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SEASONAL EFFECTS ON ROADKILL OF WILD VERTEBRATES IN A STRETCH OF A BRAZILIAN NORTHEAST FEDERAL HIGHWAY

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Abstract: In Brazil, roadkill of wild animals represents an important part of the local biodiversity loss. Even so, studies focused on road ecology are still very scarce for many regions of the country. The present study aimed to monitor the mortality of wild vertebrates on the Federal Highway BR-235, in Sergipe (Brazil), and analyze possible seasonal variations in roadkill rates. Between August 2020 and July 2021, two samples were taken per month in a stretch of 20 km of the BR-235, traveled by motorcycle at a speed of 40 to 50 km/h. Seventy-five individuals of 30 vertebrate species were recorded. The roadkill rate was 0.156 individuals per kilometer covered. The most recorded classes were birds with 29 individuals (13 spp.) and mammals with 23 individuals (10 spp.). The species with the highest number of records was *Rhinella* sp. with 16 records (21.6%), *Coragyps atratus* with eight records (10.8%) and *Didelphis albiventris* with seven records (9.4%). Among the species recorded, two are threatened with extinction (*Leopardus tigrinus* and *Puma yagouaroundi*). A greater number of roadkill was registered in the rainy season. The results reveal this stretch of BR-235 as a source of continuous mortality for the region's fauna.

Keywords: collision; mortality; national park; road ecology; wildlife.

INTRODUCTION

One of the most noticeable impacts on vertebrate fauna, generated by the implementation and operation of highways, is the roadkill of wild animals (Benítez-López *et al.* 2010, Van der Ree *et al.* 2015, Laurance 2018). This has been identified as the main cause of wild vertebrate mortality due to the direct influence of human activities in Brazil and worldwide (Bager *et al.* 2016, Laurance 2018).

Roadkills generally occur due to two aspects: first, the road cuts through the habitat of a given taxon, interfering with the movement of individuals during daily movements and migration period; and the second aspect results from the abundance of food along the highways serving as an attraction for the fauna (Dornas *et al.* 2012). However, the impacts of highways can go beyond roadkill. These can also affect the dispersal process of animals, acting as barriers and preventing some species from crossing the road due to heavy traffic, restricting these species to only one side of the road (Coffin 2007; Laurance *et al.* 2009). This culminates subdividing populations, which can lead to decreased genetic diversity and population viability (Balkenhol & Waits 2009, Jackson & Fahrig 2011).

Roadkill can be influenced by seasonal variations, and the magnitude of this variation depends on the taxon (Santos *et al.* 2012). Medium and large mammals are usually the most affected group, regardless of the season (Caro *et al.* 2000, Coelho *et al.* 2008). For birds, it is difficult to identify a pattern in relation to seasonal variation, possibly due to the great taxonomic diversity of this group and the need for greater sampling effort when compared to other groups (Bager & Rosa 2011). Amphibians, in turn, are usually more affected in rainy seasons (Santos *et al.* 2012), which are associated with migration events that, like reptiles, occur for reproduction or dispersal of juveniles (Mazerolle 2004). Although several studies indicate that the rainy season has higher roadkill rates, there is evidence where dry periods can present higher values. The explanation for this is a possible decrease in the food supply, which should lead to increased dispersal of animals in search of food during the dry season (Cunha *et al.* 2010).

Estimating the species subject to roadkill in different environments, as well as establishing the proportion and possible relationships with the species ecology, contributes to the establishment of mitigation measures (Erritozoe *et al.* 2003, Bager & Rosa 2012). Understanding the mechanisms involved in the relationship between road projects and the ecology of populations and communities is highly applicable and can support decision-making in territorial planning and conservation strategies (Dramastad *et al.* 1996, Forman 2004).

In Brazil, roadkill represents an important part of the local loss of biodiversity, with a recent estimate of 475 million wild animals killed per year (CBEE 2020). Even so, studies directed towards road ecology are still very scarce for many geographic regions (Miranda 2007). In the state of Sergipe, in particular, there is no documented study on this topic, revealing a knowledge gap focused on road ecology. Based on this, the present study aimed to monitor the mortality of wild vertebrates in a stretch of Federal Highway BR-235, in Sergipe, and analyze the possible seasonal variations in roadkill rates. Our study prediction is based on the results of several studies from different states (Smith & Dodd 2003, Pinowski 2005, Coelho *et al.* 2008, Santos *et al.* 2012, Machado *et al.* 2015, Braz & França 2016, Carvalho *et al.* 2017, Miranda *et al.* 2017, Ferreguetti *et al.* 2020), which showed that accidents are more frequent during the rainy season. This is associated with the reproductive period and greater availability of food resources, which encourages the displacement of fauna, increasing the probability of road and highway crossings and, consequently, the chances of collision with vehicles.

