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CAN HUMAN DEMOGRAPHIC OR BIOLOGICAL FACTORS INFLUENCE MAMMAL ROADKILL? A CASE STUDY IN THE GO-060 HIGHWAY

Danielle Rodrigues de Araújo[1], Paulo Ribeiro[2] & Leonardo Teófilo Teles[3]*

[1] Universidade Estadual de Goiás, Programa de Pós-Graduação *Stricto Sensu* em Recursos Naturais do Cerrado, Fazenda Barreiro do Meio, BR-153, nº 3105, CP 459, CEP 75132-400, Anápolis, GO, Brazil.

[2] Universidade Paulista, Instituto de Ciências da Saúde, Campus Goiânia-Flanboyant, Fazenda Botafogo, BR-153, Km 503, CEP 74845-090, Goiânia, GO, Brazil.

[3] Universidade Estadual de Goiás, Laboratório de Biodiversidade, Campus de Ciências Exatas e Tecnológicas, BR-153, nº 3105, Fazenda Barreiro do Meio, CP 459, CEP 75132-400, Anápolis, GO, Brazil.

E-mails: msc.araujodr@gmail.com; phpinheiro@yahoo.com.br (*corresponding author); ltteles@gmail.com

Abstract: Roads cause several environmental impacts, such as roadkill of wild animals, which may result in the decrease of local fauna density. Roadkill occurs because roads intersect the habitats of many taxa, especially in fragmented landscapes, such as the Cerrado biome. The present study aimed to determine whether demographic variables or biological characteristics influence the mammal's roadkill rate. A survey was conducted in the section of the GO-060 highway located between the municipalities of Trindade and Iporá, from April to September 2012, during the dry season. We used Kruskal-Wallis tests to investigate possible differences among roadkills per sector, species, order, food habit, and activity pattern. Pearson correlation was used to verify the association between roadkill rate and home range. The influence of body mass on the roadkill rate was estimated through a simple linear regression. To verify whether human demographic variables influence the roadkill, we used a multiple linear regression. We recorded 89 individuals of mammals during 18 field trips and obtained a roadkill rate of 0.025 individuals/km/day. Mammals with different food habits have different roadkill rates, once herbivorous mammals are less prone to be roadkilled than omnivorous and insectivorous species. Characteristics such as home range, body mass and activity patterns were not determinant of roadkill rates in this study. Similarly, human demographic variables did not influence the number of roadkills. Biological and ecological characteristics should be considered when implementing measures to reduce roadkill. Hence, it becomes clear that surveys of fauna roadkill should consider both human demographic and biological variables, once, in this research, none of them are relevant by itself, they can be considered complementary information, and can be used to support practical actions.

Keywords: animal-vehicle collision; behavior; human population; mammal ecology; road ecology.

INTRODUCTION

Roads cause great environmental impacts, resulting in habitat fragmentation and an increase in edge effects (Coffin 2007, Sousa & Miranda 2010). Therefore, roads may affect for example, species diversity and richness, abundance of individuals and intra- and interspecific relationships (Bager &

Fontoura 2012). Impacts caused by roads include the isolation of populations (Grilo 2012) and the decrease of local population density (Rosa & Mauhs 2004, Prado *et al.* 2006, Bager *et al.* 2007). Birds and mammals are generally the classes of vertebrates that are more likely to be killed on roads (Rosa & Mauhs 2004, Milli & Passamani 2006, Prado et al. 2006, Souza et al. 2010, Grilo 2012).

According, biological characteristics, such as abundance, activity pattern and threat category, could influence mammal roadkill (Caceres 2011). This occurs because roads intersect the habitats of certain taxa (Rosa *et al.* 2012), especially in very fragmented landscapes, such as the Cerrado biome (Carvalho *et al.* 2009), which is also the Brazilian biome with the third greatest richness of mammals (251 species, 32 of which are endemic) (Paglia *et al.* 2012). The Cerrado is recognized as one of the 34 world's hotspots of biodiversity (Bellard *et al.* 2014) and is continuously affected by anthropic activities. The devastation of the Cerrado was driven mostly by agricultural expansion and by the resultant construction of roads that were necessary for transporting goods and people to other regions of Brazil (Cunha *et al.* 2010, Goiás 2002). Determining which characteristic is more prone to influence mammal roadkill is fundamental, especially in a biome with great mammalian diversity.

In this context, the present study aimed to determine whether the roadkill rate of medium to large-sized terrestrial mammals in the Cerrado biome is associated with human demographic variables (i.e., human development index, total area of the municipality, population size, and population density), as well as biological characteristics of the species (i.e., food habits, activity pattern and home range). We expected that more developed municipalities, higher body mass and carnivore habit are strong factors that could increase mammal roadkill.

MATERIAL AND METHODS

Study area

The GO-060 highway is 310 km long, and it is located between the municipalities of Goiânia and Piranhas, in the State of Goiás, Brazil. We surveyed a 197 km stretch of this road, which includes the cities of Trindade and Iporá (Figure 1).

