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Article

Overview of roadkills in the Serra da Macaca Park Road (SP-139), state of São Paulo, Brazil

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ABSTRACT. Fatalities involving wildlife on roads and highways due to collisions with automotive vehicles represent a severe threat to the conservation of several species of terrestrial vertebrates throughout the world. However, in addition to the negative impact caused by collisions, there are also serious social and economic implications that arise from this situation. This study aims at qualifying and quantifying the collisions with fauna in the Serra da Macaca Park Road (SP-139), since the end of the revitalization work that the road was underwent – in 2015 – over a stretch of 33 km that crosses the *Parque Estadual Carlos Botelho* (PECB), as well as identifying the predisposing factors that lead to such accidents. The ecological analyses were generated by a combination of the records kept by the fiscalization service of the Fundação Florestal and samples collected in the field. In total, the loss of 80 individuals belonging to 27 species was recorded over an estimated period of three years. Reptiles were the most affected group, followed by mammals. A significant part of the animals was unable to be recognized to the species level, since the taxonomic identification was conducted based on the morphology of the external characteristics and several of the carcasses were completely dilacerated. We identified that the temporal variations in the fatalities are related mainly to the intensity of the traffic in the road and to the differential response of herpetofauna to the stimuli of seasonality.

KEYWORDS. Wildlife, roads, Atlantic Forest, conservation, seasonality.

RESUMO. Breve panorama dos atropelamentos de fauna na Estrada Parque Serra da Macaca (SP-139), estado de São Paulo, Brasil. As fatalidades de animais silvestres nas rodovias, decorrentes de colisões com veículos automotores, constitui grave ameaça à conservação de diversas espécies de vertebrados terrestres em todo o mundo. Entretanto, além do impacto negativo causado pelos atropelamentos, existem também implicações socioeconômicas muito sérias advindas desse tipo de conflito. O presente estudo teve como objetivo qualificar e quantificar os atropelamentos de fauna ocorridos na Estrada Parque Serra da Macaca (SP-139), desde a conclusão das suas obras de revitalização – no ano de 2015 – em um trecho de 33 km que atravessa o Parque Estadual Carlos Botelho (PECB), assim como delimitar localmente os principais fatores predisponentes. As análises ecológicas foram geradas pela combinação dos registros catalogados pelo serviço de fiscalização da Fundação Florestal com as amostras coletadas em campo. Na contagem total, detectou-se a perda de 80 indivíduos pertencentes a 27 espécies, em um período aproximado de três anos. O grupo dos répteis foi o mais afetado, seguido pelos mamíferos. Uma parte significativa dos animais não pôde ser reconhecida ao nível de espécie, visto que a identificação foi realizada com base na morfologia dos caracteres externos e muitas das carcaças estavam dilaceradas. Constatou-se que as variações temporais das fatalidades estão ligadas principalmente à intensidade de tráfego na via, e à resposta diferencial da herpetofauna aos estímulos da sazonalidade.

PALAVRAS-CHAVE. Animais silvestres, rodovias, Mata Atlântica, conservação, sazonalidade.

The adverse effect of land transportation over the populations of terrestrial vertebrates is easy to notice through the simple detection of the carcasses exposed in the environment (Seiler & Helldin, 2006). Fatalities caused by the traffic of vehicles are currently considered the main unnatural source of mortality for wildlife (Saénz-de-Santa-María & Tellería, 2015). This external factor affects the populations of animals to varying degrees (Madsen, 2002), leading to the simplification of communities and even to the local extinctions (Jackson & Fahrig, 2011). In addiction to roadkills, roads can cause barrier effect to animal movement (Rosa & Bager, 2013), when some species avoid them.

Roadkills almost always happen due to an intricate combination of factors, of which traffic intensity, speed of the vehicles, structure of the landscape and animal activity are the most proeminent (Clevenger *et al.*, 2003; Lester, 2015). Temporal variations indicate the existence of an association between the seasonal peaks in the number of collisions, the dispersion of young individuals and migratory movements (D'Amico *et al.*, 2015; Canal *et al.*, 2018). Likewise, the analysis of the spatial variables is another crucial element in the investigation of the cause-effect relationships for this fenomenon (Coelho *et al.*, 2008).

