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Do highways without shoulders and proper mowing have more roadkill cases?

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Abstract

Highways eliminate the diversity of animals due to roadkill, altering ecological patterns. The expansion of the road network lags behind the advancements in the field. The situation is worse for country lane, which are neglected by public managers since they do not have shoulder not proper mowing. The influence of the lack of road shoulders and the periodic mowing on wildlife roadkill remains unknown. Therefore, this study aimed to evaluate if the lack of road shoulders and periodic mowing influences the number of roadkill. Then, the diversity of road-killed vertebrates in road LMG-878 was described, as well as their seasonality. The roadkill of highway MG-265 were compared with road shoulder and periodic mowing, and LMG-878, which has no road shoulder and no periodic mowing. T-tests with total values were used, as well as the data relativized by the sampling effort to verify this difference. The LMG-878 was analyzed with species accumulation curves, an estimator of richness to verify the potential for roadkill and seasonality. The comparison with other reports of roadkill was performed using the indices described in the literature. Thus, the highways without shoulders and without periodic mowing have higher occurrences of roadkill. The LMG-878 had 83 cases of roadkill, which included 25 cases for amphibians, 28 for birds, 25 for mammals, and five for reptiles. The diversity of wildlife killed on roads may be even greater than what was found since the estimates of roadkill did not reach stability. The implementation of speed reducers or fauna passages to the places with the highest rates of roadkill is recommended.

Keywords: Conservation, biodiversity, speed reducers, ecological standards.

Introduction

Highways are dividers of animals' communities since the suppression of vegetation, degradation of watercourses, and disconnections of forest patches lead to habitat degradation, alteration of the local climate, and consequent increase in wildlife mortality (GRILO et al., 2018; COSTA et al., 2022). Highways have the negative aspect of roadkill, which maximizes biodiversity losses—especially when they eliminate individuals—affect biodiversity patterns, and ecological processes (IBISCH et al., 2016; MAXWELL et al., 2016).

Roadkill is among the leading causes of animal species mortality in Brazil, along with urban sprawl, energy production, mining activities, pollution, and agriculture (IUCN, 2022). Many factors influence the number of roadkill, such as the type of highway (MACHADO et al., 2016), landscape connectivity (GRILO et al., 2011), barriers to movement (BHATTACHARYA et al., 2003), behaviors (KERLEY et al., 2002), among others. In Brazil, these factors generate more than 475 million cases of roadkill per year (SISTEMA URUBU, 2023), affecting population dynamics and community structures, with increased risk of local and regional extinctions

of species (GRILO et al., 2018). The Brazilian federal highway network has 75,553,000 km (BRASIL, 2022), however, approximately 62% have maintenance problems (CNT, 2021). Thus, large highways have been transferred to private companies that charge different values for the maintenance of the highway, its shoulders, and other surroundings (e.g., vegetation), improving their general conditions. This scenario is different for country lanes, which remain in a medium or poor state of maintenance (EM, 2023). The low financial income generated by these highways with lower traffic flow leads to neglections, such as the lack of road shoulders and maintenance (mowing) of the roadside vegetation. The lack of shoulders and periodic mowing on country lanes is negligence (SALOMÃO et al., 2019; LIMA, 2022) and its effect on wildlife roadkill is unknown.

In the south of Minas Gerais, specifically in the southern, most highways are in a particularly poor state of conservation (EM, 2023) and few studies address the results of roadkill, including country lanes. These studies only describe the road-killed species, or compare paved and unpaved highways, or employ different methodologies, such as the use of bicycles, differing from other scientific studies (PRACUCCI et al., 2012; MACHADO et al., 2015).

Thus, we hypothesize that highways without shoulders and lacking periodic mowing have a higher number of roadkill, as well as a higher record of roadkill in hot and humid periods. Therefore, this study aimed to evaluate whether the absence of shoulders and periodic mowing influence the number of road-killed animals. Moreover, we aimed to describe the diversity of road-killed vertebrates in LMG-878 between the municipalities of São Gonçalo do Sapucaí and Cordislândia (south of the state of Minas Gerais), as well as the seasonality of the records of roadkill.

