**Vertebrate mortality on a road in the Brazilian semiarid environment: Seasonality patterns and Hotspots**

**ABSTRACT**

Mortality from collision with vehicles is the most visible impact of road traffic on wildlife. To reduce this mortality on the roads, it is necessary to know the factors are associated these collisions. The purpose of our work was to identify seasonal factors that are most influential on the vertebrate mortality rate on highways in the Brazilian semiarid region and identify the location of road-kill hotspots. We monitored one stretch of a highway over a one-year period. We recorded mortality rates according to taxon, ecological groups, richness and size. We used a modified K statistic to depict the spatial road-kill patterns. Pearson and Spearman correlations and linear regression were used to obtain the association between seasonal factors and road-kill. We estimate that 189 vertebrates are road-killed per kilometer every year, totaling < 7 thousand road-killed per year on a 40-km segment of the BR-122 highway. The estimated road mortality magnitude obtained in this study corresponds to four times the number of observed carcasses during the road surveys. We found a positive relationship between vertebrate road-kill events and the rainy season. The highest road-kill mortality rate was for amphibians, birds and reptiles; its peaks coincided with the rainy season. Mammals exhibited higher road-kill mortality rate in the dry period. Daily rainfall and temperature are the factors that most influenced the road-kill events. We found one significant stretch of road-kill hotspot for every group, except mammals. With the expected expansion of the road network, it should include habitat protection, road-crossing structures, speed reducers and campaigns to raise awareness about road impacts on wildlife.

Keywords: rainy season; road ecology; spatial pattern; wildlife collision; road-kill.

**1 INTRODUCTION**

The transport infrastructure linked to road and rail transport interferes with routine, such as leisure and work trips, or in the transport of products that maintain the social organization models we know (Forman et al., 2002). Despite the benefits, highways impose high costs due to traffic accidents and environmental damage, such as waste disposal, deforestation fronts, disease spread, pollution, soil erosion (Farias et al., 2019), habitat fragmentation, in addition to interference in the life history and population dynamics of wildlife (Alexander et al., 2005; Forman and Alexander, 1998). According to Frair et al. (2008), roads affect biodiversity because a higher road density increases wildlife mortality rates, mainly due to the four following factors: habitat loss, resource inaccessibility, population subdivision and traffic mortality (Jaeger et al., 2005; Seiler, 2001). The latter is one of the most direct impacts of highway operation (Bager et al., 2016) and causes damage to biodiversity and the health of users.

In the United States, there are approximately 2 million collisions per year between vehicles and animals (Huijser et al., 2008). In France, the average of fatal accidents involving ungulates is approximately 50 per year and almost 2,500 people are injured (Bruinderink and Hazebroek, 1996). In Europe alone (without Russia), estimations are as high as 500,000 collisions per year, with economic losses of over $ 1 billion (Danielson and Hubbard, 1998). In Brazil, collisions generate a loss of USD 157.5 million per year owing to health and vehicle damage, property loss and institutional assistance (IPEA, 2015). Estimates show that more than 475 million wild animals die in Brazil every year, and the Northeast region is responsible for 10% of this amount (CBEE, 2018). In the northern hemisphere, there are several studies on road-kill and related mitigation measures (Spellerberg, 2002; Ascensão and Mira, 2005; Jaeger et al., 2005; Grilo et al., 2009). Yet, there is little research available in South America (Fahrig and Rytwinski, 2009; Ascensão et al,,2017), and even less in regions with semiarid ecosystems (Bastos et al., 2019; Pereira et al., 2017), as in northeast Brazil.

According to Miles et al. (2006) the dry tropical forest in northeastern Brazil is one of the most extensive and contiguous areas. The semiarid region occupies the largest portion of northeast Brazil (9,92%) (IBGE, 2002) and covers 6,76% of the Brazilian territory (IBGE, 2020). The Brazilian semiarid has a relatively dense human population and has an extensive road network compared to other arid regions, approximately 15% of the Brazilian road system (IPEA, 2009). Despite the extensive road network and local biodiversity, research related to road ecology is concentrated in south and southeast Brazil (Pereira et al., 2017).