Usually, the reproduction of amphibians and the way they explore resources involve continuous habitats, which, if fragmented by the road network, contributes towards a reduction in the populations of batracheans (Braz & França, 2016). On the other hand, reptiles usually benefit from the heat absorbed by the asphalt during the day for their thermal regulation processes, leading to a dangerous behavioral pattern that increases the risk of fatalities (Fahrig *et al.*, 1995). Several medium-and large-sized mammals are generalists in the use of the landscape (Bocchiglieri *et al.*, 2010) and, therefore, are less dependent on specific environmental conditions. As such, species of mammals that have the habit of foraging along the margins of roads are supposedly more susceptible to roadkills (Coffin, 2007). According to Rosa & Bager (2012), the rates of roadkills with birds may be influenced both by seasonality and by the type of environment the road crosses, and the authors established a relationship between fatalities in this group with events such as harvest season and transportation of grains.

Even though there is a considerable number of studies regarding fauna roadkills, in many cases the results are no more than descriptions of isolated cases (Clevenger *et al.*, 2003), and some basic questions still need to be answered for a better environmental adjustment of the road network (Seiler, 2001). In theory, a standardized data collection allows several types of ecological studies to be conducted (Schwartz *et al.*, 2019), but in practice the monitoring of wildlife roadkills still faces some operational limitations. Novel and creative solutions have arisen to overcome these limitations, such as the use of smartphones to transform any driver into a potential "citizen scientist" (Vercayie & Herremans, 2015), able to send records of carcasses (pictures and geographic coordinates) to a database capable of managing such data.

Besides the ecological impact, fauna roadkills also have severe social and economic implications. Freitas & Barzcz (2015) assessed accidents resulting by the interaction between animals and vehicles focusing on this particular aspect. For this purpose, they used news available on the internet specifically for Brazil. Of the 125 accidents analyzed, there were 66 human deaths, a number which clearly show the dimensions of the problem. Even though accidents involving collisions with domestic animals were more common, accidents involving wildlife led to a higher number of human fatalities, particularly in those caused by capybaras.

According to Langley *et al.* (2006), properly understanding the risks is a prerequisite for the adoption of any safety measures. In their study, they emphasized that trivial precautions such as the adoption of defensive driving, and the proper use of seatbelts and helmets are enough to decrease the physical and material damages. Huijser *et al.* (2009) suggested that the benefits brought on by the adoption of measures to mitigate fauna roadkills would exceed their implementation costs, considering the global costs arising from this type of accident.

Estimating the relevance of collisions between animals and vehicles requires the integration of multidisciplinary studies, with results depending on the chosen criteria (Seiler & Heldin, 2006). Finding a balance between the many variables and interests involved represents an additional challenge in the decision-making process (Lester, 2015).

This study aims at evaluating fatalities arising from collisions between vehicles and animals in the Serra da Macaca Park Road (SP-139) focusing on the following aspects: qualifying and quantifying the events, and identifying the main predisposing factors that lead to them.

MATERIALS AND METHODS

The methodology adopted in this study was approved by the Ethics Committee in the Use of Animals of the School of Veterinary Medicine and Animal Science of the Universidade Estadual Paulista (UNESP – *Campus* de Botucatu) under CEUA Protocol n. 0127/2019. The project was also approved by the techno-scientific committee of the Fundação Florestal – Letter Cotec n. 485/2019, and was properly added into the Brazilian National Management System of the Genetic Heritage and Associated Traditional Knowledge – Register SisGen n. A18FA6A.

The *Parque Estadual Carlos Botelho* (PECB) (24°08'S and 47°58'W) is located in the southeast part of the State of São Paulo, Brazil, and covers an area of 38.705,440 ha of tropical rainforest. The protected area was recognized by UNESCO as a Natural World Heritage Site. The PECB, together with *Parque Estadual Intervales*, *Parque Estadual Turístico Alto do Ribeira* and *Estação Ecológica Xitué* is part of the *Serra de Paranapiacaba* Forest Continuum, covering a total area of approximately 120.000 ha of protected Atlantic Forest (Brocardo *et al.*, 2012) (Fig. 1).

