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Papers

Dynamics of Roads: The role of Traffic in the Number of Accidents with Fauna

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Abstract
The present study sought to acknowledge the effects of velocity and vehicle traffic on animal roadkills on roads nearby Protected Areas (PA) in the Distrito Federal - Brazil. Data on roadkill events for three road segments were superimposed on information on traffic volume, records of speeding infractions, and installation of vertical signs (VSs). The results showed a weak positive correlation between roadkill events and the annual traffic volume ($\rho = 0.470$; $p < 0.05$). No statistical significance was found in the correlation indices between roadkill events and speeding infractions, and there was no evidence that installing VSs had an effect on the records of roadkill within 200 m ($V = 387$; $p > 0.3$) or 500 m ($V = 437.5$; $p > 0.5$) of the VSs. The data analysis showed a possible correlation between the fauna that had become accustomed to the road environment that were in collisions between animals and vehicles (AVCs) and the consequent intensification of the edge effect, fragmentation, and isolation of these species in adjacent PAs. It is proposed that new studies evaluate the installation of structures capable of reconnecting the affected areas, the continuity of monitoring projects, and the provision of improved access to data on traffic violations.

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INTRODUCTION

In Brazil, investments in transportation infrastructure are historically justified by economic development (PEREIRA; LESSA, 2011). However, the concentration of road transportation and consequent expansion of highways impact one of the main environmental protection strategies adopted in the country: the creation of Protected Areas (PAs; BRASIL, 2000).

PAs are territorial spaces delimited to protect native areas and their natural systems. Currently, PAs covers approximately 18% of Brazil (BRASIL, 2021). This designation of areas with different legal regimes does not prevent fauna and flora from being exposed to the impacts of highways (FORMAN et al., 2003; NELBOLD et al., 2015). Depending on the adaptability of the biota, the environmental changes caused by road infrastructure may affect the composition and distribution of organisms that inhabit the surrounding areas (COFFIN, 2007; LAURANCE; GOOSEM; LAURANCE, 2009).

For faunal species that have become accustomed to road environments, the direct negative effects include Animal-Vehicle Collisions (AVCs; FORMAN et al., 2003; RYTWINSKY; FAHRIG, 2012). It is estimated that approximately 475 million animals are hit by vehicles on Brazilian highways each year (CBEE, 2021). In PAs created to protect species sensitive to environmental changes and/or at risk of extinction, the control of AVCs is essential and can be complex depending on the location of the reserve (BRASIL, 2000; STRASSBURG et al., 2017).

Because it is a megadiverse country, Brazil has areas where the socio-environmental characteristics show the difficulties encountered in trying to address the impacts of AVCs in PAs in urban environments. In the Cerrado, the second largest biome in the country, there are areas of ecological importance, but the misidentification of the typical vegetation types in the biome - mainly related to the advancement of urbanization and agriculture - compromises the conservation of the high endemism rates observed in their natural environments (MYERS et al., 2000; MARRIS, 2005; FRANÇOSO et al., 2016; STRASSBURG et al., 2017). Currently, approximately 9% of the Cerrado area is protected by PAs (BRASIL, 2021); however, most of the reserves are bordered by highways (LAURANCE; BALMFORD, 2013).

Considering that highways are the physical infrastructure used to facilitate the movement of motor vehicles, it is expected that the variables that define the period of greatest activity of PA inhabitants near these roads are also influenced by traffic dynamics (SELVA et al., 2015; VISINTIN; VAN DER REE; MCCARTHY, 2016; VISINTIN et al., 2018).

The variables speed and traffic volume describe vehicle flow, which, in turn, can define the window of opportunity for a successful animal crossing or even influence the behaviors and occurrences of animals in the zone of road influence.

Measures aimed at mitigating the effects of these variables on the intensification of AVCs are commonly observed on Brazilian highways (BAGER, 2003). Vertical signs (VSs) are used to inform drivers about the maximum speed allowed on roads or to warn them about the possible crossing of wild animals, and it is the main mitigation measure for preventing roadkill on highways (KHALILIKHAH; HEASLIP, 2017). Therefore, the role of speed in AVCs is recognized, but evaluating the effectiveness of monitoring license plates to manage speed is still incipient and poorly understood (RYTWINSKI et al., 2016).