MATERIAL AND METHODS

Study area

The study was carried out on the Federal Highway BR-235, which connects the capital of the Sergipe state (Aracaju) to the Brigadeiro Velloso Proving Ground in Novo Progresso Municipality, in the state of Pará. The monitored section (20 km long), in Sergipe, starts in the municipality of Itabaiana (10º41'9" S, 37º25'29"W) and ends in the municipality of Laranjeiras (10º45'12"S, 37º10'11"W; Figure 1). It is important to point out that this road stretch passes through the Serra de Itabaiana National Park (PARNASI) (Figure 1), one of the most important areas of scientific studies in Sergipe, which protects Atlantic Forest remnants and endangered species, such as *Leopardus tigrinus* (Schreber, 1775; Mammalia: Felidae), *Puma yagouaroundi* (É. Geoffroy Saint-Hilaire, 1803; Mammalia: Felidae), *Sapajus xanthosternos* (Wied-Neuwied, 1826; Mammalia : Cebidae) and *Bradypus torquatus* (Illiger, 1811; Mammalia: Bradypodidae) (ICMBio 2016). However, despite its

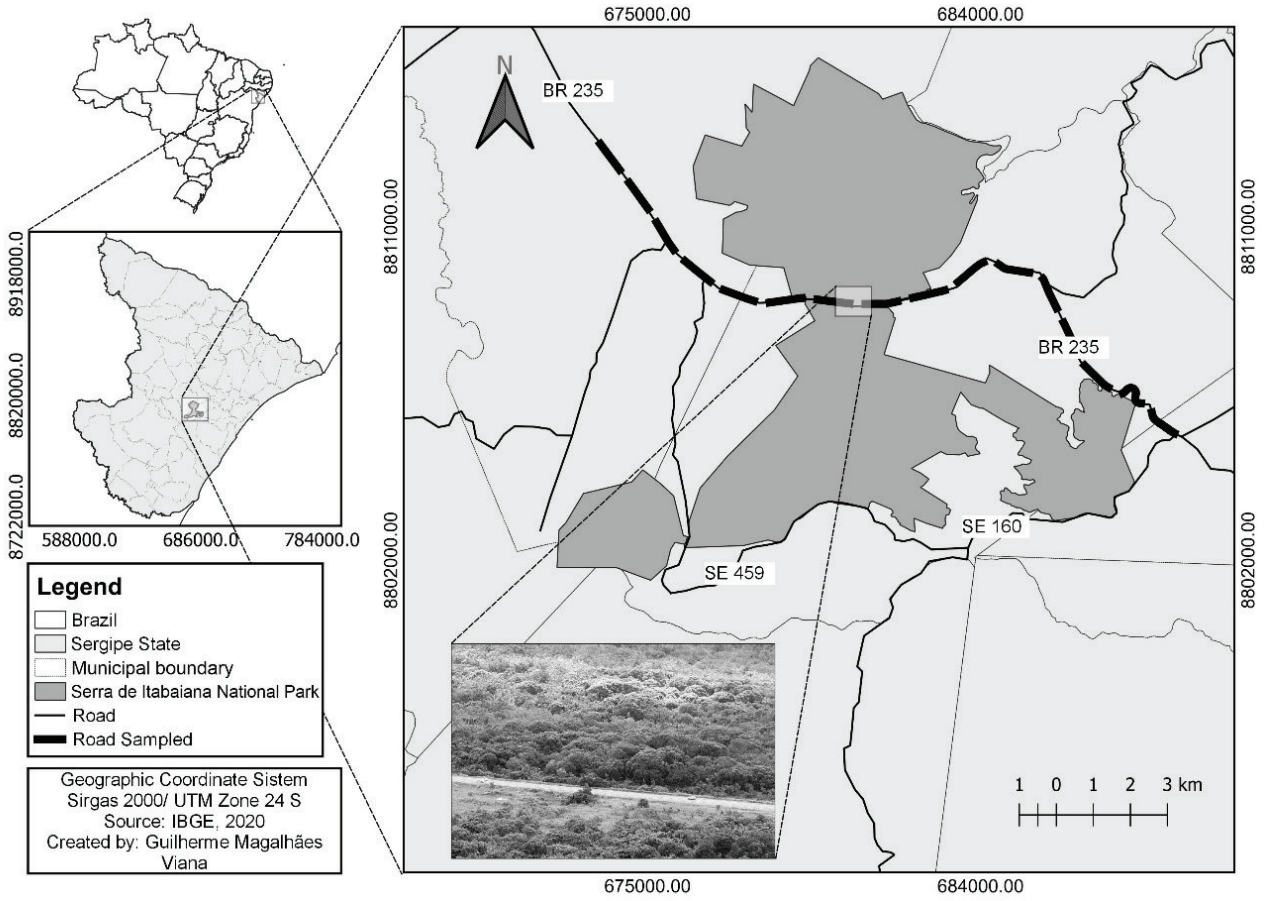

Figure 1. Location of the stretch of the Federal Highway BR-235 sampled for wild animal roadkill. This highway cuts the Serra de Itabaiana National Park, one of the most important protected areas of the Sergipe state, northeastern Brazil.

importance, PARNASI suffers from several human impacts that can compromise its biodiversity; among these, wildlife roadkill, which occurs frequently on the BR-235 (ICMBio 2016).