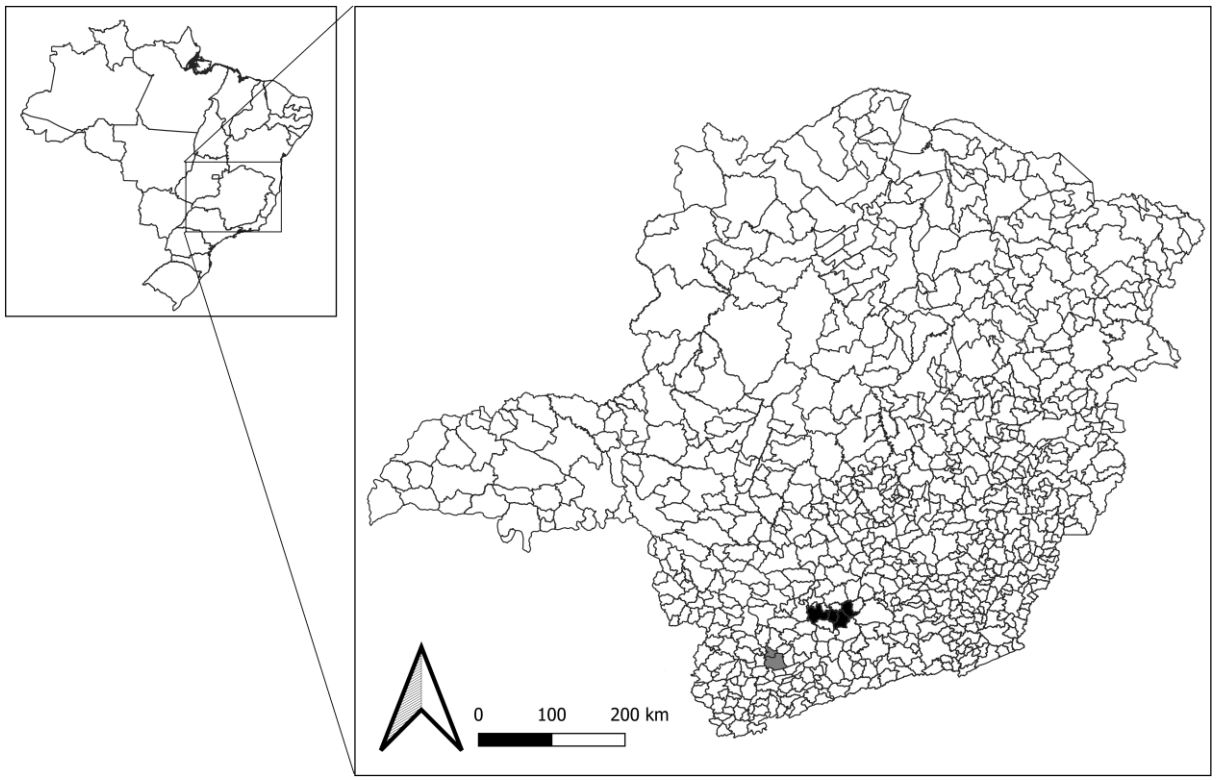
Material and methods

The study was developed in LMG-878, which connects the municipalities of São Gonçalo do Sapucaí and Cordislândia, in the south of the state of Minas Gerais (Figure 1). The region has a CWA type climate, according to the Köppen classification, with rainy summers and dry winters (ALVARES et al., 2013), and the average rainfall ranges from 1,300 to 1,700 mm (SANTOS et al., 1998).

The landscape of the region is multi-composite with coffee, maize, and soybean crops, as well as many semi-deciduous forest patches and different types of *Cerrado* areas. The road has a single lane in both directions, around 20 m wide, and an average traffic of 80 vehicles per day (Figure 2A). The test to verify the presence of a significant difference between the highways with and without road shoulders and mowing (roadside maintenance) was performed with the data of the asphalted highways of Machado et al. (2015). Their study was carried out on the MG-265 highway, which connects the municipalities of Lavras and Nazareno, in the southern Minas Gerais. The region has a CWA type climate, according to the Köppen classification, with rainy summers and dry winters (ALVARES et al., 2013), and the average rainfall ranges from 1,300 to 1,700 mm (SANTOS et al., 1998). The MG-265 has a single lane in both directions, around 20 m wide, and average traffic of 180 vehicles per day (Figure 2B).

The state of maintenance of both highways is precarious, with several potholes in the lane, which increase with each rainy season. However, the conditions of the highway LMG-878 are worse, since it has no road shoulder and the vegetation is mown sporadically (more than two years between mowing). In some regions of LMG-878, the vegetation invades 1.5 m toward the center of the carriageway (Figure 3).

