A total of 7,680 km was traveled in 120 sampling days. The coordinates, record date, and a photo were taken for each medium or large mammal individual found roadkilled. We considered all carcasses found on the roadway and shoulders. After recording the essential information, the carcasses were removed to avoid duplicate records.

Fragments forest sample. For mammal sampling around the road, six forest remnants representing the regional landscape were selected. The sampled fragments were located between 500 meters and 3 kilometers from the road, and were at least three kilometers apart from each other, within family farming properties. Three fragments were sampled each month, totaling six repetitions per fragment. In July, September, November, January, March, and May, fragments F1 (116.20 ha), F2 (141.54 ha), and F3 (51.50 ha) were sampled; and in August, October, December, February, April, and June, fragments F4 (48.73 ha), F5 (197.15 ha) and F6 (254.64 ha) were taken as samples.

We used Bushnell HD camera traps for sampling mammals in the surrounding area (O'Connell et al., 2011). Three camera traps were installed in each fragment, distributed at the edge and inside of the fragment, and near streams. The traps remained active for 10 to 12 consecutive days per month, coinciding with sampling on the road. The total trapping effort amounted to 1,296 trap days during the study period. Records were treated independently, and individuals of the same species captured within one hour by the same trap, while those that could not be individualized were considered a single record. The protocol was approved by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA — Permit number 52837-1).

Ecological traits. The following categories of ecological traits were recorded. Feeding habits: carnivores (Car; individuals that eat meat,

including rodents, mammals, fish, amphibians, or reptiles), herbivores (Her; individuals that eat primarily plants), insectivores (Ins; specialized carnivores that feed on insects), and omnivores (Oni; animals that have a widely varied diet). Habitat: forest (For; animals normally restricted to forests) and broad (Bro, individuals that can use a variety of different habitats besides forests). Substrate use: Arboreal (Arb), Semi-arboreal (Sarb), and Terrestrial (Ter). We followed the descriptions of Weber et al. (2013) to identify mammals and determine the ecological traits, and consulted *The Red Book of the Endangered Brazilian Fauna*: Volume II: Mammals (Brazilian list; ICMBIO, 2018) for conservation status.

Data analysis

We used Spearman's correlation test to evaluate the monthly number of individuals by species between the sites (Road and Forest fragments). The comparisons between the sites (Road and Forest fragments) concerning the number of species (number of species recorded per site at each month), number of individuals (number of individuals recorded per site at each month), and ecological traits (the proportion of registered species in each category per site at each month) were made using one-way ANOVA, followed by a Tukey post-hoc test.

Results

We recorded a total of 15 species of native medium and large-size mammals (Table 1), belonging to six orders and nine families: Artiodactyla (Cervidae), Carnivora (Canidae, Procyonidae, Mustelidae and Felidae), Cingulata (Dasypodidae), Didelphimorphia (Didelphidae), Lagomorpha (Leporidae), and Pilosa (Myrmecophagidae). The species *Coendou spinosus* was found only roadkilled but it was also considered occurring in the surrounding area. Thus, we found 15 species in the forest fragments and 10 species in the road (66% of the total record).

The number of species ($F_{1,22}$=9.25; p=0.003) and the number of individuals ($F_{1,22}$=42.62; P < 0.001) found in forest fragments was significantly higher than those found roadkilled. The number of roadkills seems to reflect the number of records in the surrounding area (Spearman correlation rs=0.569/p=0.026), i.e., species more abundant in the surrounding area tend to be more roadkilled. However, two species (*Mazama nana* and *Procyon cancrivorus*) are among the most recorded in the surroundings (N>20 records) but were less frequently roadkilled. Of the five most frequently roadkilled species (N>10 roadkills), four are among the most recorded in the surrounding area. The exception is *Coendou spinosus*, which is a frequently roadkilled species, but was not recorded in the surrounding area.

The analysis of the ecological traits showed that carnivores and forest species were proportionally less recorded roadkilled when compared to the occurrences in the surrounding area. The broad habitat use species were proportionally more recorded roadkilled. No difference was found for the other ecological traits (Table 2).