In the forementioned studies, records are predominantly of medium and large mammals, species that traverse extensive areas in search of food. Therefore, they become more vulnerable to being road-killed (Forman et al., 2002). In the few studies about seasonal environments, there is a higher road-kill rate of amphibian and reptile species, as their physiologies are closely related to variations in precipitation and temperature (Pereira et al., 2017; Bastos et. al., 2019). Climatic seasonality is responsible for the cyclical availability of resources, and this interferes with the wildlife behavior.

Resource availability is also related to landscape conservation, so that it may favor road-kill events in areas with heterogeneous use and vegetation cover (Spellerberg, 2002; Souza et al., 2014; Pereira et al. 2017; Bastos et. al., 2019). However, to improve the effectiveness of such measures, local evaluations of road-kill events may be important before the adoption of general recommendations for mitigation, such as crossing structures. In order to reduce the road-kill rate and improve mitigation infrastructures, it is necessary to carry out fauna inventories and monitor collisions, so as to identify the areas of greatest risk and relate them to their respective local landscapes (Coelho et al., 2008).

The objective of our present work was, therefore, to identify the seasonal factors that most influence vertebrate road-kill events in a semiarid environment so as to estimate the annual road-kill rate and identify the location of road-kill hotspots. We believe that in this environment, precipitation seasonality interferes with the behavior of the fauna, inducing or not the collisions.

**2 STUDY AREA**

The study was carried out on 40 km of the BR-122 highway, located in northeast Brazil, between the cities of Quixadá and Ibaretama, in the state of Ceará(Fig. 1). The study area crosses 9 km of the Quixadá Monoliths Natural Monument.

Diagrama

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**Figure 1.** Location of the study area.

This road stretch consists of two-way traffic with regular conditions, a narrow shoulder, horizontal signs in good conditions and vertical signs in regular conditions. The study area is inserted in the climatic context of the Brazilian semiarid, in the seasonal tropical savanna biome (Coutinho, 2016) and in the Caatinga area (regional nomenclature for tropical savanna), with open and dense shrub physiognomies in addition to special environments such as riparian forest and rupicolous vegetation (Moro et al., 2015).

The average annual rainfall is 751 mm and a seasonality caused by the compartmentalization in two pluviometric seasons is characteristic of the region: the first semester is rainy (89.6%), with a peak between February and May, while there is drought in the second semester. Monthly relative humidity varies between 45 and 80%. Temperatures are high, annual thermal amplitude is reduced (26º and 29ºC); at the same time, there is a significant daily thermal amplitude (33 and 23°C) and high evapotranspiration rate, which implies an annual water deficit. Surface water bodies have an intermittent regime and water mirrors only during the rainy period and in the first months of the dry season (Zhang et al., 2016). As for land use, there are plantations, pastures, small rural communities, urban stretches and mining areas (Appendix S1). The wild fauna to be found is characterized predominantly by small-and-medium-sized species of wide distribution and with generalist habits, such as *Rhinella jimi* and *Cerdocyon thous*, in addition to restrictive species such as *Leopardus emiliae*.

**3 METHOD**

The experimental design consisted of the following steps: 1) highway monitoring ; 2) data systematization; 3) calculation of the road-kill rate; 4) collection of meteorological data (precipitation, humidity and air temperature) (Souza et al., 2014); 5) spatial scale hotspots.

**3.1 Highway monitoring**

Between September 2017 and August 2018, twelve (12) campaigns were carried out. Inspections took place by car on three consecutive days and started at 5 a.m. The displacement occurred at a speed of 40 km/h with two auxiliaries to view the vertebrate carcasses. At each occurrence, coordinates, time, carcass size, photographic records and species identification were collected. To avoid double counting, the carcasses were removed. In order to reduce the under-sampling of road-kill mortality rate, the detectability of observers and the carcass removal rate were quantified (Taylor and Goldingay, 2004; Santos et al. 2011). For detectability, 40 pieces of varying sizes were taken from a refrigerator and distributed over 5 km on the highway shoulders, but without any observer being present. Subsequently, the observers sought to detect these pieces by following the method used in monitoring. This way, the observer’s success was quantified. The presence/absence of the carcasses was verified for one week.