Figure 1. Map of the study area. In black, the location of MG 265 between the municipalities of Lavras and Nazareno. In gray, the LMG-878 between the municipalities of São Gonçalo do Sapucaí and Cordislândia.



Source: Prepared by the authors, 2023.

Figure 2. Highways used comparatively in this study. The letter A represents the highway LMG-878 and letter B represents the highway MG-265. Source: Developed by the authors, 2023.

The authors traveled the LMG-878 twice a day. The departure occurred around 11 am and the return around 6 pm. The section covered includes 2,188.8 km per season (one dry and one rainy), totaling 4,377.6 km. The sampling occurred for 46 days in the rainy and hot period (late 2021), as well as another 46 days for the dry and cold (mid-2022). For each carcass sighted, the coordinates and the identification of the material *in loco* were recorded. The highways were monitored by a motor vehicle with a maximum speed of 50 km h^{-1} and two observers analyzed both the center and the lateral areas of the road (escape area).

Figure 3. Section of LMG-878 with lack of maintenance regarding the roadside vegetation. The red line is 1.5 m towards the center of the carriageway.

Source: Prepared by the authors, 2023.

Information on the species followed Paglia et al. (2012) and Quintela et al. (2020), with the listing of the *Sociedade Brasileira de Mastozoologia* (SBM, 2020) for mammals. For amphibians and reptiles, information from the *Sociedade Brasileira de Herpetologia* (SBH, 2018) was used, and for birds information from the *Comitê Brasileiro de Registros Ornitológicos* (CBRO, 2021) was used. Data on conservation status were retrieved from the International Union for Conservation of Nature (IUCN, 2022).

Statistical analyses

To evaluate the potential for new roadkill, a species accumulation curve was created, based on the number of roadkill records divided by the number of species and their respective 95% confidence interval (BURNHAM; OVERTON, 1978). The species-richness estimation curve was generated using the first-order Jackknife method. To compare the hot and rainy seasons with the cold and dry seasons, two curves of species accumulation were created, to verify the seasonal pattern of roadkill. The curves were created using the EstimateS tool (COLWELL et al., 2012).

The difference between highways with and without shoulders and mowing of roadside vegetation was presented by bar graphs. The analysis of descriptive data (bar graphs) synthesizes and shows the central tendency and dispersion of these data (REIS, 1996). This trend was tested by t-tests with total values and with the adjusted data by the sampling effort. The Bioestat 5.0 program (AYRES et al., 2007) was used with a 95% significance level.

The comparison with other cases of roadkill reported in the literature was performed using the indices described by Zanzini et al. (2018). The indices are: IEA_S = Spatial Index of Roadkill of Species; IEA_N = Individual Roadkill Index; ITA_S = Temporal Index of Roadkill of Species; ITA_N = Temporal Index of Individual Roadkill; IKA_S = Linear Index of Roadkill of Species; and IKA_N = Linear Index of Individual Roadkill.