The aforementioned traffic variables can thus be related to roadkill indices to design new conservation strategies or even evaluate techniques that have already been applied to reduce the environmental damage generated by the loss of fauna due to collisions on highways (SELVA et al., 2015; VAN DER REE; SMITH; GRILO, 2015).

Thus, the present study aims to understand the role of speed and traffic volume in AVC indices for the roads that border the PAs of a federal unit of Brazil and to verify whether the SVs installed on these highways can prevent such incidents.

MATERIALS AND METHODS

Study area

The study was conducted in the Distrito Federal (DF) - Brazil. It is the smallest federal unit in the Brazilian territory, occupying an area of approximately 5,800 km² (IBGE, 2021). This area has a lithology representative of the Central Plateau ecoregion and native vegetation typical of the Cerrado biome (ARRUDA et al., 2006).

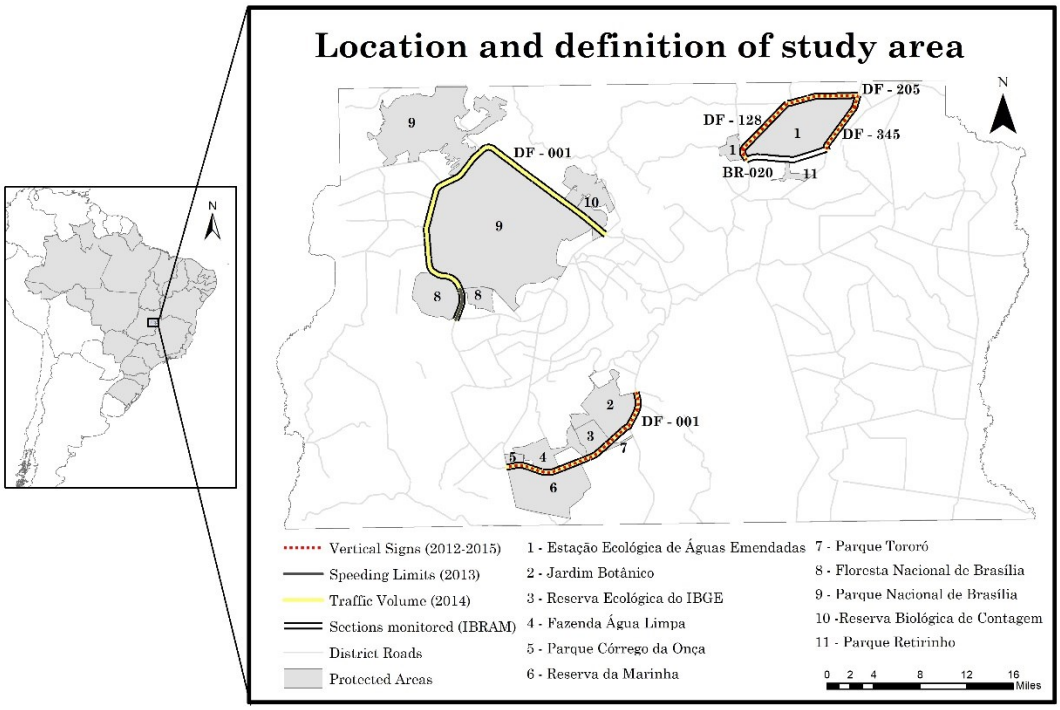
The studied highways were defined based on the data on wildlife collisions produced by the

Instituto Brasília Ambiental (IBRAM), the entity responsible for the supervision and administration of the PAs in the DF.

Monitoring was conducted along sections of highways close to the PAs and along three routes: two on the DF-001 highway and another in segments of the DF-128, DF-345, DF-205, and BR-020 highways.

Notably, however, the combination of AVC information and data on infractions, vehicle volume and VS resulted in three spatiotemporal versions of the original area: one for each analysis. Only the district roads were evaluated; therefore, the BR-020 segment was disregarded (Figure 1).