**3.2 Data Systematization**

Registered animals were classified by taxon, ecological group and size. Species that could not be identified during the campaign were sent to zoologists. Next, the road-kill rate for each group and the species richness sample were calculated. The registered species were classified according to the following taxa: amphibians, reptiles, birds and mammals; ecological groups *Bird 1* (saprophages), *Bird 2* (granivores), *Bird 3* (owls and hawks); *Rep 1* (snakes and lizards), *Rep 2* (tortoises); *Mam 1* (*C. thous*), *Mam 2* (skunk, raccoon, armadillo), *Mam 3* (*L. emiliae*) and *Mam 4* (*Sylvilagus brasiliensis*); and according to the sizes *IND L* (<300 mm) and *IND B* (>300).

Classification of road-killed species according to size and ecological group was necessary for the analysis of taxa that have small to medium-sized species, in addition to different habits (Carvalho and Mira, 2011). In the case of the mammals’ group, *Mam 1* (*C. thous*) are in a separate group from the rest, due to the high number of road-killed individuals in relation to other mammals; *Mam 2* is a group where there are mammals with generalist habits; whereas *Mam 3* (*L. emiliae)* has more restricted habits and there were only two records; and, lastly, as for *Mam 4* (*S. brasiliense*), there was only one occurrence and it fit within small mammals. Regarding birds, in the same way, granivores are the most hit species and are smaller in size than other birds, so they were concentrated in a separate group. Regarding saprophages, due to their habits, which even interfere with the removal of other individuals’ carcasses, they were separated from the other birds. As for reptiles, the two groups have different habits: while turtles are aquatic, snakes and lizards have a terrestrial habit.

**3.3 Road-kill rate**

In order to estimate the road-kill rate, equation 1 was used (Teixeira et al., 2013):

(1)

Where *N* is the number of carcasses found throughout the monitoring, *p* is the observers’ detection efficiency, *TR* is the persistence time and *TS* is the interval between samples (Taylor and Goldingay, 2004; Slater, 2002). The total road-kill rates were calculated by taxon, ecological group and size.

The mammalian and reptile taxa and the *IND* *B* group showed *p* =100%. The other taxa and the *IND L* group presented 75%. As for the TR, birds remained 0.55 days, and mammals and *IND B* remained 3.03 days. The rest of the animals stayed one day. This analysis was applied to the different taxonomic road-kill groups on BR-122, using the program Siriema v.1.0 (Coelho et al. 2006).

**3.4 Road-kill x Seasonality**

Data concerning accumulated rainfall (mm) on field inspection days was used from the Ibaretama post, made available by the Ceará State Foundation for Meteorology and Water Resources (FUNCEME, 2018). The choice of accumulated rainfall was based on the influence that recent rainfall may have on animal behavior. Daily averages of temperature and humidity of the Quixeramobim meteorological station (~38 km for stretch 1) were made available by the National Institute of Metereology (INMET, 2018). All values were standardized with the Z Test.

The relationship between seasonal factors and the number of road-kill events was assessed using Pearson (parametric data) correlations (Souza et al., 2014). They were established for the groups with more than five records in the 12 campaigns.

For the correlations that showed significance (α=5%), we evaluated the relationship between total vertebrates, ecological groups, taxonomic groups, size mortality and accumulated rainfall, temperature, and humidity by a linear regression (Pereira et al., 2017).

**3.5 Spatial scale and hotspots**

We evaluated the dispersion of collision events at different spatial scales for taxonomic groups (amphibians, reptiles, birds, mammals), for the total group of vertebrates and for each seasonal period (rainfall period and dry period). The description of road-kill spatial distributions was to evaluate the randomness of these events, and, when there was a non-random distribution, to assess at which scales the aggregation is more intense. We used a modified Ripley’s K statistic to evaluate this non-randomness of the spatial distribution of events over multiple scales (Ripley, 1981; Clevenger et al., 2003; Coelho et al., 2008). To define the different scales evaluated, we used an initial radius of 100 meters and increments of 500 meters for each step and 1000 simulations. This initial radius size was chosen because we considered that it corresponds to a scale on which most common mitigation measures can be effective (Coelho et al., 2008).

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We used a 500-meter unit of measurement and divided the road into 80 segments of 500 meters each. We chose this segment length because Ripley's *K* statistic identified the occurrence of clustering on that scale and because some mitigation measures for amphibians, reptiles, birds, and mammals can be easily implemented targeting a 500-m – 2-km road segment, as for example, a wildlife passage connected by funnel fencing (Baxter-Gilbert et al., 2015, Gonçalves et al., 2017).