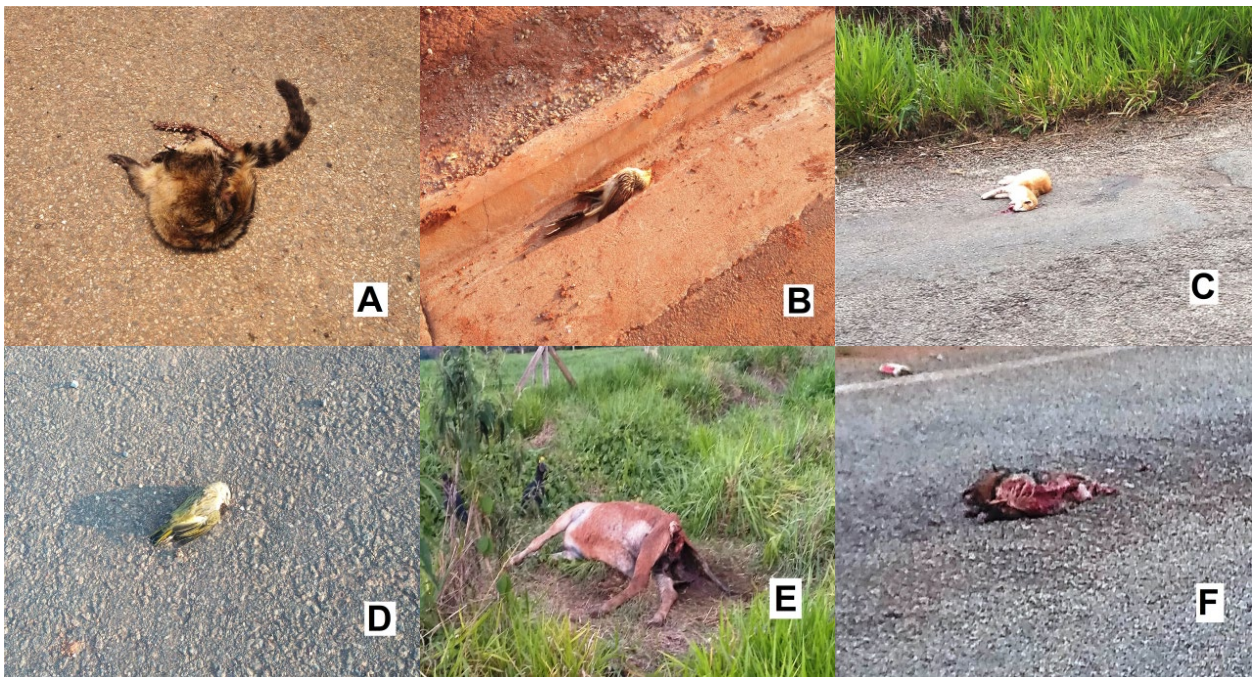
Results

In total, 83 roadkill were recorded, comprising 25 amphibians, 28 birds, 25 mammals, and five reptiles (Figures 4 and 5). Notably, three sections of the highway have an accumulated number of roadkill records: one within the municipality of Cordislândia, one in the municipality of São Gonçalo do Sapucaí, and another in the border region between the two municipalities. These sites were highlighted for causing more than 10 accumulated roadkill in a 2 km-long section (Figure 6) (Table 1).

The species identified with the highest number of roadkill was the amphibian *Rhinella icterica* with 17 records, followed by the bird *Passer domesticus* (six records) and the mammals *Felis catus* (5), *Canis familiaris* (4), and *Dasypus novemcinctus* (4) (Table 1).

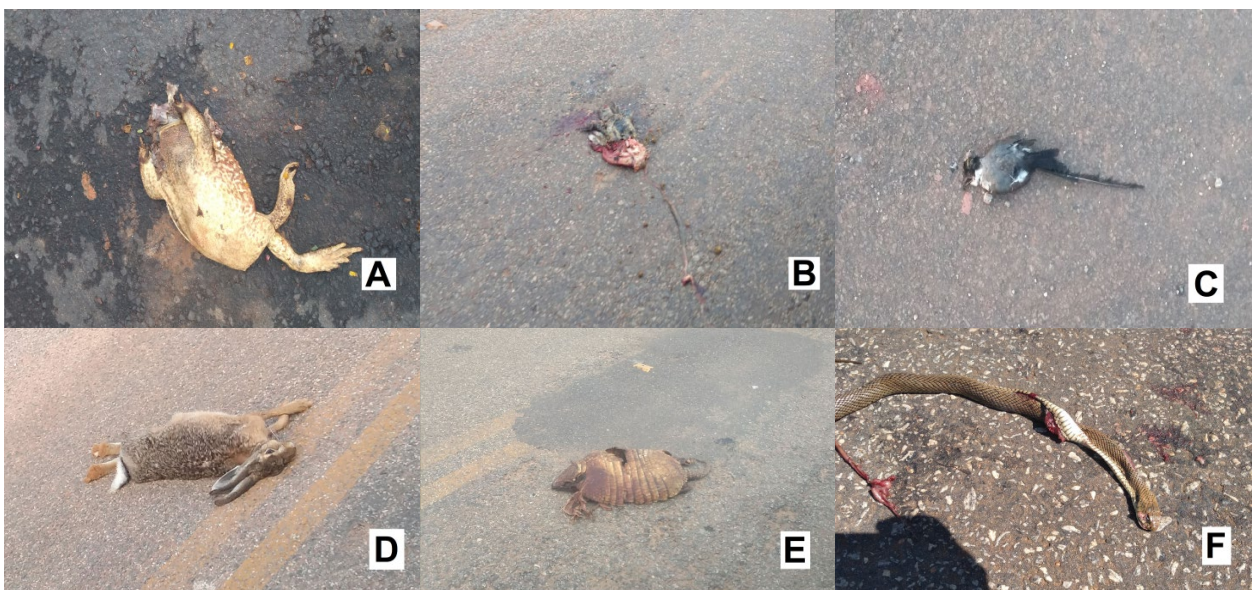
The species accumulation curve did not reach the asymptote, and according to the first-order Jackknife estimator, the number of roadkill reached 66.64% of what could be found (Figure 7A). There were more roadkill in the hot and rainy period (Figure 7B).