Figure 1 - Location and definition of the study area. The double black lines are the road sections monitored by IBRAM; the dotted red show the evaluation of the efficacy of VS between 2012 and 2015; the areas in dark gray represent the correlation of AVCs to traffic violations in 2013; the areas in yellow represent correlations between AVCs and traffic volume in 2014; areas in gray are the conservation units bordered by highways; and the gray lines are the district roads of the Distrito Federal.



Source: The authors (2021); Adapted: IBRAM (2013).

Data collection

Roadkill information was collected between April 2010 and March 2015. The methods were the same as those described in the final report of the Rodofauna project, and the database was obtained from the IBRAM website (IBRAM, 2013; IBRAM, 2021).

The information on the location of the electronic speed controllers (ESCs), vehicle volume, and VSs was obtained from field work and reports provided by the Departamento de Estradas e Rodagem do Distrito Federal (DER-DF; DER-DF, 2014), which is the responsible department for road, traffic and mobility infrastructure on DF's highways.

ArcGIS *software* (ESRI, *v.* 10.8) was used to organize the spatial information from the databases and prepare maps. The statistical analyses were conducted in R *studio* (*v.* 2021.09.0).

Statistical analysis

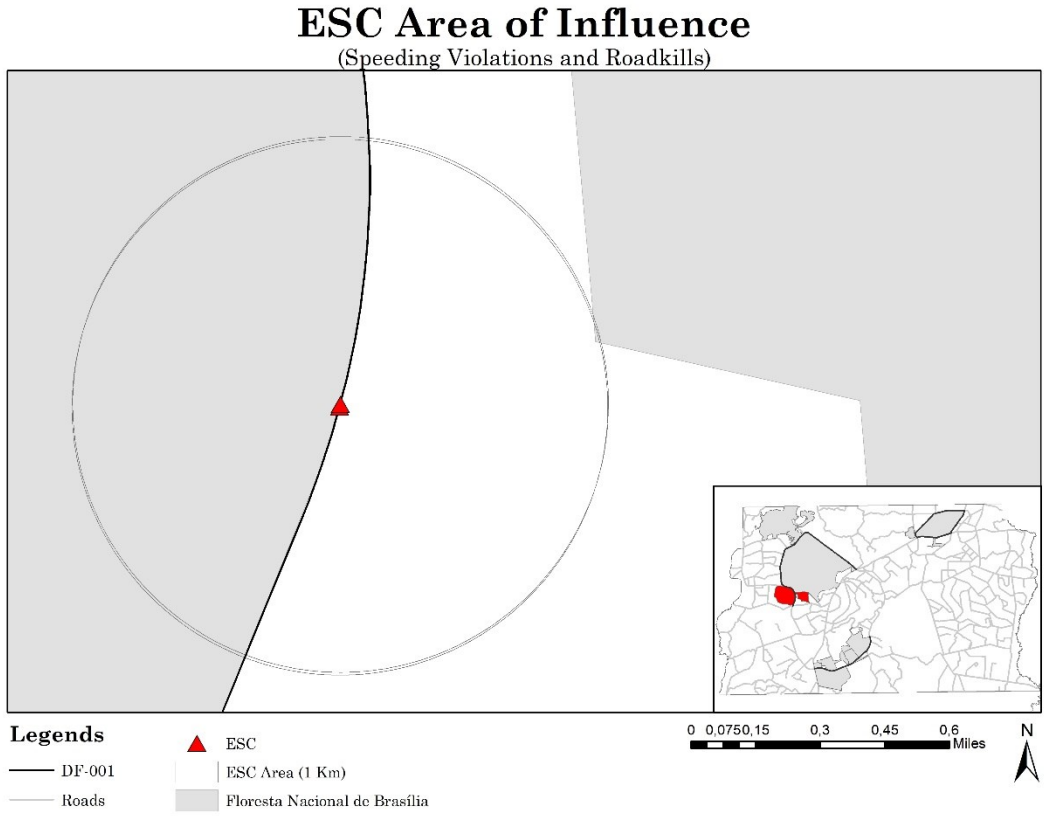
To evaluate the influence of speed on the rates of animal collisions, the maximum limit allowed within each road segment was assumed to be the minimum used by drivers.