This road stretch in Sergipe is located in an area of ecological tension, with transitional or ecotone vegetation (Dantas & Ribeiro 2010, IBGE 2014), being influenced by two floristic provinces: the Atlantic and the Northeastern (semiarid) provinces. According to the Köppen-Geiger classification, the region's climate is As' – tropical with dry summer (Alvares *et al.* 2013). Rainfall season occurs between April and September, peaking in May (175 mm), with mean annual precipitation of 782 mm and the average annual temperature is 24 °C (Climate-data.org 2021).

Data collection

We performed 24 samplings over 12 months (two monthly samplings from August 2020 to July 2021) along a 20 km stretch, totalizing 480 km sampled. Each sampling was performed with a motorcycle at a speed of 40 to 50 km/h, only on days without precipitation. Samplings started in the morning (normally 7:00 a.m.) and lasted the necessary time to travel the entire route (20 km long), stopping the motorcycle at each sighting to carry out the records. Only registers of wild fauna roadkill were taken. When a wild animal was run over, it was identified at the lowest possible taxonomic level and photographic records were taken. After registration, the carcasses were removed from the road to avoid double counts and additional roadkill of carrion animals (Costa 2011, Hegel *et al.* 2012, Santos *et al.* 2012).

For the identification and taxonomic nomenclature of vertebrate species, specialized literature for mammals (Reis *et al.* 2010, Paglia *et al.* 2012), birds (Sigrist 2009, Pacheco *et al.* 2021), reptiles (Bérnils & Costa 2012, Costa & Bérnelis 2018) and amphibians (Freitas 2015, Segalla *et al.* 2016) was used. Photo submissions to expert

scientists were also carried out. To determine the conservation status of the animals, the lists of the Brazilian Fauna Threatened with Extinction (ICMBio 2018) and the International Union for Conservation of Nature's Red List (IUCN 2021) were consulted.

Data analysis

The sampling effort was evaluated by comparing the recorded wild vertebrate richness with that estimated by the Chao 2 estimator in the EstimateS 9.1 program (Colwell 2013). Vertebrate roadkill rate was also calculated using the relationship between the number of individuals registered and the total kilometers traveled (Turci & Bernarde 2009, Ramos-Abrantes *et al.* 2017). Shapiro-Wilk was used to test data normality and data showed a normal distribution, except for precipitation/ rainfall. In order to understand the correlation between precipitation (mm) and roadkill records per month, we used a Spearman's Correlation. We extracted the accumulated monthly rainfall data from the Climate Monitoring Program of the Northeast Region (PROCLIMA) (Souza et al. 2001). We also performed a *t*-test to verify whether there was a significant difference between the average number of road killed individuals and species in the dry (October – March; N = 6 months) and rainy (April – September; N = 6 months) period. We performed all statistic tests using the PAST 3.08 program (Hammer *et al.* 2001).

RESULTS

Seventy-five wild road killed vertebrates were recorded, belonging to 30 species (Table 1) and four main taxa. Considering the total number of kilometers covered in this study (480 km), the rate of being run over was 0.156 individuals per kilometer covered. The most representative class in number of registered individuals was Aves with 29 records (38.6%), followed by Mammalia with 23 records (30.6%) and Amphibia with 19 records (25.3%) (Figure 2). Birds and mammals also showed high richness, with 13 (43.3%) and 10 species (33.3%), respectively (Figure 2).

The most road killed species was *Rhinella* spp. with 16 records (21.6%), followed by *Coragyps atratus* (Bechstein, 1793; Aves: Cathartidae) with eight records (10.8%), and *Didelphis albiventris* (Lund, 1840; Mammalia: Didelphidae) with seven records (9.4%) (Table 1). Two road killed species were classified as vulnerable to extinction: the small wild cat (*Leopardus tigrinus*; Figure 3N) (ICMBio 2018; IUCN 2021), and the Moorish cat (*Puma yagouaroundi*; Figure 3J) (ICMBio 2018). Both species were road killed on the edges of dense vegetation in the road stretch crossing PARNASI (10°46'12.976"S, 37°21'1.314"W; 10°47'28.352"S, 37°17'2.807"W).

The rarefaction curve did not reach the asymptote, indicating that more species could still be recorded in the sampled road stretch if greater sampling efforts were applied (Figure 4). The roadkill records increased with increasing rainfall quantity (r_s = 0.75; p = 0.01; N = 12). A significant difference was found in the number of individuals (t = 4.58; p = 0.001; N = 12) and species (t = 4.58; p = 0.001; N = 12) of wild vertebrate roadkill between the dry and rainy periods, with the largest number of records verified in the rainy season (Table 1 and Figure 6).

DISCUSSION

Roadkill of wild fauna has been one of the most evident environmental impacts generated by roads, affecting a great variety of vertebrate species in the most different ecosystems around the world (Seiler 2001). Although only 20 km were covered in this study, the sampled stretch of Federal Highway BR-235, in Sergipe, had a high number of records of wild vertebrate roadkill, especially in the rainy season. The results reveal this stretch of BR-235 as a source of continuous mortality for the fauna of the region, especially for the species that live in the PARNASI, since this stretch crosses the park, and all the recorded species in the present study occur in this conservation unit (Carvalho & Vilar 2005).