Figure 4. Six of the roadkill records in this study. "A" represents *Nasua nasua* (21°53'27.33"S 45°36'59.06"W), "B" *Guira guira* (21°53'17.04"S 45°36'10.68"W), "C" *Felis catus* (21°53'53.09"S 45°39'38.66"W), "D" *Sicalis flaveola* (21°53'28.31"S 45°37'2.63"W), "E" *Equus caballus* (21°52'20.19"S 45°40'35.42"W), and "F" *Didelphis albiventris* (21°51'49.19"S 45°40'49.36"W).



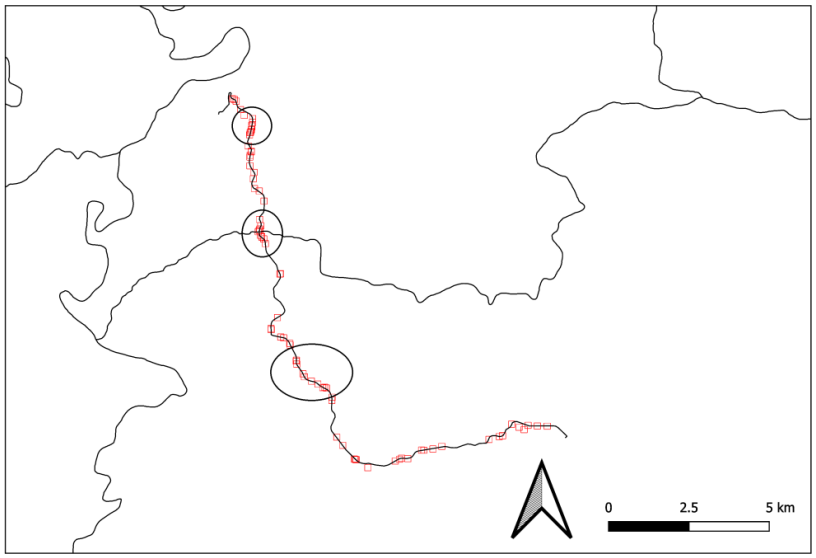
Source: Prepared by the authors, 2023.

Figure 5. Other six roadkill records in this study. "A" represents *Rhinella icterica* (21°53'51.70"S 45°38'48.50"W), "B" *Salvator merianae* (21°47'23.17"S 45°41'49.95"W), "C" *Tyrannus savanna* (21°53'33.64"S 45°36'35.72"W), "D" *Lepus europeus* (21°52'5.59"S 45°40'42.60"W), "E" *Dasypus novemcinctus* (21°52'28.23"S 45°40'26.31" W), and "F" *Erythrolamprus miliaris* (21°50'32.19"S 45°41'0.50"W).



Source: Prepared by the authors, 2023.

Figure 6. Locations of roadkill records (marked with red square). The circle highlights three regions with the highest cumulative cases of roadkill.



Source: Prepared by the authors, 2023.