Serra da Macaca Park Road (SP-139), within the jurisdiction of the *Departamento de Estradas de Rodagem* (DER/SP), is a popular name for the 33-km section of the road that crosses the PECB. The road contains a type of eco-friendly paving system, composed of interlocked concrete blocks that allow the rainwater to drain, trap less heat, and produce noise from the friction between tires and pavement to scare the fauna away (G1, 2015). Your daily vehicle traffic is considered low. Truck and hazardous cargo traffic have been restricted, and weight limit is nine tons. Despite the inherent impacts of a road, the SP-139 represents an opportunity for reginal integration, and enables passersby to visit the forest reserve (Instituto Florestal, 2008).

The predominant climate in the region is the humid mesothermal climate, without a well-defined dry season. The yearly averages for temperature and rainfall vary between 15 and 19°C, and 1,475 and 2,582 mm, respectively. The uneven topography of the area includes altitudes ranging from 30 to 1,020 m above sea level. The Serra da Macaca Park Road (SP-139) clearly reflects this altitude gradient.

From March 2018 to February 2019, four field incursions were conducted on the area, lasting in total 10 consecutive days. The single-lane stretch of road was covered in a car on both ways at a constant speed of 20 km/h. Two observers were present in the car and the samples were

taken during the morning period (between 6:00 and 9:30 a.m.). The search for carcasses and wounded animals that may be hidden in the forest margins was aided by random hikes. The data collection process focused on the date and geographical location of each event.

Whenever possible, the taxonomic identification of the records was made to the level of the species based on the available literature (Develey & Endrigo, 2004; Marques *et al.*, 2005; Reis *et al.*, 2011) and on consultations with researchers at the Universidade Estadual Paulista (UNESP) specializing in terrestrial tetrapods.

The logistic curve was used to assess the correlation between number of accidents and vehicle flow. The traffic at the Serra da Macaca Park Road (SP-139) was measured by the management of the PECB over a period of one year. In order to standardize this correlation test, the records of collisions considered were also trimmed into a period of one year. In addition, for clarification purposes, *Fundação Florestal* disclosed roadkills data collected by the fiscalization service of the protected area since the inauguration of the revitalized stretch of the road. The periodic variation in the vehicle flow was compared using a two-way Student's t-test with a significance level of 5%. The assumptions of normality and homogeinity of the variances were verified through the Shapiro-Wilk and Levine tests, respectively. The seasonal distribution of the fatalities was evaluated through the chi-squared test.