This study found a rate of 0.156 wild vertebrates killed per kilometer traveled, a result higher than reported in other studies carried out in the Northeast region Brazil (Ramos-Abrantes *et al.* 2017 = 0.087 individual/km; Cezar *et al.* 2021 = 0.006 individuals/km). It is also higher than the result found by Sousa & Miranda (2010), even though a different index was used to estimate the rate of roadkill (0.036 individual/km/year). It was also superior to that found in studies conducted in

Table 1. List of wild vertebrates run over in a stretch of Federal Highway BR-235 in the state of Sergipe (Brazil), between August 2020 and July 2021. *Endangered species (VU; ICMBio 2018; IUCN 2021).

Taxon	Records (%)	Seasons	
		Dry	Rainy
Amphibia			
Leptodactylus vastus Lutz, 1930	2 (2.6%)	1	1
Pristimantis spp.	1 (1.3%)	0	1
Rhinella spp.	16 (21.3%)	2	14
Reptilia			
Boa constrictor (Linnaeus, 1758)	1 (1.3%)	0	1
Philodryas spp.	1 (1.3%)	1	0
Salvator merianae (Duméril & Bibron, 1839)	1 (1.3%)	1	0
Spilotes pullatus (Linnaeus, 1758)	1 (1.3%)	1	0
Aves			
Athene cunicularia (Molina, 1782)	4 (5.3%)	1	3
Caracara plancus (Miller, 1777)	2 (2.6%)	2	0
Columba livia Gmelin, 1789	1 (1.3%)	1	0
Columbina talpacoti (Temminck, 1810)	1 (1.3%)	1	0
Coragyps atratus (Bechstein, 1793)	8 (10.6%)	2	6
Crotophaga ani Linnaeus, 1758	3 (4%)	1	2
Estrilda astrild (Linnaeus, 1758)	1 (1.3%)	0	1
Guira guira (Gmelin, 1788)	1 (1.3%)	1	0
Machetornis rixosa (Vieillot, 1819)	1 (1.3%)	1	0
Megascops choliba (Vieillot, 1817)	2 (2.6%)	0	2
Nyctidromus albicollis (Gmelin, 1789)	2 (2.6%)	0	2
Passer domesticus (Linnaeus, 1758)	1 (1.3%)	0	1
Volatinia jacarina (Linnaeus, 1766)	2 (2.6%)	0	2
Mammalia			
Callithrix jacchus (Linnaeus, 1758)	2 (2.6%)	1	1
Carollia spp.	1 (1.3%)	0	1
Cerdocyon thous (Linnaeus, 1766)	5 (6.6%)	1	4
Dasypus novemsinctus (Linnaeus, 1758)	1 (1.3%)	0	1
Didelphis albiventris Lund, 1840	7 (9.3%)	3	4
Euphractus sexcinctus (Linnaeus, 1758)	1 (1.3%)	1	0
Leopardus tigrinus (Schreber, 1775)*	1 (1.3%)	0	1
Procyon cancrivorus (Cuvier, 1798)	2 (2.6%)	0	2
Puma yagouaroundi (É. Geoffroy Saint-Hilaire, 1803)*	2 (2.6%)	0	2
Tamandua tetradactyla (Linnaeus, 1758)	1 (1.3%)	0	1
Total of individuals	75 (100%)	22	53
Total of species	-	17	21

the Amazon region (Turci & Bernarde 2009 = 0.078 individuals/km; Gumier-Costa and Sperber 2009 = 0.004 individuals/km; Pinheiro & Turci 2013 = 0.138 individuals/km) and on roads bordering the Emas National Park (0.045 individuals/km; Silveira 1999), a 130.000 ha conservation unit located in the states of Goiás and Mato Grosso do Sul. It is important to highlight that all these studies had a greater sampling effort than the present study.

The rarefaction curve did not stabilize, indicating that the vertebrate community was not sufficiently sampled. This demonstrates that