Table 1 – Species and number of individuals of medium and large size mammals recorded roadkilled and in the fragments on BR153 road, State of Rio Grande do Sul, southern Brazil. Feeding habits: Carnivorous (Car), Herbivorous (Her); Insectivorous (Ins), Omnivorous (Oni). Habitat use: Broad (Bro), Forest (For). Substrate use: Arboreal (Arb); Semi-arboreal (Sarb); Terrestrial (Ter).

Species	Roadkilled	Fragments	Feeding habitat	Habitat use	Substrate Use
Didelphis albiventris	66	49	Oni	Bro	Sarb
Dasypus novemcinctus	21	117	Oni	Bro	Ter
Cerdocyon thous	14	57	Oni	Bro	Ter
Coendou spinosus	11	0	Her	For	Arb
Nasua nasua	11	85	Oni	Bro	Sarb
Galictis cuja	5	7	Car	Bro	Ter
*Lepus europaeus**	3	2	Her	Bro	Ter
Leopardus guttulus	2	8	Car	For	Sarb
Mazama nana	1	44	Her	For	Ter
Procyon cancrivorus	1	22	Oni	For	Ter
Eira barbara	0	2	Oni	For	Sarb
Leopardus wiedii	0	12	Car	For	Sarb
Mazama gouazoubira	0	5	Her	Bro	Ter
Puma yagouaroundi	0	1	Car	Bro	Ter
Tamandua tetradactyla	0	1	Ins	For	Sarb
Total	**135**	**412**	-	-	-

**Lepus europaeus* is an exotic species that belongs to the Leporidae family and can be found currently in the wild in the South America (see Jaksic, 2023).

Table 2 – Analysis of variance between the proportion of medium and large size mammals recorded roadkilled and in the forest fragments on BR153 road, for ecological trait. Northern Rio Grande do Sul, from July 2018 to June 2019.

Ecological traits	Test result
Feeding habits	
Carnivore	$F_{1,22}$=6.35; p=0.01
Herbivore	$F_{1,22}$=0.65; p=0.42
Omnivore	$F_{1,22}$=1.43; p=0.24
Substrate use	
Terrestrial	$F_{1,22}$=1.28; p=0.26
Semi-arboreal	$F_{1,22}$=0.91; p=0.34
Habitat	
Broad	$F_{1,22}$=16.59; p<0.01
Forest	$F_{1,22}$=19.24; p<0.01

The following ecological traits predominate in the five most frequently roadkilled species (N>10): omnivorous, broad habitat use, and terrestrial or semi-arboreal. Among these, only *Coendou spinosus* has an herbivorous diet and is forest-restricted and arboreal (Giné et al. 2015). Four species are listed in the *Red Book of the Endangered Brazilian Fauna* (ICMBIO, 2018) as vulnerable (VU): *Mazama nana*, *Puma yagouaroundi*, *Leopardus guttulus* and *Leopardus wiedii*.

Discussion

Our results show that road mortality concentrates on a few species that present the following ecological traits: generalist (broad) and locally abundant habitat use. Although more than half (66%) of the species registered in the fragmented forests were subject to vehicular mortality, it was more frequent in five species. The number of roadkilled species when compared to the number of species recorded in the surrounding areas reinforces the proposal that roadkills affect only a portion of species that occur in the surroundings (Moore et al., 2023). The concentration of roadkills in a portion of the species seems to be a pattern found in studies that evaluate species richness and frequency of roadkills (Cáceres, 2011; Cirino et al., 2022). Part of the species recorded are not subject to roadkill, or these occur at low rates.

Of the analyzed ecological traits, only broad habitat use indicated a greater possibility of roadkills. In a highly fragmented region, species that can move through different environments can cover larger areas and are more likely to cross the roads. The capacity to use anthropic areas mainly indicates that for these species the road is not an effective barrier to movement. This trait may expose species to vehicle run-over events, as the animals do not avoid roads (Rytwinski and Fahrig, 2015). This hypothesis is corroborated by the lower tendency of roadkills by forest species, which restricts their chances of crossing roads.