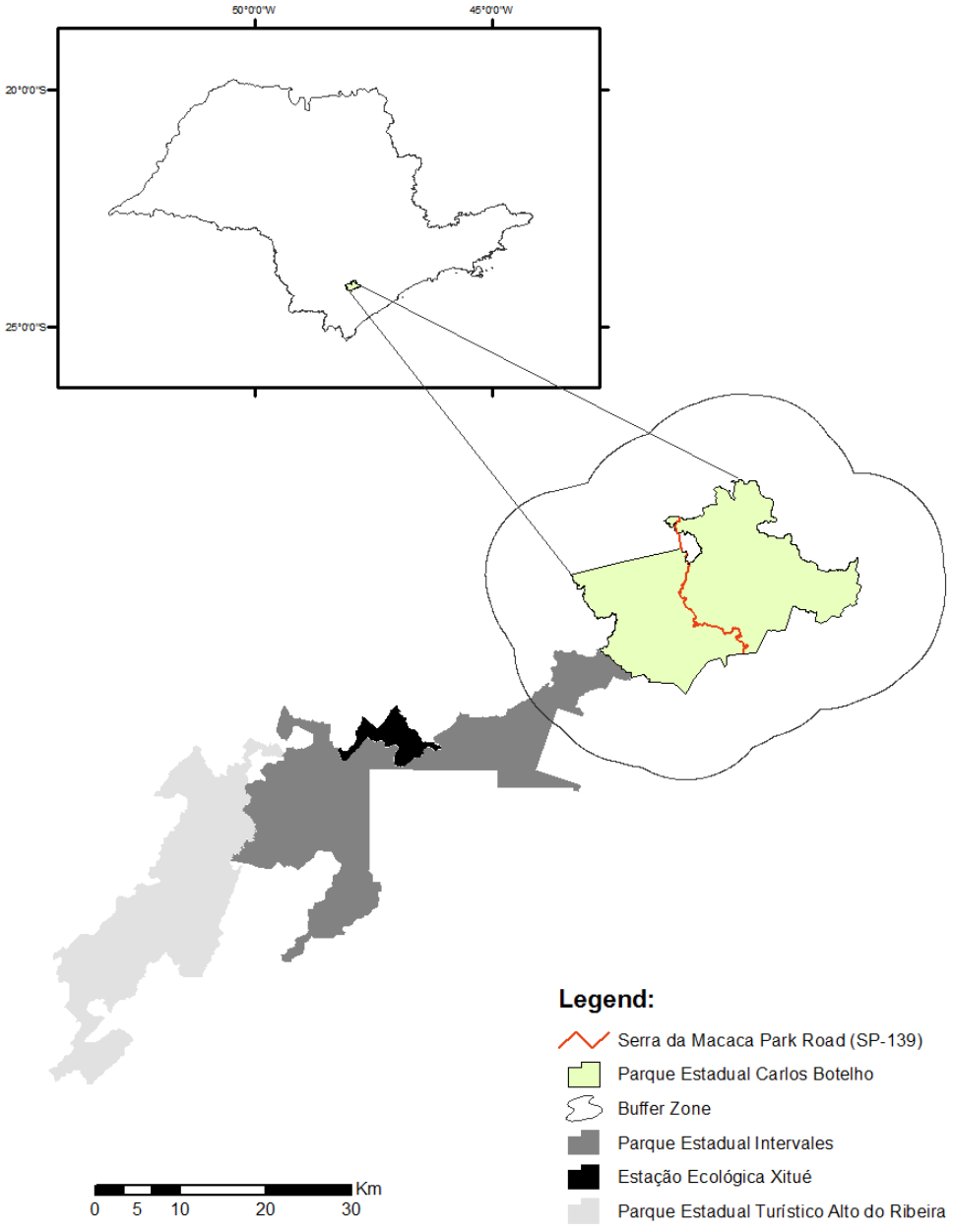

Fig. 1. Map of the study area. Focus on the Parque Serra da Macaca Road, which crosses the *Parque Estadual Carlos Botelho* (PECB), State of São Paulo, Brazil.

Except for logistic curve, all other statistical analyses were conducted in the software "R" v. 3.5.1 (RStudio Team, 2020). Logistic curve was performed using "SAS" version 9.2 (SAS Institute Inc).

RESULTS

A total of 80 deaths of terrestrial vertebrates due to roadkills were verified during the studied period. Most accidents (n = 64) were recorded by the *Fundação Florestal*, while 16 accidents were recorded through the field incursions. Of this total, 51 animals (63.75%) were identified as belonging to 27 species, while 25 animals (31.25%) were unable to be identified to the species because the carcasses were too deteriorated or in advanced stages of decomposition, most of which were reptiles (n = 19). Another four individuals (5%) were identified only to the genus level (Tab. I). Reptiles accounted for most of the accidents (53%), followed by mammals (31%), birds (9%) and amphibians (7%) (Fig. 2). The most common species observed were the black and white tegu (*Salvator merianae* Duméril & Bibron, 1839) with nine individuals (11.25%), the jararaca (*Bothrops jararaca* Wied, 1824) with six individuals (7.5%) and the southeastern four-eyed opossum (*Philander quica* Temminck, 1824) with four individuals (5%).