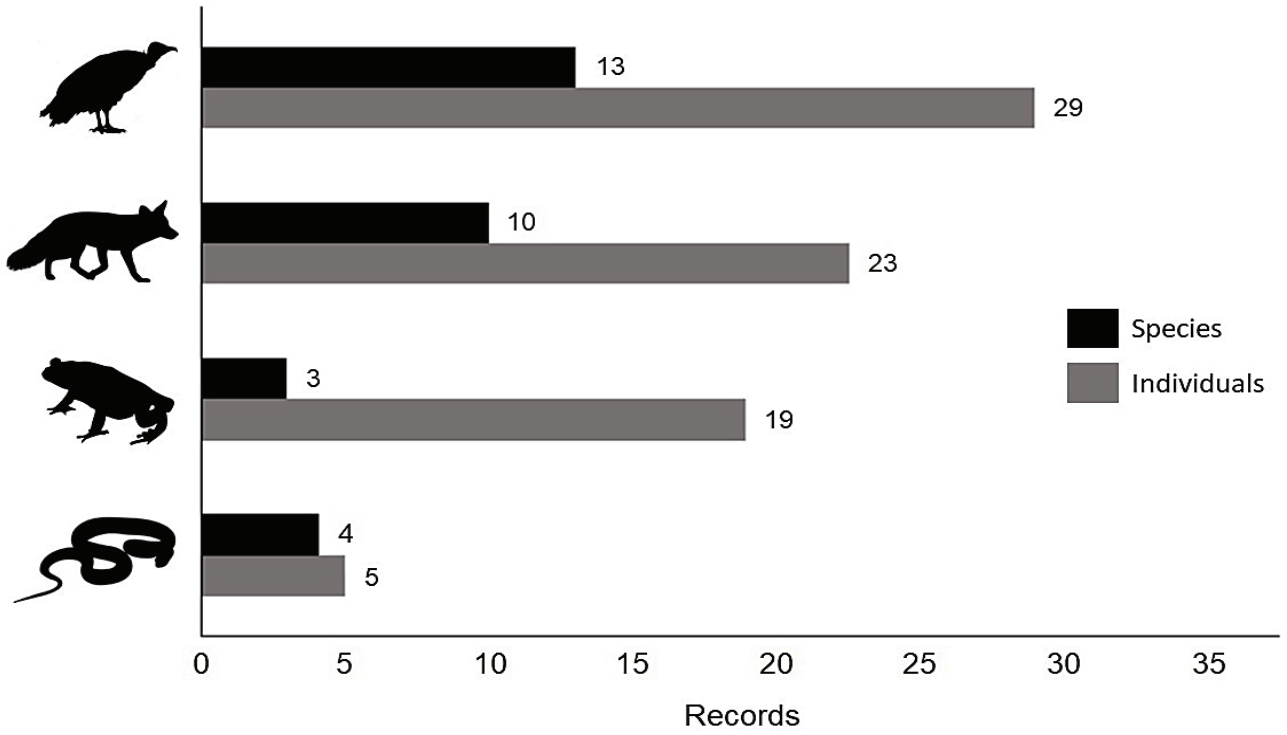

Figure 2. Richness and abundance of wild birds, mammals, amphibians and reptiles run over on a stretch of Federal Highway BR-235 in the state of Sergipe (Brazil), between August 2020 and July 2021.

the richness of animals road killed in the area is potentially greater than that recorded. In most studies on vertebrate roadkill, the sampling sufficiency curve does not reach the asymptote, indicating that the vertebrate species were not fully sampled and that a longer sampling period would be indicated to better inventory the local fauna (Gumier-Costa & Sperber 2009, Turci & Bernarde 2009, Santana 2012).

Probably the number of animals registered in this study is underestimated, considering that several animals when colliding with vehicles can be thrown off the road or can even move away from the highway to a different location after being run over, and die later without being detected (Rodrigues *et al.* 2002, Turci & Bernarde 2009). In addition, small animals can be easily removed from the road by scavengers (e.g., birds of prey) (Silva *et al.* 2007, Ratton *et al.* 2014), consequently not being counted. It is important to highlight that along the sampled stretch of BR-235 it is common to observe the presence of vultures (*C. atratus*) on the road, looking for carcasses of dead animals on the roads. As a result of this type of behavior, vultures can also be road killed (eight records; 10.8%), triggering new cycles of roadkill (Bager & Rosa 2010, Vieira *et al.* 2019).

Many studies on wildlife roadkill normally identify birds and mammals as the most affected classes (Rosa & Mauhs 2004, Melo & Santos-Filho 2007, Deffaci *et al.* 2016, Oliveira *et al.* 2017, Miranda *et al.* 2021), which corroborates our findings. However, the dominance of roadkill of one taxa over others can vary for different reasons (e.g., local richness and abundance, landscape features, ecological requirements, sampling design) (Laurance *et al.* 2009, Bager & Rosa 2011). For instance, certain species of birds appear highly susceptible to roadkill (Prada 2004). Clevenger *et al.* (2003) mention that flight and foraging on the road are factors that increase the vulnerability of birds to being road killed. The small body weight and delicate constitution of many bird species make them affected by the strong displacement of air caused by the passage of high-speed vehicles (Prada 2004), in addition to collision with vehicles.

Considering the mammals commonly killed by vehicle collisions, the opossum (*Didelphis* spp.) represents a large part of its records (see *D. albiventris*), as in other studies (Smith & Dodd 2003, Rosa & Mauhs 2004, Pinowski 2005, Cherem *et al.* 2007, Deffaci *et al.* 2016, Costa 2018, Ferreguetti *et al.* 2020). Opossums use roadsides to forage and are highly active among these areas,