The ability to move through terrestrial and arboreal substrates and the feeding habits of omnivores were the most frequent ecological traits in the majority of roadkilled species (*Didelphis albiventris*, *Dasypus novemcinctus*, *Cerdocyon thous*, and *Nasua nasua*). These characteristics, taken together, are related to the use of different habitats and support the conclusion that the use of broad habitats increases the chances of roadkills. Only *Coendou spinosus*, the fifth most frequently roadkilled species, is restricted to forest habitat and arboreal substrate. This species is solitary and may descend to the ground to cross deforested areas (Marques and Anjos, 2023; Pessanha et al., 2023; Secco et al., 2022). Unlike other species recorded in this study, *Coendou spinous* is a species with low mobility when moving on the ground, which may increase roadkills. The lack of records in the surroundings is possibly due to the method used (camera traps), which primarily records animals moving on the ground.

If some ecological traits can increase roadkills, on the other hand, other attributes can reduce them. Species that are abundant in the surrounding area but were little registered roadkilled probably avoid the roads (Rytwinski and Fahrig, 2015; Medrano-Vizcaíno et al., 2022). The avoidance of roads contributes to geographic isolation, interrupting processes such as plant dispersal, preventing the movement of the animals and, consequently, the gene flow (Forman et al., 2003). The fragmentation caused by roads can also create hostile conditions for local fauna and the road can be seen as a difficult barrier to cross (Rytwinski and Fahrig, 2015; Fernandes et al., 2022; Ferreira et al., 2022).

Another trait that can reduce the chances of animals being run over is the ability to safely escape from vehicles while crossing the road (Secco et al., 2024). Species that are likely to successfully escape when crossing roads have high locomotor skills (agile and fast), such as felines and cervids (Cáceres, 2011). Species such as *Mazama nana*, *Mazama guazoubira*, *Leopardus guttulus*, *Leopardus wiedii*, and *Puma yagouaroundi* have such traits, and were not or were rarely found roadkilled. The lower probability of roadkills of carnivores registered in this study may be more because of the locomotor ability of the species than the eating habit itself. Three of four recorded carnivore species are felines and have high mobility, with greater potential to escape being killed by cars (Cáceres, 2011).

However, a lower rate of roadkills does not mean a lower population impact. The importance of roadkills in maintaining populations is associated with population size (Barriendos et al., 2021; Pessanha et al., 2023), i.e., even species with lower rates of roadkills may have declining populations due to vehicle runover. On the other hand, some species are frequently run over but do not necessarily have their populations strongly reduced by the impact of roads, which may be the case of *Didelphis albiventris* e *Dasypus novemcintus*.

Overall, the number of roadkills indicates a moderate correlation to the abundance of individuals of each species in the surrounding areas. Of the six species most recorded in the surroundings, four are among the most frequently roadkilled. However, two species are abundant in the surrounding areas and are rarely roadkilled, possibly because they are more restricted to forest environments (*Procyon can-*

crivorus) or can avoid roads (*Mazama nana*) (Emmons and Feer, 1997; Regolin et al., 2016).

Information about the ecological traits of medium and large species of mammals, number of individuals in the surrounding of roads, and probability of collision with vehicles can support proposals for mitigation measures, mainly if focusing on the groups most impacted or with greater ecological relevance, here meaning species in decline, with reduced populations and/or categorized as threatened, either locally or regionally. However, it must be clear that mitigations measures that are useful to certain groups may be ineffective, or even harmful, for others. In this sense, studies on which measures are most efficient for each group (whether taxonomic or functional) seem to be the best way to identify more effective mitigation measures that meet the conservation objectives of the species in each region.

Conclusions

Our work contributes to highlight the relationships between species, number of individuals and ecological traits of the species of the medium and large mammals with the proportion of the roadkill. Our predictions showed largely correct. That is, the chances of roadkill were influenced by some ecological traits and abundance in surrounding. We show that the number of roadkills was associated with a set of factors that increase the possibility of collision. However, the ecological traits singly do not indicate an elevated chance of vehicle runover. The main factors that maximize the chances of roadkill in the studied region are broad habitat use and the abundance in the surrounding areas. The ecological traits that decrease the likelihood of roadkills are related to the restricted use of forest fragments. Our data indicate that the capacity to move and occupy different environments, mainly associated with high abundance, increases the probability of roadkills to medium and large-size mammals in the study region.

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Author's contributions

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