A positive correlation ($r^2 = 0.72$) was identified between vehicle flow and roadkills (Fig. 3). To obtain the logistic curve we removed an outlier with 12 roadkills. Furthermore, as the "x" values were very high, it was not possible to estimate the parameters properly. For this reason, the "x" values were divided by 5.000. Results show a rapid increase in the roadkills with vehicle flow above 10.000 / month. In average, about 5,210 more vehicles use the road during Spring and Summer than during Fall and Winter (Fig. 4), a statistically significant result according to the t-test ($t = - 2.765$, g.l. = 10, $p = 0.019$). The incidence of collisions according to the body temperature of the vertebrates was also significantly different ($X^2 = 4.909$; g.l. = 1; $p = 0.027$) for the seasonal periods studied (Fig. 5).

Tab I. List of species found dead in the Serra da Macaca Park Road (SP-139) (State of São Paulo, Brazil), number of records and relative frequency. Regional data is according to São Paulo (2018) and National data (BR) follow the ICMBio (2018) (LC, Least Concern; NT, Near Threatened; VU, Vulnerable; X, Exotic).

Taxon	Popular Name	N	%	Status	
				SP	BR
BIRDS					
Cracidae					
Penelope obscura Temminck, 1815	dusky-legged guan	2	2.5	NT	LC
Rallidae					
Aramides saracura Spix, 1825	slaty-breasted wood rail	1	1.25	LC	LC
Strigidae					
Pulsatrix koeniswaldiana Bertoni & Bertoni, 1901	tawny-browed owl	1	1.25	LC	LC
Trogonidae					
Trogon rufus Gmelin, 1788	black-throated trogon	1	1.25	LC	LC
Ramphastidae					
Ramphastos dicolorus Linnaeus, 1766	red-breasted toucan	1	1.25	LC	LC
AMPHIBIA					
Bufonidae					
Rhinella icterica Spix, 1824	yellow cururu toad	1	1.25	LC	LC
Rhinella ornata Spix, 1824	striped toad	1	1.25	LC	LC
REPTILIA					
Teiidae					
Salvator merianae Duméril & Bibron, 1839	black and white tegu	9	11.25	LC	LC
Viperidae					
Bothrops jararaca Wied, 1824	jararaca	6	7.5	LC	LC
Colubridae					
Chironius bicarinatus Wied, 1820	two-headed sipo	1	1.25	LC	LC
Spilotes pullatus Linnaeus, 1758	yellow rat snake	2	2.5	LC	LC
Dipsadidae					
Imantodes cenchoa Linnaeus, 1758	blunt-head vine snake	1	1.25	LC	LC
Erythrolamprus aesculapii Linnaeus, 1766	false coral snake	1	1.25	LC	LC
Xenodon neuwiedii Günther, 1863	neuwied's false fer-de-lance	1	1.25	LC	LC

Tab I. Cont.

Taxon	Popular Name	N	%	Status	
				SP	BR
Elapidae					
Micrurus corallinus Merrem, 1820	coral snake	2	2.5	LC	LC
MAMMALIA					
Didelphidae					
Didelphis aurita Wied-Neuwied, 1826	big-eared opossum	3	3.75	LC	LC
Didelphis sp.	opossum	3	3.75		
Philander quica (Teminck, 1824)	four-eyed opossum	4	5	LC	LC
Myrmecophagidae					
Myrmecophaga tridactyla Linnaeus, 1758	giant anteater	1	1.25	VU	VU
Tamandua tetradactyla Linnaeus, 1758	southern anteater	1	1.25	LC	LC
Dasypodidae					
Dasypus novemcinctus Linnaeus, 1758	nine-banded armadillo	2	2.5	LC	LC
Cervidae					
Mazama bororo Duarte, 1996	small red brocket deer	1	1.25	VU	VU
Mazama sp.	brocket deer	1	1.25		
Cebidae					
Sapajus nigritus Goldfuss, 1809	black capuchin	2	2.5	LC	LC
Procyonidae					
Nasua nasua Linnaeus, 1766	south american coati	1	1.25	LC	LC
Cricetidae					
Oligoryzomys flavescens Waterhouse, 1837	yellow pygmy rice rat	1	1.25	LC	LC
Cuniculidae					
Cuniculus paca Linnaeus, 1766	agouti	1	1.25	NT	LC
Sciuridae					
Guerlinguetus brasiliensis Gmelin, 1788	Ingram's squirrel	2	2.5	LC	LC
Leporidae					
Lepus europaeus Pallas, 1778	european hare	1	1.25	X	X