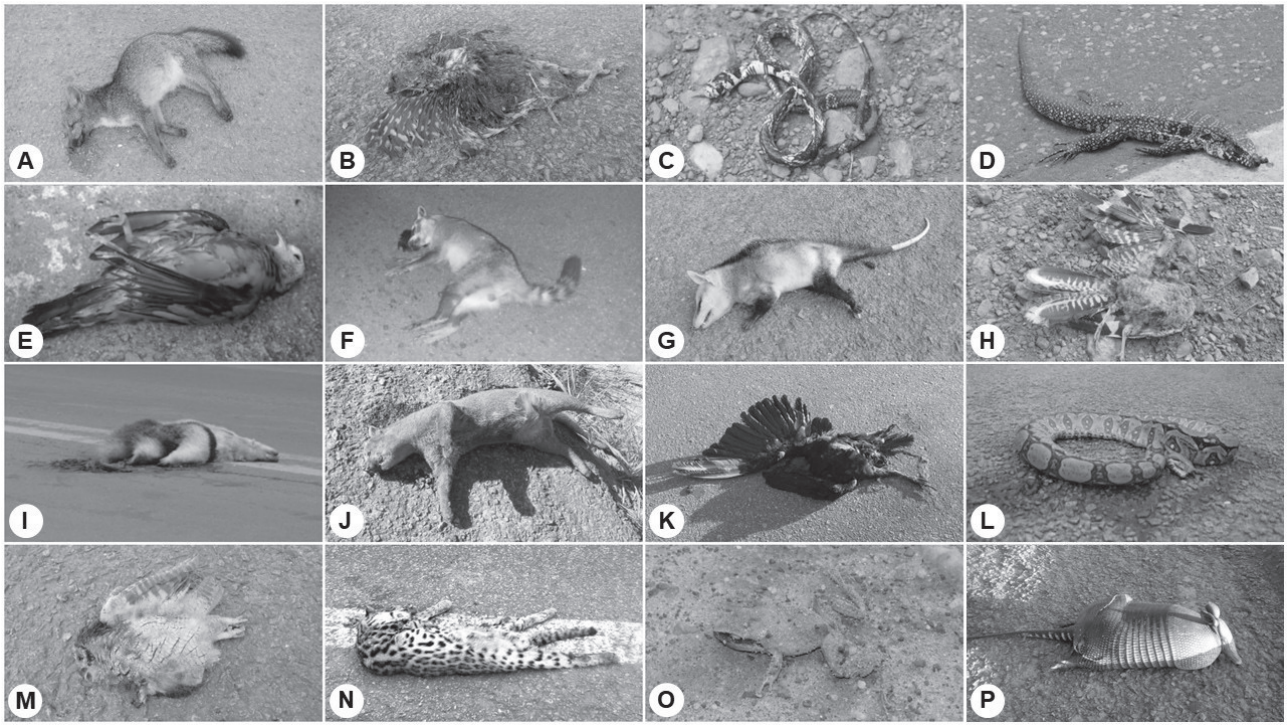

Figure 3. Some wild vertebrates run over in a stretch of Federal Highway BR-235 in the state of Sergipe (Brazil), between August 2020 and July 2021: (A) Cerdocyon thous, (B) Athene cunicularia, (C) Spilotes pullatus, (D) Salvator merianae, (E) Columbina talpacoti, (F) Procyon cancrivorus, (G) Didelphis albiventris, (H) Nyctidromus albicollis, (I) Tamandua tetradactyla, (J) Puma yagouaroundi, (K) Coragyps atratus, (L) Boa constrictor, (M) Megaschops choliba, (N) Leopardus tigrinus, (O) Pristimantis spp., and (P) Dasypus novemcinctus. Credits: C. Silva.

being more prone to being run over (Gumier-Costa & Sperber 2009). *Didelphis* species are cited as seed dispersers of embaúbas (Urticaceae) (Medellin 1994; Cantor et al. 2010). On the margins of the stretch of BR-235, the vegetation altered by edge effects can be seen, with many pioneer species such as Urticaceae. This fact may explain the high mortality of *D. albiventris* that forage on the roadside and often cross it.

Besides birds and mammals, our data recorded high amphibian roadkill, particularly by *Rhinella* spp. frogs (16 records; 21.6%). This result may be associated with small bodies of water and/or periodically flooded areas that can be found along the sampled stretch. In addition, the type of vehicle used for carrying out the samplings (motorcycle), together with the low speed (between 40 and 50 km/h), might also have contributed to this result, since the probability of detection of small run over animals increases with reduced speed (Rosa *et al.* 2012). Amphibians are generally the least recorded group in monitoring carried out by car (Clevenger *et al.* 2003, Coelho *et al.* 2008, Teixeira *et al.* 2013, Santos *et al.* 2017), except for those using low speed (e.g. <40 km/h) (Glista *et al.* 2007, Garriga *et al.* 2012).

Among the wild vertebrates found dead in the BR-235, two species are threatened with extinction in the VU category, *L. tigrinus* and *P. yagouaroundi*. According to Oliveira & Cassaro (1999), all wild cat species found in Brazilian territory are threatened with extinction due to the reduction and fragmentation of their habitats. Highways are currently among the main means for the populational declines of this group (Cherem *et al.* 2007, Hegel *et al.* 2012, Oliveira & Silva 2012). Therefore, the impact of roadkill is a critical demographic factor, especially for medium and large mammals or those threatened with extinction, such as *L. tigrinus* and *P. yagouaroundi*. Unfortunately, it is difficult to estimate the demographic impact caused by roadkill on many wild vertebrates, due to the lack of studies on the population size of the most impacted species.