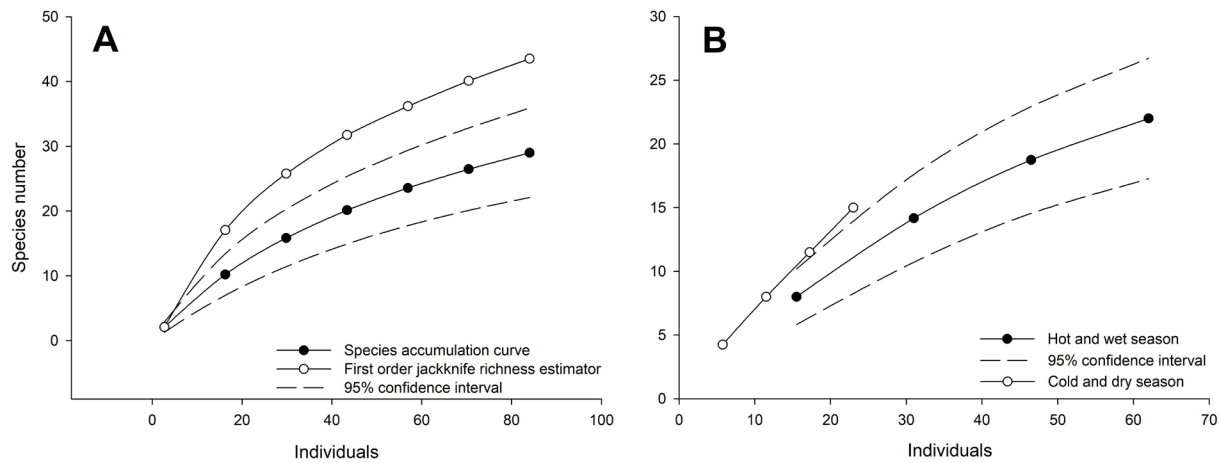
Table 1. List of roadkill species, their respective number of roadkill cases and the conservation status according to the International Union for Conservation of Nature (IUCN) for the roadkill recorded between the municipalities of Cordislândia and São Gonçalo do Sapucaí. NT = Near threatened.

Class	Species	Number of roadkill cases	IUCN
Amphibians	Family Bufonidae *Rhinella icterica* (Spix, 1824)	17	-
	Unidentified	8	-
Birds	Family Phasianidae *Gallus domesticus* (Linnaeus, 1758)	2	-
	Family Columbidae *Zenaida auriculata* (Des Murs, 1847)	3	-
	Family Cuculidae *Crotophaga ani* Linnaeus, 1758	3	-
	Guira guira (Gmelin, 1788)	2	-
	Family Apodidae *Chaetura meridionalis* Hellmayr, 1907	1	-
	Family Cathartidae *Coragyps atratus* (Bechstein, 1793)	3	-
	Família Tyrannidae *Pitangus sulphuratus* (Linnaeus, 1766)	2	-
	Tyrannus savana Daudin, 1802	1	-
	Family Passeridae *Passer domesticus* (Linnaeus, 1758)	6	-
	Family Icteridae *Pseudoleistes guirahuro* (Vieilot, 1819)	1	-
	Family Thraupidae *Sicalis flaveola* (Linnaeus, 1766)	3	-
	Unidentified	1	-

Class	Species	Number of roadkill cases	IUCN
Mammals	Family Didelphidae *Didelphis albiventris* Lund, 1840	3	-
	Family Dasypodidae *Dasypus novemcinctus* (Lineu, 1758)	4	-
	Family Equidae *Equus caballus* Boddaert, 1785	3	-
	Family Canidae *Canis familiaris* Linnaeus, 1758	4	-
	Lycalopex vetulus (Lund, 1842)	1	NT
	Family Felidae *Felis catus* (Linnaeus, 1758)	5	-
	Family Mephitidae *Conepatus semistriatus* Boddaert, 1785	1	-
	Family Procyonidae *Nasua nasua* Lineu, 1766	1	-
	Family Leporidae *Lepus europeus* Pallas, 1778	1	-
	Sylvilagus brasiliensis (Linnaeus, 1758)	1	-
	Family Cricetidae *Oligoryzomys* sp. (Olfers, 1818)	1	-
Reptile	Family Teiidae *Salvator merianae* AM.C. Duméril & Bibron, 1839	1	-
	Family Colubridae *Erythrolamprus miliaris* (Linnaeus, 1758)	1	-
	Ophiodes striatus (Spix, 1824)	1	-
	Family Viperidae *Crotalus durissus* Linnaeus, 1758	2	-