These analyses were applied to the different taxonomic road-kill groups on BR-122 using the program Siriema 2.0 (Road Mortality Software) (Coelho et al., 2006).

**4 RESULTS**

Vertebrate road-kill was higher in the rainy season, yet with different results for each taxon. Despite being an area with high anthropogenic disturbance, almost 95% of the road-killed were wildlife. We found one hotspot for all groups.

**4.1 Road-kill mortality rate**

In 36 inspections (1,440 km covered), we recorded 570 vertebrate deaths (189 ind.km-1.year-1), represented by 53 species (Appendix S2). Among these records, 304 were from the amphibian taxon (32.4 ind.km-1.month-1), all of the Anura order, followed by birds, with 105 (15.9 ind.km-1.month-1), and reptiles, with 83 individuals (2.70 ind.km-1.month -1), and by mammals, with 78 deaths (1.50 ind.km-1.month-1), mostly *C. thous* (Fig. 2a). The road-kill mortality rate by ecological group was higher in the *Bird 2*, *Bird 3*, *Rep 1* and *Mam 1* (Fig. 2b) groups. In the size category, 237 individuals represented the *IND B* group (4.8 ind.km-1.month-1), and 333 represented the *IND L*. group (27.9 ind.km-1.month-1), which mainly consists of amphibians and birds (98%).

Uma imagem contendo relógio, desenho, medidor

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**Figure 2.** Road-kill mortality rate by taxon (a) and ecological group (b).

Among the total amount, 73 carcasses could not be identified due to deterioration; 56 of them were amphibians of the Bufonidae family, 1 was a bird of the Passeriform order, 2 were reptiles of the Squamata order and 13 were small birds.

The taxa that exhibited the greatest richness were reptiles (26) and birds (15), while mammals and amphibians were represented by only 6 species each. The most registered species were: *R. jimi* (204), *C. thous* (59), *Leptodactylus macrosternum* (27), *Coragyps atratus* (23), *Boa constrictor* (19) and *Pseudoboa nigra* (11).

**4.2 Road-kill x Seasonality patterns**

The campaigns that had precipitation during the inspection days were those of February (39 mm), April (37 mm), January (14 mm) and March (7 mm). It did not rain during the inspections the other months. The highest number of species and the highest total monthly collision rate were recorded during the rainy season (January to June) (Fig. 3a), and the lowest in the dry season (June to December) (Fig.3b).

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**Figure 3.** Seasonal road-kill distribution: a) richness; b) number and road-kill rate per taxon.

Road-kill data showed normal distribution in the Shapiro-Wilks test (p>0.05), whereas rain data did not, on account of the number of zeros in the matrix. Given this low normality of precipitation data, we decided to use Pearson and Spearman correlations (Table 1). In the Pearson test, the total of road-kill events and richness of monthly campaigns displayed a positive correlation with precipitation (0.856; 0.613). Only for the amphibian taxon, the correlation was positive (0.903). Among the ecological groups, *Rep 2* (tortoises) and *Bird 2* presented a positive correlation (0.865; 0.609). With regards to size, the *IND L* group had a positive correlation (0.909).

**Table 1.** Correlations between road-kill events and seasonal factors

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Groups | Precipitation1 | Precipitation2 | Humidity1 | Temperature1 |
| Total | **0.856\*\*** | **0.715\*\*** | **0.696\*\*** | -0.547 |
| Bird | 0.485 | 0.282 | 0.166 | 0.04 |
| Mammal | -0.455 | **-0.641\*\*** | **-**0.447 | 0.445 |
| Reptile | 0.344 | 0.487 | **0.778\*** | **-0.859** |
| Amphibian | **0.903\*** | **0.784\*** | **0.745\*** | **-0.577\*** |
| Bird 1 | 0.161 | -0.082 | -0.225 | 0.012 |
| Bird 2 | **0.609\*\*** | 0.488 | 0.26 | 0.127 |
| Bird 3 | -0.559 | 0.062 | 0.152 | 0.053 |
| Mam 1 | -0.143 | **-0.639\*\*** | -**0.596\*\*** | **0.605** |
| Rep 1 | -0.037 | 0.273 | 0.467 | **-0.665** |
| Rep 2 | **0.865\*** | 0.575 | **0.696\*\*** | **-0.597\*\*** |
| Richness | **0.613\*\*** | 0.273 | 0.561 | -0.459 |
| IND L | **0.909\*** | **0.783\*\*** | **0.733\*\*** | -0.574 |
| IND B | -0.207 | -0.202 | 0.333 | 0.123 |

1Pearson correlation; 2Spearman correlation; \*p<0,01; \*\*p<0,05.