Based on this premise, the incident data were correlated with the speeding infractions recorded on the roads monitored by IBRAM. As the database provided by the DER-DF contained infractions from only 2013, the roadkill events observed in 2013 were analyzed. In this period, there were two ESCs fixed in both directions of

DF-001 in the stretch that surrounded the PA Floresta Nacional de Brasília (FNB; Figure 2).

On highways, given the use of different speeds depends on the driver, data on this variable were obtained based on the fines given in the region near the measurement point. Thus, only the roadkill events observed at a distance of up to 1000 m from an ESC was included in the analysis (Figure 2).

Figure 2 - Road sections monitored by IBRAM, conservation units, speed reducers and respective areas of influence.



Source: The authors (2021).

The vehicle volume information refers to the values of average daily traffic (ADT; DER-DF, 2014). Considering that the method for obtaining the ADT was based in 2014, the data on roadkill events related to this variable was obtained from the records in 2014. The roads analyzed by the IBRAM were 108.5 km long and were divided into twenty road segments for the measurement of the ADT. As the road segments were different in length, the roadkill count was calculated every km, and the ADT values were divided by the length of each road segment to ensure data uniformity.

Species diversity and dominance indices were obtained by calculating the *Simpson* index (SIMPSON, 1949).

To verify if there was a difference between the occurrence of roadkill before and after the installation of the VSs on the roads, the location and date of installation were requested from the DER-DF, but the database provided by the agency did not have both data for all VSs. As the efficacy analysis depends on the concomitant availability of the two variables, all roads whose VSs did not have both types of information were disregarded.

The effect of VSs is restricted to the drivers' areas of vision; therefore, roadkill events occurring within two zones of influence were considered: one at 200 m and the other at 500 m from a VS (COLLINSON et al., 2019). The incidents that occurred were evaluated within the same interval, before and after the dates on which the VSs were installed.

The estimations of the different degrees of influence between higher speeds and the allowed speed and the average volume of traffic on the AVCs were verified using Spearman's correlation coefficient test, defined after verifying the data distribution by the Shapiro–Wilk test (SHAPIRO; WILK, 1965; TORMAN; COSTER; RIBOLDI, 2012).

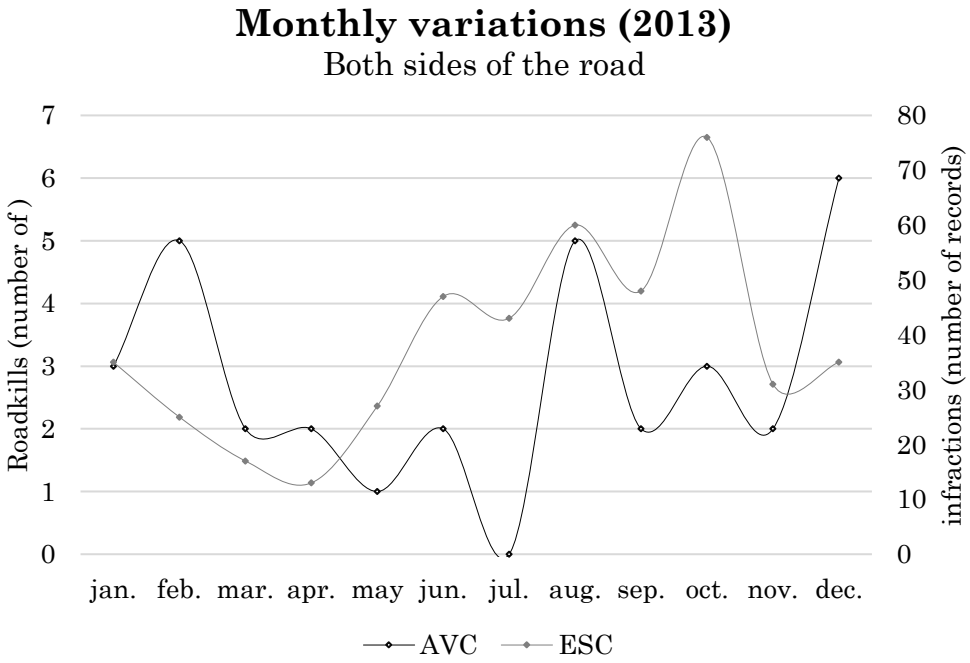
The effects of installing VSs were calculated by applying the Wilcoxon test and exploratory data analysis (REY; NEUHAUSER, 2011).