Comparing roadkill records between the dry and rainy periods, a greater number of records was observed in the rainy season (71%

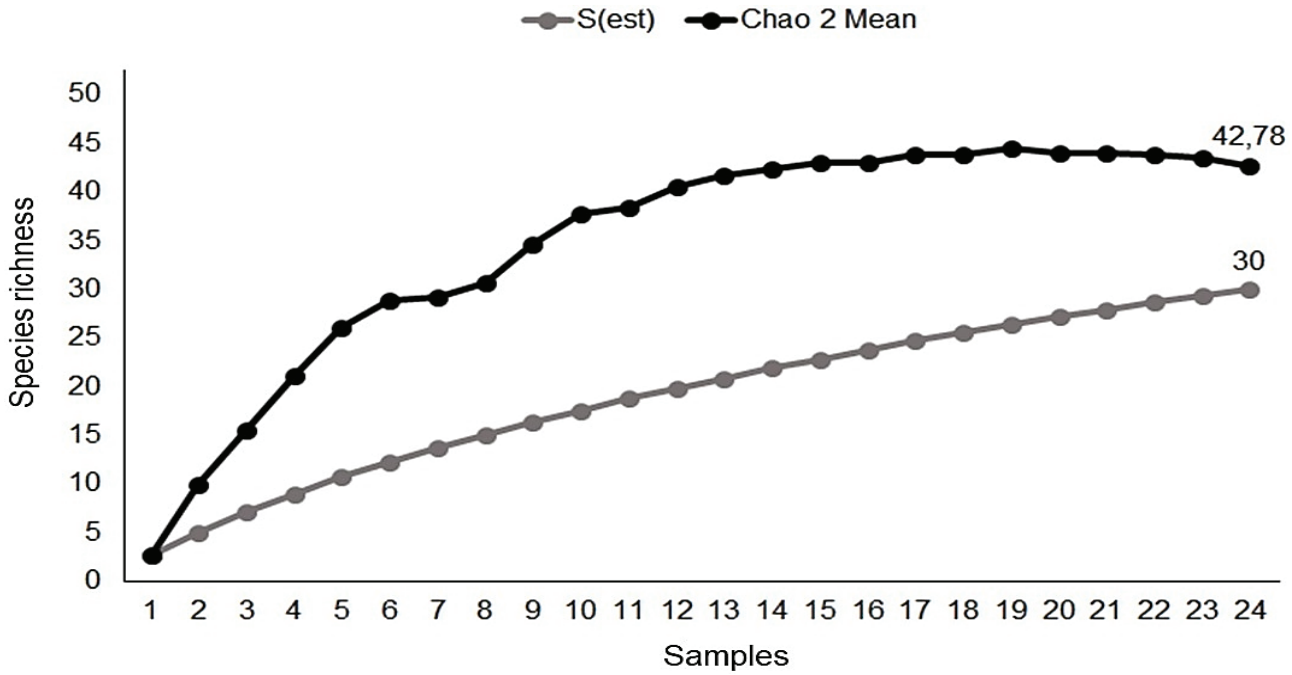

Figure 4. Collector curve with the recorded (S) and estimated (Chao 2 Mean) wild vertebrate richness in a stretch of Federal Highway BR-235 in the state of Sergipe (Brazil), between August 2020 and July 2021.

of individuals and 21 spp.). Several studies (Smith and Dodd 2003 Pinowski 2005, Coelho *et al*. 2008, Santos *et al*. 2012, Machado et al. 2015, Braz & França 2016, Carvalho *et al*. 2017, Miranda *et al*. 2017, Ferreguetti *et al*. 2020) point out that wildlife roadkill occurs mainly in the rainy season, because it is associated with the reproductive period and greater availability of food (*e.g.*, fruits, seeds, flowers, other animals, as insects). These factors stimulate the movement of fauna, increasing the probability of road crossing, and consequently, the chances of collision with