**Diagrama

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**Figure 4.** Relationship between seasonality patterns and road-kill events: a) Richness x precipitation; b) Bird 2 x precipitation; c) Total of road-kill events x precipitation; d) Amphibians x precipitation; e) Rep 2 x precipitation; f) Groups of mammals x precipitation; g) Reptiles / Rep 2 x air temperature; h) Reptiles / Rep 2 x relative humidity.

In the Spearman test, besides the correlations already observed in the previous test, the mammal taxon and the ecological group *Mam 1* showed a significant negative correlation with precipitation. In groups with significant correlations regarding precipitation, linear regression was applied to assess the significance of this association. The linear functions between precipitation with species richness (R²=0.585) and with the *Bird 2* group (R²=0.266) attained fewer explanatory powers than the relation with the other groups (Fig. 4a; Fig. 4b), given that the ANOVA test did not evidence any significance for the linear relationship (p>0.05). This indicates other factors which influence this association. The linear functions obtained between total road-kill rate (R²=0.559) (Fig. 4c), the amphibian taxon (R²=0.652) (Fig. 4d) and the *Rep 2* group (R²=0.644) (Fig. 5e) with accumulated precipitation had a better explanatory power. These groups exhibited the same association: a road-kill increase in the rainy season. Yet in the groups *Mam 1* (R²=0.209) and mammals (R²=0.229) a road-kill decrease could be observed in the rainy season (Fig. 4f).

The average daily temperature varied between 25º to 29ºC, while relative humidity ranged between 60% and 80%. The correlation of temperature with total road-kill rate and richness was not significant (p<0.05). Only the taxa amphibians and reptiles showed a negative correlation with temperature (-0.577; -0.859). The same was true for the ecological groups *Rep 1* and *Rep 2* (-0.665; -0.597), whilst *Mam 1* exhibited a positive correlation (0.605). Only the linear relationship between the group’s reptiles and *Rep 2* with temperature (R²=0.728; 0.913) showed significance (p>0.05). This means: the higher the temperature, the lower the number of road-killed reptiles (Fig. 4g).

Relative humidity displayed a positive correlation with total road-kill rate (0.696), reptiles (0.778), amphibians (0.745) and *Rep 2* (0.696); at the same time, the correlation between *Mam 1* road-kill and humidity was negative (-0.596). The other groups showed no significant correlation. Only the relationship between the reptile taxon road-kill and the *Rep 2* group with humidity (R²=0.129; 0.514) presented significance (p>0.05) (Fig. 4h). On wetter days, more road-kill events were recorded. The groups of amphibians and *Mam 1* manifested no significant association with humidity.

**4.5 Hotspots**

Road-kill events showed significant non-random spatial distribution on highways for the total amount of vertebrate, amphibian, reptile, bird and seasonality (rainfall period and dry period) assemblages. Only mammal assemblages showed random spatial distribution. Significant aggregations occurred with similar radius amplitude for these groups (Appendix S3). Regarding the dry and rainy season, we did not find any significant difference in the location of the road-kill hotspot, only the dry period apparently showed more variation in the aggregation points.

The hotspots were concentrated, apparently, in environments with heterogeneous vegetation coverage. With the presence of the open shrub caatinga, presence of water surface, rupicolous vegetation and an extensive area of agriculture (between stretch 10 and 15 of the highway, Fig. 5). Although other areas showed hotspots, the aggregation of these points was considered random according to the K statistic.

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**Figure 5.** Road-kill aggregation intensity (black lines) and 95% confidence limits (dotted lines) along 40 km of BR-122: (a) total road-kill rate for vertebrates; (b) Rainy season; (c) Dry season; (d) amphibians; (e) reptiles and (f) birds. Values above the upper confidence limit indicate significant mortality hotspots.