RESULTS AND DISCUSSION

According to the information provided by the DER-DF on the same days that the roads were monitored by IBRAM, the two ESCs recorded 457 infractions (170 on the right side and 287 in the opposite direction of the road).

When investigating the monthly variations in the AVCs and the infractions that occurred on each side of the road, no relevant correlations were observed. However, when the samples were added in both directions, the variation in the AVCs in 2013 was similar to that of the infractions that occurred between May and November (Figure 3). The differences between the variations observed on both sides of the road can be explained by the structural conditions of the segment since the high volume decreases the life of the asphalt and increases the need for road maintenance. In 2014, more than half of the roads evaluated in the DF had worn pavement, cracks in meshes, patches, sags, undulations, or holes (CNT, 2014).

Figure 3 - Monthly variations in CAVs and records of infractions in 2013.



Source: The authors (2021).

The apparent similarity in the distribution of data over the months was not confirmed by the *Spearman test* since there was no statistical significance in the analysis of the correlation between the AVCs and the infractions in each and both directions of the road segments (Table 1). However, the indices obtained show a positive and minimal relationship between traffic volumes and CAVs ($\rho = 0.470$; $p < 0.05$; Table I).

Table 1 - Correlation coefficients (ρ) and two-tailed significance of the correlations between roadkill events; records of infractions on both and on each side of the roads; and traffic volumes (km^{-1}).

Correlation of *Spearman* test				
	Right	Left	Total	ADT
P	0.125	0.326	0.170	0.470
P value	0.698	0.300	0.595	< 0.01

Source: The authors (2021).

The low statistical significance found may be related to the limited data on infractions (available only in 2013). Therefore, projects such as Rodofauna, which enables the collection of roadkill data over a wide time scale, are necessary and should be enhanced to better understand the effects of traffic dynamics on AVCs. Conversely, access to records of infractions should be improved, considering the limitations related to confidentiality or imposed by the relevant legislation. Thus, the relationship between these two variables could be reassessed with more robust datasets, and the lack of significance in the results can be addressed by increasing the sample size.

The volumetric indices of measured traffic have a high amplitude (annual daily averages of 164 to 21847 vehicles), and the segment with the highest traffic volume was DF-001, where the previously evaluated ESCs are located. On highways, traffic volume is a temporal variable positively related to the times of greatest demand. In urban areas, so-called *rush hour* has the potential to influence the behavior of animal aversion to highways (GAYNOR et al., 2018; FAHRIG; RYTWINSKI, 2009); however, when evaluating the relationship of AVCs at a broad time scale, such as average daily volumes, the positive relationship between the investigated variables did not suggest aversion behaviors on the busiest roads. In addition, the composition of the roadkill shows that most of the affected species had become accustomed to road environments.

According to the data, Tiziu (*Volatinia jacarina*) accounted for approximately a quarter (24.14%) of the identified roadkill animals during the study period. This species is a wild, passerine bird present throughout Brazil and frequently seen in altered areas and savannas (CARVALHO; MACEDO; GRAVES, 2007). Domestic cats (*Felis catus*) and dogs (*Canis familiaris*) accounted for the second-largest portion of the roadkill data (15.05%). The roadkill recorded in 2014 involved at least 81 species of fauna, of which 76 were wild and two (*Sylvilagus brasiliensis* and *Pseudalopex vetulus*) were threatened based on the Red Book of Threatened Species (IUCN, 2021).

In addition, the size of a PA was not proportional to the species diversity in it, a relationship commonly identified in protected areas (Table 2; PRIMACK; RODRIGUES, 2006; MAIORANO; FALCUCCI; BOITANI, 2008).

Table 2 - Number of individuals (n) and species (s) collected in the roads adjacent to the evaluated PAs. Length of the roads surrounding the PAs (ext.rod); frequency of roadkill per kilometer (AVC/km); Simpson's dominance index (D); and diversity index (1-D).