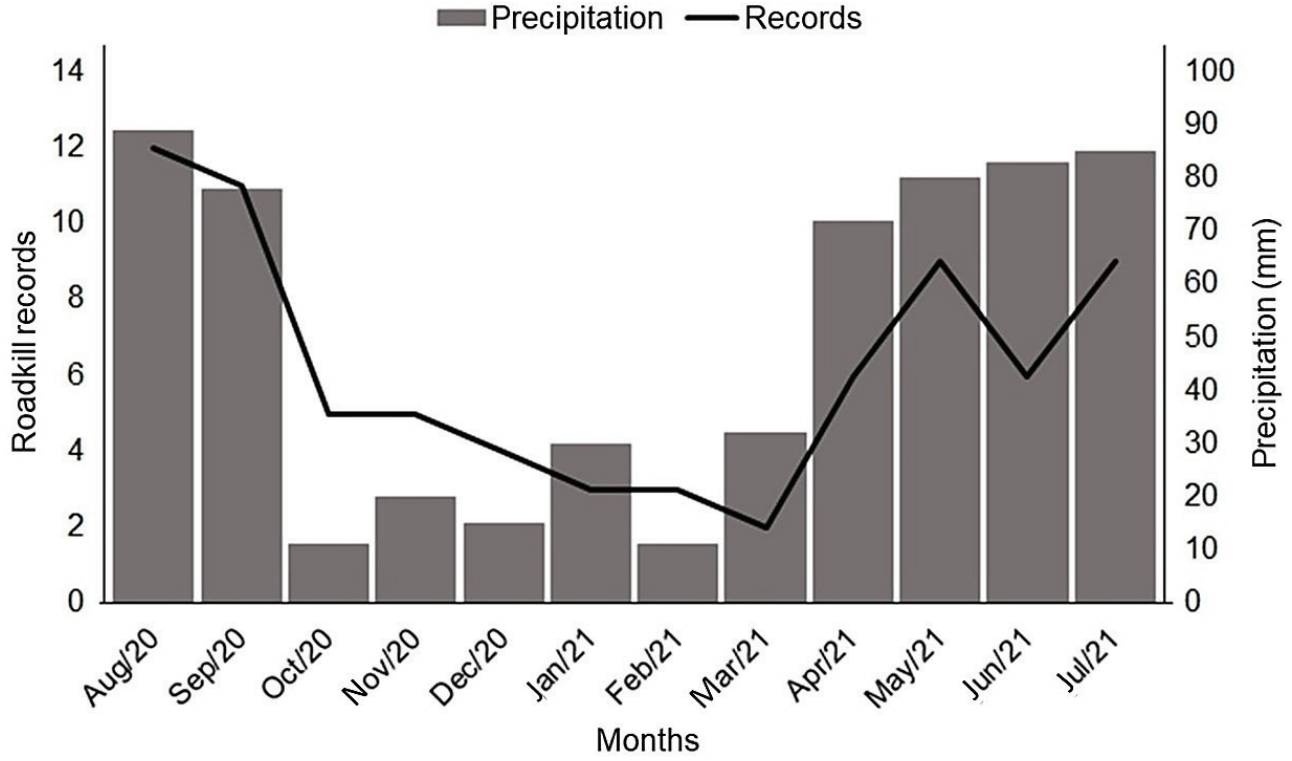

Figure 5. Relationships between the roadkill records and accumulated rainfall (mm) in a stretch of Federal Highway BR-235 in the state of Sergipe (Brazil).

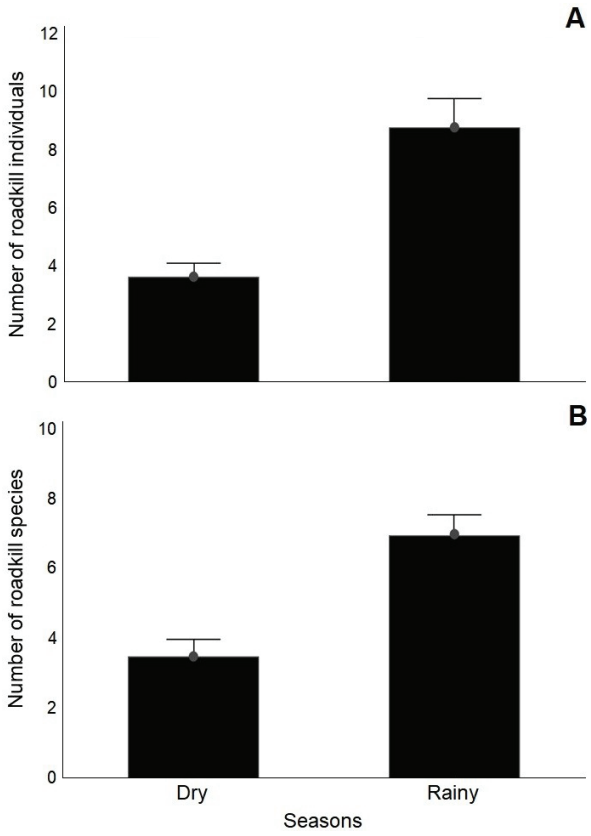

Figure 5. Mean (±SE) of the number of individuals (A) and species richness (B) run over in a stretch of Federal Highway BR-235 in the state of Sergipe (Brazil). Both results showed significant differences between season periods.

vehicles. The decrease in visibility in driving during rain could also be responsible for more roadkill during the rainy season (D'Amico *et al.* 2016, Rendall *et al.* 2021), however, this hypothesis should be tested using empirical data. It is important to state that our study evaluated data considering a single year of sampling. Sampling consecutive years would allow a better understand of the roadkill pattern and enable more robust conclusions on the differences between the dry and rainy seasons.

This is the first study carried out on this topic in the state of Sergipe, especially on the stretch of highway BR-235 that crosses PARNASI, considered an important protected area in Sergipe. We emphasize that additional data are needed to better understand how seasonality modulates the roadkill rate on the stretch of BR-235, with our data suggesting that the rainy season increases the incidence of roadkills. More studies are required to understand which factors drive roadkill rates in this region, such as landscape characteristics around the highways, road conditions and speed concentration points (Clevenger *et al.* 2003, Goosem 2007, Coelho *et al.* 2008). However, the negative influence of the highway on the wildlife in the sampled stretch is evident. The results presented here can promote the implementation of some mitigating measures, including the installation of speed control devices, educational campaigns, and construction of fauna bridges/corridors that allow animals to safely cross the road, especially in the rainy periods.

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