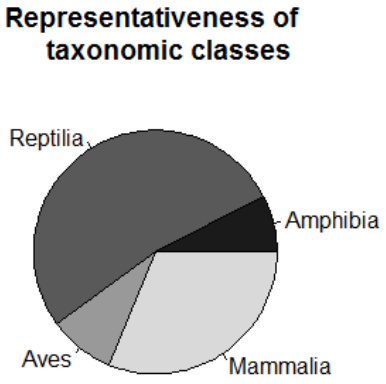

Fig. 2. Rate of roadkills with the groups of fauna sampled on the Serra da Macaca Park Road (SP-139), State of São Paulo, Brazil.

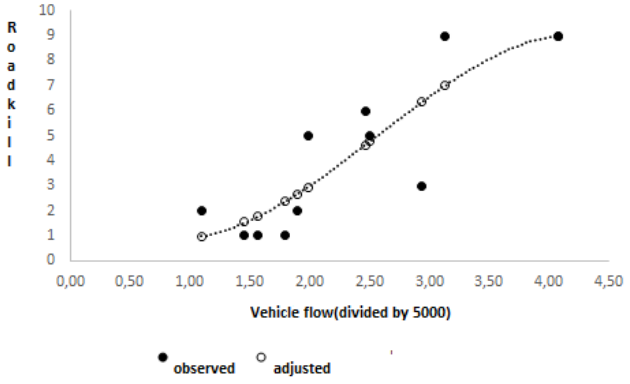

Fig. 3. Correlation between the number of roadkills and vehicle flow on the Serra da Macaca Park Road (SP-139), State of São Paulo, Brazil: r^2 = 0.72 and y = 9.864/(1+exp(-(-3.912+1.536x))).

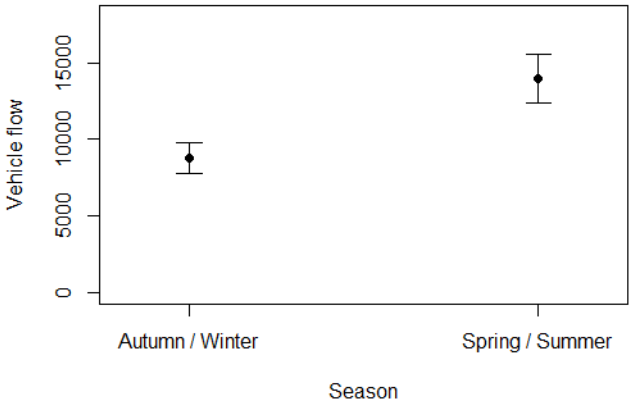

Fig. 4. Mean (points) and standard deviation (bars) for the vehicle flow recorded on the Serra da Macaca Park Road (SP-139), State of São Paulo, Brazil, between November 2015 and October 2016. The differences are statistically significant according to the t-test (t = - 2.765, g.l. = 10, p = 0.02).

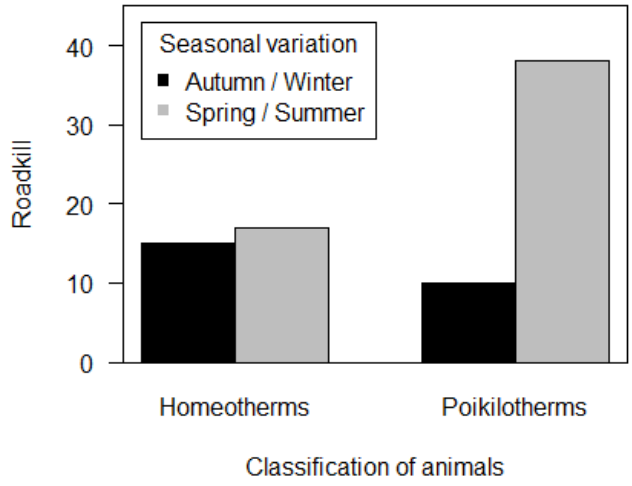

Fig. 5. Seasonality of the roadkills. Homeotherms = birds and mammals. Poikilotherms = amphibians and reptiles.