AVCs and Diversity Indices						
	n	**s**	**ext.rod (km)**	**AVC/km**	**D**	**1-D**
ESECAE	211	54	23.6	8.941	0.082	0.918
JBB/FAL/IBGE	198	48	23.8	8.319	0.104	0.896
PNB/FNB	261	43	50.1	5.210	0.127	0.873

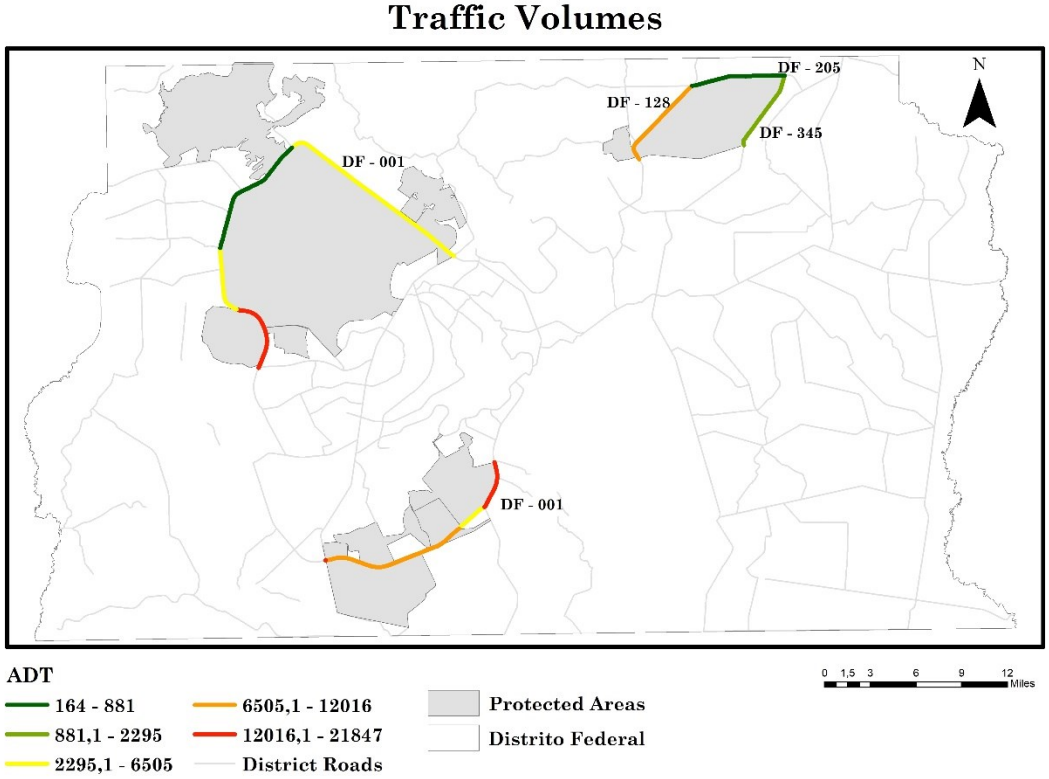
Source: The authors (2021).

Together, the PAs Parque Nacional de Brasília and the Floresta Nacional de Brasília (PNB; FNB) cover 516.91 km² but have the lowest diversity of species in AVCs (0.872). The PA Estação Ecológica de Águas Emendadas (ESECAE), 91.81 km², has the greatest diversity of records (0.918), an amount close to but higher than that observed in the PA mosaic that surrounds the route to the south of DF-001 (JBB/FAL/IBGE). The area of the parks is proportional to the length of the adjacent roads; therefore, the AVC rates were also high in the smallest reserve.

The representative portion of the most abundant species in the AVC samplings was already predicted, but in extensive reserves, it is expected that the species richness is higher than that observed in smaller areas, a fact not observed in the AVC ratio (HANSEN; DEFRIES, 2007; Table 2). Such information could be explained by the buffer zones of the PAs, which ensure greater protection of the central regions compared to their margins (GRAY et al., 2016). However, as all the PAs are delimited by highways and the AVCs occur in road environments, there is no reason that the smaller reserves should have the greatest diversity of species in collisions on adjacent roads.

In addition, the highways that surround the extensive areas of the PAs also had segments with high ADT (Figure 4).