The hotspot for total road deaths and hotspots in the rainy period coincided with amphibian hotspots because the largest number of deaths was from amphibians in the rainy period.

In the dry period, the hotspot of the total vertebrate death rate coincided with the other groups. However, there was a greater dispersion of these points coinciding with the random pattern of deaths of mammals that predominated in the dry period.

**5 DISCUSSION**

Vertebrate mortality on the roads was positively related to the rainy season. The number of road-kill events was twice as high in this period. Our results suggest that in the semiarid, precipitation and temperature interfere with animal behavior, inducing or inhibiting collisions.

We estimate that 190 vertebrates are road-killed per kilometer every year, totaling < 7,000 thousand road-killed animals every year on a 40-km segment of BR-122. The estimated road mortality magnitude obtained in this study corresponds to four times the number of observed carcasses during the road surveys, considering detection and removal of carcasses. Of this total, 53% were frogs, 18% were birds, 14% were reptiles and 13% were mammals. Although the study area underwent several anthropogenic transformations, only 30 (5%) domestic animals were found.

In contrast, in a study carried out in the Brazilian swamps called Pantanal, 61% of the animals involved in traffic accidents were wild mammals and there was no record of amphibians (Souza et al., 2014). In mountainous landscapes in Canada, 46% of the road-killed animals were mammals and 7% were amphibians (Clevenger et al., 2003). These differences suggest that ecosystem and methodology may influence collisions and their registration. Large mammals, for example, use the road to move more easily (Coffin, 2007), and this fact can favor a higher mortality rate. In the semiarid region of Brazil, however, the mammal population is mostly composed of small and medium-sized species (Marinho et al., 2018) which may use drainage channels to traverse roads or experience the barrier effect, caused by temperature and noise, and this contributes to reduce wildlife road-kill (Clevenger et al., 2003).

The road-killed species in the study are generalists (except: *L. emiliae*), possibly because there are resources near the roads, such as garbage and smaller species. In a study carried out in a Mediterranean region of Portugal, the most vulnerable carnivore species were also generalists (Grilo et al., 2011). Road-kill usually affects few species and with the following characteristics: population locally abundant, highly mobile, with generalist habitats, in search of resources on the road (Forman et al., 2002).

The present work evidenced rainfall to have greater explanatory power in the total mortality rate, in richness and in the amphibians, reptiles, mammals, *Mam 1* and *Bird 2* groups. In roads in the Santa Fe, Argentina Attademo et al. (2011) also found a positive correlation between precipitation with vertebrate road-kills. Temperature and humidity were negative and positive, respectively, associated with reptile road-kill. The higher number of amphibian road-kill events indicate a direct relation with the population size of these species, their relationship with the road and with rainfall. The number of amphibian road-kill events was five times higher in the rainy season than in the dry one. In another monitoring, also in the Brazilian semiarid region, the highest number of amphibian deaths also occurred in the rainy season (Pereira et al., 2017).

Regarding richness, this investigation revealed a more substantial number of road-killed species in the rainy season, maybe because of an increase in resources, a greater displacement of amphibians, birds and reptiles and a higher number of species in the reproductive stage. Variations in road-kill rates are seasonal and related to differences in species behavior (Garriga et al., 2017; Souza et al., 2014).

The behavior and ecology of reptiles and amphibians is closely related to the physiology of these taxon. For reptiles, mainly snakes and lizards, searching roads for thermoregulation on days with mild temperatures is an ectothermic reaction. Turtles, on the other hand, express a close relationship with rainy days due to their aquatic habit, which favors migration. In a study in southern Brazil, it was suggested that thermoregulation may be one of the causes of reptile road-kill events (Gonçalves et al., 2017). As far as amphibians are concerned, their skin permeability and water-dependent reproduction activities, such as searching for calling sites, the selection of spawning sites and the dispersal of juveniles (Duellman and Trueb, 1994) increase population and migration in the rainy season and favors the collisions. Temperatures are high throughout the year and rain seasonality and water availability in the semiarid region are limiting factors for amphibians (Navas et al., 2004).

Among birds, granivorous species were the most recorded during the rainy season. Grass growing on roadsides favors these mortalities, as well as the coincidence of the reproductive period of some bird species with the rainy season. A similar result was obtained when monitoring bird road-kill events south of the country: there was an increase of 100% of these deaths in the rainy season (Rosa and Bager, 2012).