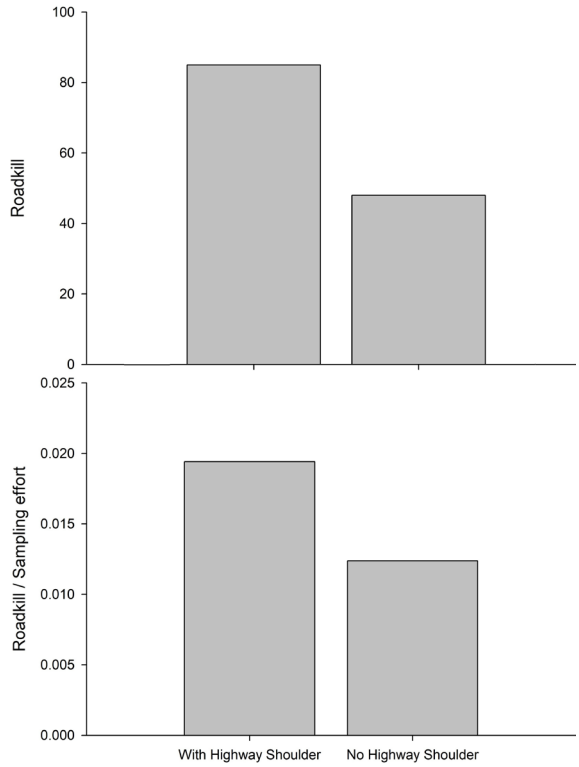
Source: Prepared by the authors.

Figure 7. Species accumulation curves, 95% confidence intervals, and first-order richness estimator for the study area. "A" represents the overall species accumulation curve of the study and its respective confidence interval and richness estimator. "B" represents the two seasons curves, separately, and the hot and humid season presents its respective confidence interval.



Source: Prepared by the authors, 2023.

Figure 8. Differences between roadkill with and without road shoulder, with total values (above) and adjusted by the sampling effort (below).



Source: Prepared by the authors (2023) and by Machado et al. (2015).

The cases of roadkill on the highway in this study, lacking road shoulders and mowing, is higher than that recorded by Machado et al. (2015), on a highway with shoulder and regular mowing of roadside vegetation. This situation occurs both for the total values and for the values adjusted by the sampling effort, proven by the significance of the t-test (Figure 8) (Table 2).

The rates of roadkill have intermediate values when compared with other studies developed in Brazil, since 0.0066 species/km were obtained; 0.0189 road-killed individuals/km; 0.63 species/monitoring campaign; 1.8 individuals/monitoring campaign; 150.95 km/roadkill species; and 52.74 km traveled/roadkill individual (Table 3).

Discussion

The reduced investment in Brazilian highways leads to an increase in the number of accidents (KRAMER, 2021). The lack of resources for this infrastructure results in the absence of road shoulders and roadside vegetation without

Table 2. T-test for the comparison of total and adjusted values by the sampling effort of the highway with and without road shoulder/mowing of roadside vegetation.

	Test	Value
Total values	T	4.52
	P	<0.05
Adjusted	T	3.60
	P	<0.05

Source: Prepared by the authors (2023) and by Machado et al. (2015).

Table 3. Comparative table with the rates of roadkill among articles published in Brazil.

Index	This study	Machado et al., 2015	Zanzini et al., 2018	Bastos et al., 2019
IEA_S	0.01	0.01	0.01	0.12
IEA_N	0.02	0.12	0.01	0.29
IKA_S	150.95	215.41	306.66	8.53
ITA_S	0.63	0.43	0.38	1.71
ITA_N	1.80	1.14	1.00	4.17
IKA_N	52.74	80.78	115	3.50

Source: Prepared by the authors, 2023.

periodic mowing, especially on country lanes, as LMG-878. We found a significant difference, with a more roadkill cases on highways without shoulder and with unmown vegetation. Thus, animals may not notice the boundary between the highway and the vegetation, so they invade the road area, even though they are covered with grasses. This happens since the lateral grasses are a few meters high, and their lateral decay advances onto the highway, invading it by a few meters and giving the impression of protection for the animal. However, these animals are already in an area prone to roadkill.

From the regional point of view, the study area deserves special attention, since it is a poorly urbanized region with a high number of medium and large forest patches. The municipalities of Cordislândia and São Gonçalo do Sapucaí have approximately 3,000 and 25,000 inhabitants, respectively (IBGE, 2022). Therefore, even though no provision for building road shoulders and no dates are scheduled for the maintenance of roadside vegetation, the construction of speed bumpers, as well as traffic education emphasizing respect for wildlife can mitigate such effects.