Figure 4 – Average daily traffic (ADT) on the highways evaluated in 2014



Source: The authors (2021).

When evaluating the landscape, the PAs located in developed areas are commonly associated with islands of native vegetation surrounded by an expanse of modified environments (PRIMACK; RODRIGUES, 2006). This scenario is usually based on the conceptual model of island biogeography that explains habitat fragmentation, which in practice may have some limitations (MACARTHUR, 1965; LAURANCE, 2008).

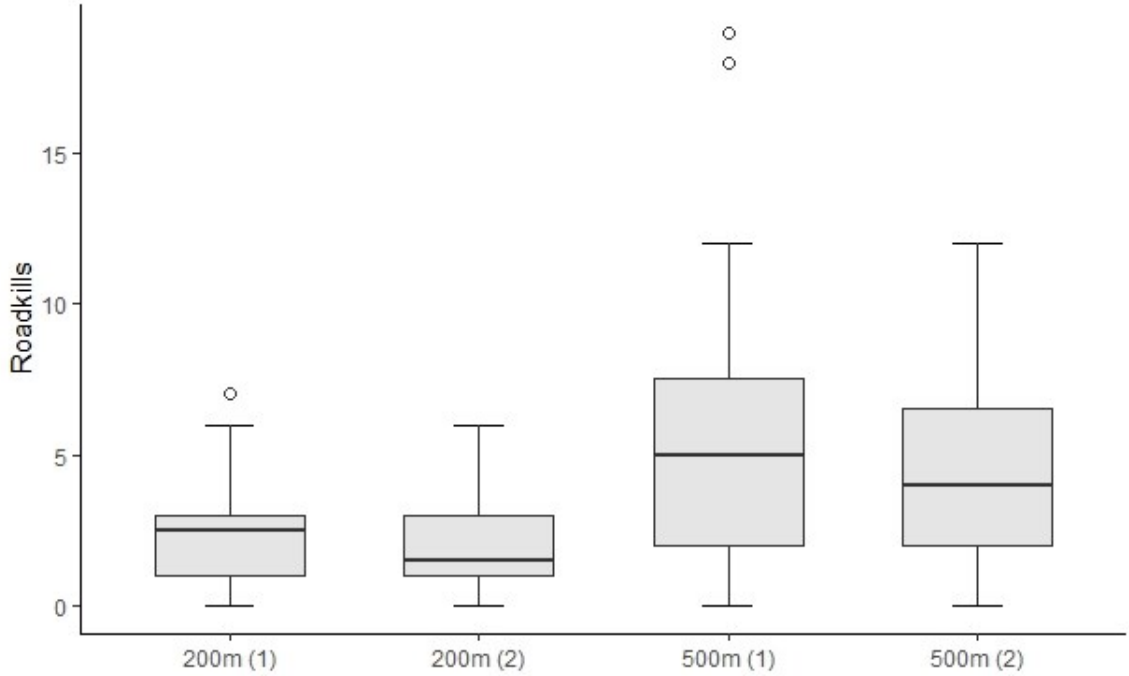
Space is dynamic: in anthropic environments, changes are accelerated and constant (NELBOLD et al., 2015; LIU; HE; WU, 2016). Highways are unique areas, as vehicle flow is continuous in linear sections. With a well-defined pendulum pattern and atypical periods, roads follow another process of habitat fragmentation when close to PAs (FORMAN et al., 2003; RYTWINSKI; FAHRIG, 2012) in that roads would be better understood in comparison to rivers, where flow rates vary at different time scales.

The changes in the chemical and physical environments that occur due to the operation of highways aggravate the edge effect on PA margins, and the native vegetation changes as the distance from the center of a PA increases (VAN DER REE et al., 2011; LAURANCE; BALMFORD, 2013). For the fauna, the less tolerant species are isolated in the PA, and those accustomed to disturbances run the risk of being hit with each road contact.

In the present study, the frequencies of roadkill and lower species diversity indices in the busiest stretches of highway suggest a possible selection of species that could be used to determine annual variations in AVCs. Thus, it is important to consider that the concentration of vehicles in the road segments studied exacerbates the edge effect in PA buffer zones and the isolation of species in PAs, which affect the survival capacity of local populations, demographic decline, water availability, and genetic diversity (LAURANCE, 2008; FORMAN et al., 2003; HOOPER et al., 2012).