DISCUSSION

The number of roadkills recorded in the Serra da Macaca Park Road (SP-139) was low in comparison with the results observed in similar studies. For instance, Carvalho *et al.* (2014) recorded 257 collisions with vertebrates belonging to 52 species over a stretch of 70 km of the MS-080 road between March 2011 and September 2011. Even though the results observed in the Serra da Macaca Park Road (SP-139) are consistent, it is natural and statistically expected for the true number of fatalities to be subestimated since the survey did not consider factors such as detectability and the rate of removal of carcasses (Teixeira *et al.*, 2013).

The ability to detect carcasses is influenced by the characteristics of the road, the size of the animals involved and the accuracy of the observers. The removal rate, in turn, is determined by the local climatic conditions, the activity of necrophagic animals and the traffic of vehicles (Coelho *et al.*, 2014).

Most part of the recorded species is habitat generalist. Even so, the general list is diverse and includes rare species, native to the Atlantic Forest and vulnerable to extinction, such as the small red brocket (*Mazama bororo* Duarte, 1996) and the giant anteater (*Myrmecophaga tridactyla* Linnaeus, 1758). The distribution of the small red brocket deer (*Mazama bororo*) is restricted to a small area of tropical rainforest between the states of São Paulo and Paraná (Duarte *et al.*, 2017). The PECB is one of the few locations where this species of deer has been observed. The giant anteater (*Myrmecophaga tridactyla*), whose population has been declining (IUCN, 2020), is one of the species of the Brazilian fauna that most commonly die on roads.

The correlation verified between vehicle flow and the roadkills is in line with the information available in the scientific literature regarding to this subject (Fahrig *et al.*, 1995; Seiler, 2001; Carvalho *et al.*, 2014). It has been observed that the Serra da Macaca Park Road (SP-139) presents an increased circulation of vehicles during the Spring and Summer, which supposedly happens because this stretch of road serves as a connection between São Miguel Arcanjo city (Brazilian highlands) and Sete Barras city (coastal region of the State of São Paulo – a popular touristic destination during Summer), and because visitation to the PECB increases during the Summer vacation period (Instituto Florestal, 2008).

There was a significant variation in the rate of roadkills between the periods compared for reptiles and amphibians. The highest incidence of fatalities also coincided with the Spring and Summer seasons, which are typically associated with an intensification in the reproductive activity of poikilothermic tetrapods (Ceron *et al.*, 2016).

The fatalities did not diverge significantly for birds and mammals in terms of seasonality. Santos *et al.* (2012) stressed the need of a more robust sampling efforts, in comparison with other groups of animals, for the evaluation of the environmental impacts caused by roadkills on the group of birds. This deficient sample size may distort the results of ecological analyses. Seasonal patterns are uncommon in the statistics regarding to mammals roadkills, particularly in cases where there is a regular offer of food resources, which inhibits the ampliation of the foraging area and, therefore, the locomotion of these species (Orlandin *et al.*, 2015).

We suggest that the low number of roadkills recorded was maily due to a series of mitigation measures implemented in the Serra da Macaca Park Road (SP-139) to avoid roadkills. It has a total of 16 canopy bridges, 12 underpasses (bridges and culverts), speed limits of 40 km/h, nocturnal closure and two OCRs (Optical Character Recognition), at the entrance and exit of the protected area. The absence of records of some species that are more sensitive to habitat fragmentation, which are known to occur in the PECB, allow us to infer the local existence of the barrier effect.

We conclude that the temporal variations observed in roadkills involving poikilothermic animals may be attributed to differences in the vehicle flow that passed through Serra

da Macaca Park Road (SP-139), and to increased abundance and mobility of these individuals during certain times of the year. It was impossible to distinguish if the increased vehicle flow during Spring and Summer was caused by the tourist attractions in the PECB or by an increased number of passing travellers.

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