The area surrounding LMG-878 has a prominent species diversity in the regional scenario, since the composition of the road-killed animals includes species recorded in species inventories in the south of Minas Gerais and in the Brazilian Southeast (ALVES et al., 2022; MACHADO et al., 2016; MACHADO et al., 2017; MORAIS et al., 2018 for mammals; MOURA et al., 2022; MOURA et al., 2021a; MOURA et al., 2021b; MOURA et al., 2020 for birds; OAK, 2010; SOUZA et al., 2010; NOVELLI et al., 2012; for reptiles; and GUIMARÃES et al., 2020; MONTEIRO-LEONEL, 2004, for amphibians).

Thus, roadkill is a concerning factor since, in this study, the species accumulation curves have no asymptote. Therefore, the roadkill diversity may be even greater than that found, which requires further studies for conservation and preservation purposes. There were more roadkill cases in the hot and rainy period since the curve of the cold and dry season is outside the 95% confidence interval. Only for mammals, for example, Zanzini et al. (2018) recorded road-killed individuals of 18 species and Machado et al. (2015) recorded road-killed individuals of eight species. However, this study recorded road-killed individuals of 11 species, corroborating other studies in Brazil. Moreover, the indices (Table 3) have some approximate values between different studies conducted in the country.

The higher incidence of roadkill in the hot and rainy season results from higher primary production of the roadside vegetation. The increase in primary production generates greater availability of food for animals. These reserves are commonly used for reproductive purposes, that is, for a greater number of offspring and adaptation to periods of drought. This behavior at the base of the food web generates a ripple effect for the other trophic levels. Thus, the number of displacements during the rainy season increases due to foraging and mating behaviors (MACHADO et al., 2015), accentuated by the absence of road shoulders and roadside vegetation.

Among the recorded species, only *L. vetulus* belongs to the Near Threatened status of IUCN. This factor must be highlighted, as it demonstrates the need for interventions by the state administration, and especially municipal administration, to reduce roadkill rates and conservate regional fauna (proposed mitigation similar to MACHADO et al., 2015). The conservation of the area is also emphasized, since it is allocated in an ecotone region between two morphoclimatic domains considered hotspots of world conservation, the Atlantic Forest and the *Cerrado* (MYERS et al., 2000).

Moreover, we found that the high rate of roadkill for *R. icterica* corroborates Grilo et al. (2018), since it is one of the five species with

the highest number of roadkill cases in Brazil, however, it contradicts the results of Machado et al. (2015), given the absence of amphibian records. The higher record of amphibian roadkill has two explanations. First, the high rainfall of the sampling period (early 2022) (INMET, 2022), which increases the number of road-killed animals (PEREIRA et al., 2018), as well as a greater number of forest patches bordering the highway. There are reports that amphibians are not attracted to highways, however, they need to travel during reproductive periods (FAHRIG; RYTWINSKI, 2009), which mostly coincide with rainy periods.

The other records of high incidence of roadkill in this study are for synanthropic or domestic species, such as *P. domesticus*, *F. catus*, and *C. familiaris*. The increase in these populations is associated with the wide phenotypic plasticity and the accentuated presence of grasses with seeds, which is abundant food for birds (SICK, 1997), as well as the presence of carcasses, which can be food for some dogs and cats (FREITAS, 2009). Furthermore, these species have high mobility within their living areas and attraction to the highway, which increases the number of road-killed individuals (FORMAN et al., 2003) and due to their association with human environments with transport flow (MONJE-NAJERA, 1996).

This study is a pioneering initiative on the impacts of vertebrate roadkill in an ecotone region between the *Cerrado* and the Atlantic Forest in the south of the state of Minas Gerais. The record of the composition of this study demonstrates that new studies need to point out the hotspots of roadkill, for inclusion of mitigating methods, reducing roadkill and helping wildlife maintenance . This study was developed in local highways, however, studies with larger highways can provide a more serious panorama, given the greater flow of vehicles.

Conclusions

Thus, the highways without road shoulders and periodic mowning cause more roadkill. Furthermore, the LMG-878 that connects the municipalities of São Gonçalo do Sapucaí and Cordislândia has a regionally relevant diversity of road-killed species. However, even higher diversity can be found roadkill, since all the curves of accumulation of species did not stabilize, with higher rates of roadkill in the hot and rainy summer. Therefore, the implementation of speed reducers or fauna passages to the three places with the highest roadkill is essential, as well as the encouragement of further studies to understand the intrinsic factors related to roadkill. The installation of wildlife protection methods has been proven to be effective in reducing the mortality of different taxonomic groups. However, they are insufficient and require constant maintenance.

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