Regarding the effect of VSs on speed reduction, when investigating the distribution of roadkill data in box diagrams, there was a reduction in the medians and interquartile ranges for the two sets of AVCs recorded after the installation of VSs in both evaluated areas (200 and 500 m). Before the installation of the VSs, there were *outliers* above the upper limits (Figure 5).

Figure 5 - Box diagrams of the distribution of CAVs recorded at 200 and 500 meters from the VSs before (1) and after (2) its installation between 2012 and 2015.



Source: The authors (2021).

Even with the reduction in the absolute values (from 86 to 73 to 200 m; from 212 to 178 to 500 m) and in the variations in the occurrences within the investigated groups (Figure 5), there was no statistical significance in the median of the differences between the roadkill occurring before and after the installation of the VSs for all of the distances evaluated; thus, it is not possible to conclude that the VSs had any effect on the AVCs (Table 3).

Table 3 - Records of roadkill events before (n_1) and after (n_2) the installation of VSs, Wilcoxon test results and two-tailed significance.

	Wilcoxon test			
	n_1	n_2	V	P value
200 m	86	73	387	0.3937
500 m	212	178	437.5	0.5093

Source: The authors (2021).

The main reason behind the ineffectiveness of the VSs in reducing roadkill is based on the fact that drivers become accustomed to warnings and disregard them over time (KHALILIKHAH; HEASLIP, 2017), but this ineffectiveness may also be related to the lack of quality of the road infrastructure. VSs loses its effect when it is damaged, broken, or even obstructed by the vegetation. In 2014, 9.8% of the VSs evaluated in the DF were classified as poor or very poor (CNT, 2014).

Notably, however, most of the VSs evaluated here (84%) only informed drivers about the maximum speed allowed on the road, and the analysis of the effect of this type of VS on the reduction of AVCs assumed two factors: that the driver was prudent and that the driver maintained the legal maximum speed to inhibit roadkill events. Thus, it was concluded that VSs with a purpose other than mitigation cannot be applied for this purpose.

Between 2012 and 2015, the low proportion of VSs noting possible crossings of wild animals on the roads was limited by the lack of available data from the DER-DF; thus, the expectation of including the different types of VSs was removed from the analysis. Along routes that delimit PAs, this type of VS needs to be increased, a fact not observed in the present study.

CONCLUSIONS

The risk of fauna being hit by a vehicle is the result of the simultaneous presence of fauna and vehicles in the same location. For this scenario to result in a AVC, the actions of the driver or the animal must be insufficient to avoid collisions. Velocity influences the responsiveness of both the traffic volume and the permeability of the road.

The evaluation of the obtained data enabled the consideration that traffic volume is related to the number of AVCs. The animal diversity indices showed that on highways with higher vehicle traffic, a possible intensification of fragmentation and edge effect impacts occurred in the zone of road influence. However, the correlations found between AVCs and speeding infractions were statistically negligible. Conversely, the inclusion of VSs on the roads did not have a significant effect on the reduction of roadkill events.

Maintaining the dynamics of natural systems and designating areas to protect native environments are challenging practices that include conflicts of interest in urban planning (PIMM et al., 2010; OLIVEIRA et al., 2017; D´AMICO et al., 2020). Considering that the intensification of the pressure exerted on the PAs in anthropic environments and bordered by highways is continuous and tends to increase with the growth of cities, studies that evaluate the human dynamics that are capable of affecting PAs and that identify the practices that are successful at reducing the damage caused by AVCs are increasingly necessary. Thus, new studies should evaluate the installation of structures capable of reconnecting the affected areas and continuous monitoring for the roads adjacent to PAs. Thus, it is necessary to continue monitoring projects of roads adjacent to PAs and improve access to data on traffic violations.

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AUTHORS' CONTRIBUTION

Tatiana Rolim Soares Ribeiro conceived the study, analyzed the data and wrote the text. Ruth Elias de Paula Laranja supervised the study and worked on the revision of the text. Camila Barreiros Barbieri assisted in the statistical analysis of the data.