Mammal road-kill events, on the contrary, experienced a decrease of approximately 50% during the rainy months because the presence of resources reduces the displacement of these species. The species *L. emiliae* and *C. thous* move for great distances in the dry period in search of resources, and this makes them more vulnerable (Forman et al., 2002; Spellerberg, 2002). Similarly, the mortality of small and medium-sized mammals in southeastern United States almost doubles in the dry season (Smith-Patten and Patten, 2008).

The observed aggregated spatial road-kill patterns and according to different taxonomic groups (total, amphibian, reptile and bird road-kill rate), except for the mammal group, indicate the existence of environmental factors or others affecting the spatial distribution of these events. Surrounding landscape composition and arrangement are some factors that may be responsible for spatial road-kill aggregations (Clevenger et al., 2003; Taylor and Goldingay, 2004; Seiler, 2001; Coelho et al., 2008). We considered that traffic volume did not vary along the road. The dispersion of mammal road-kill (most of *C.* *thous*), unlike the other groups, reflects the generalist behavior of the registered species and the great capacity for locomotion. Therefore, it does not seem to have a hotspot.

The hotspot found did not vary in relation to rainfall seasonality. Perhaps monitoring for a longer period may reflect different results, because the semiarid region has peculiar characteristics. These characteristics can influence the final analysis (Pereira et al., 2017). In addition to the rainy season, followed by a dry season in the same year, it is common for interannual dry periods to occur, where the rainy season does not occur or is below average (Zhang et al., 2016). Such characteristics interfere with the behavior of local species, such as decreased resources, increased fires, reduced habitats, which alters the frequency and use of the road (Taylor and Goldingay, 2010).

The cumulative effect of human activities can influence dispersion and daily movements and, therefore, impact the abundance of wildlife (Grilo et al., 2009). For mitigation actions on implanted roads, Teixeira et al. (2017) suggest estimating mortality on the roads in relation to the abundance of the surrounding population, rather than identifying hotspots. Since there is a lack of studies on population dynamics in semiarid regions, the authors are convinced that hotspots can still be good indicators for an immediate road-kill mitigation.

It was found that carnivorous species road-kill events in the semiarid region double when these animals are in search of water during the dry period. Species that reproduce in the rainy season and possess low displacement capacity or physiological sensitivity to seasonal variation are more vulnerable to being road-killed during this period. We found one hotspot for all groups, which indicates that apparently the hotspot is related to landscape factors.

**6 CONCLUSIONS**

We found a positive relationship between rainfall seasonality and temperature with vertebrate road-kill events. In regions with a semi-arid climate, such as northeast Brazil, water is a limiting factor and strongly influences the reproductive period, migration and resource search of local species, favoring wildlife collisions with vehicles. Taxonomic groups, such as amphibians and reptiles, are even more sensitive to rainfall seasonality and temperature. Small species like frogs and small birds are the most affected,as well as generalist species, such as the fox (*C. thous*)*.* Also, landscape characteristics are strongly associated with the hotspot found.

Given our results, the subsequent measures may be suggested for environments with marked seasonality: implanting protective screens on the road margins, especially in the hotspot areas; identifying possible corridors of the respective fauna, such as drainage channels and bridges; reforesting the roadsides with native species of arboreal size to avoid the passage of birds with low overflows, and intensifying monitoring in rainy periods.

Considering the scarcity of data on the impacts of roads on the Brazilian semiarid wildlife environment, our findings provide important insights into mortality rates in markedly seasonal habitats and the impacts of roads on vertebrate populations.

With regards to future research, it seems interesting to deepen the following inquiries: what is the impact of road-kill on population dynamics, considering group sizes and frequency of deaths? What are the reasons for fewer mammal species being road-killed? How can the barrier effect of two-way roads be estimated?

**AUTHOR CONTRIBUTIONS**

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**SUPPORTING INFORMATION**

Additional supporting information can be found online in the supporting information tab for this article.

**Appendix S1**. Map of vegetation and land cover of the study area.

**Appendix S2.** Road-kill rate by species.

**Appendix S3.** Results from the 2D Ripley's K-Statistics

**Appendix S4.** Road-kill pictures on a road in the Brazilian semiarid environment.

**Appendix S5**. Abstract graphic.