The GO-060 highway is a two-lane road with a shoulder and intense traffic of vehicles that transport goods and people. Several parts are in poorly condition (*i.e.*, burrows in the road), and some parts are in a good state of conservation. During the period of data collection, the highway was partly repaved. Thus, we considered that the surveyed sector was in regular to good condition. The highway is surrounded by urban areas, forest fragments, pastures, seasonal plantations and tanneries (Cunha *et al.* 2010).

Data collection

Data was collected, when possible, once a week by car, in the sector between the cities of Trindade and Iporá, from April to September 2012, during the dry season, during the morning period (6:30-12:00) at maximum speed of 80 km/h. The sampling was conducted in round trip (both ways).

As long we limited our research to medium to large sized-mammals, we believed the speed was enough, both to find the individuals, and to avoid disturbances in the traffic. We made at least three trips per month, totalizing 3,546 km and 18 trips. Both sides of the road were surveyed in each trip. Each roadkilled specimen was photographed and, whenever possible, identified to the lowest taxonomic level. After being photographed, each carcass was removed of the road to avoid being counted again. For the analyses, we included only the individuals that were identified to the species level.

Data analysis

With the aim to verify which factors may be related with roadkill frequency, we used the following variables based on available data from literature: body mass, home range size, activity pattern, food habits, human development index, total area of municipality, population size, and population density. Roadkill rate was divided by municipality, using the absolute numbers of records.

We used Kruskal-Wallis tests to investigate possible differences between the average number of roadkills *versus* food habit and activity pattern. We chose the Kruskal-Wallis test because the sample variances were unequal. In relation to the average number of roadkills per type of food habit, we considered three trophic categories: omnivorous (OV), insectivorous (IV) and herbivorous (HV). Species with "frugivorous/omnivorous" and/or

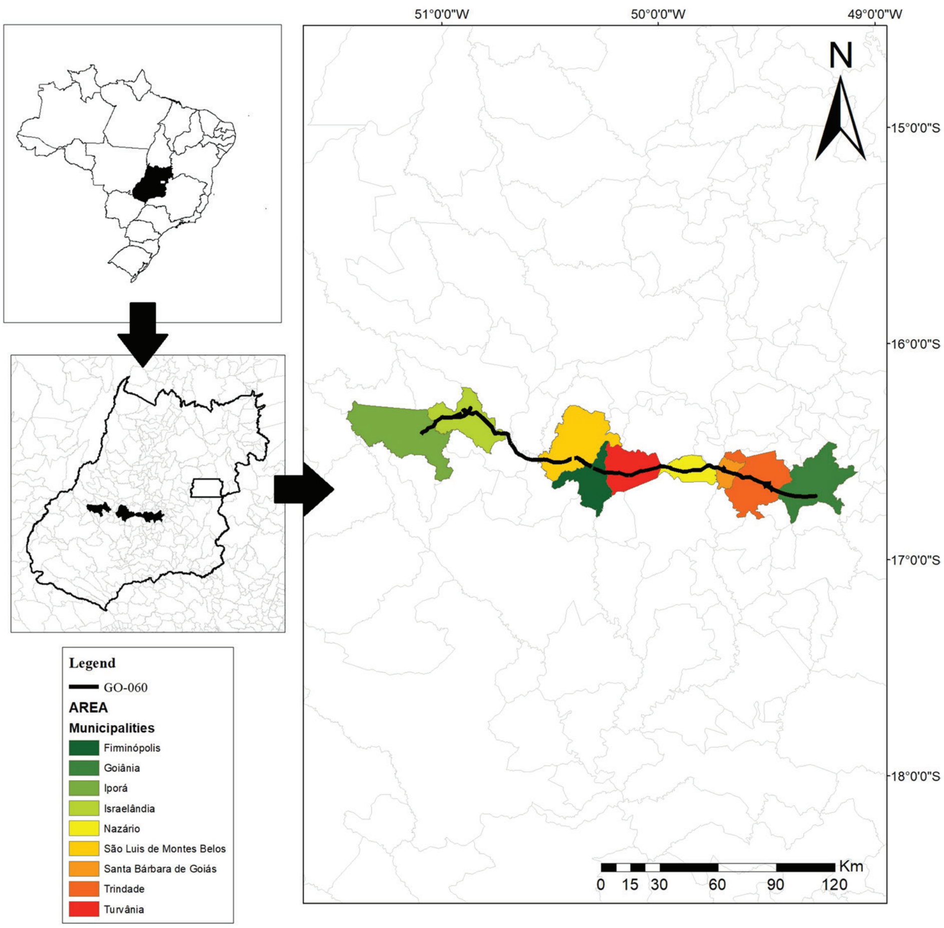

Figure 1. Sector of the GO-060 highway (in black) surveyed in this study.

"insectivorous/omnivorous" were considered omnivorous. Pearson correlation was used to verify whether the roadkill rate and home range size of the species were associated. The influence of body mass on the roadkill rate was estimated through a simple linear regression. We used secondary data from the literature for measures of body mass and home range size for the Cerrado biome. The use of these variables was standardized by using the maximum values for each species found in the literature.

To verify whether human demographic variables influence the roadkill, we used a multiple linear regression among the number of roadkill occurrences per municipality and the following variables: human development index (HDI), total area of the municipality, population size, and population density (number of inhabitants per km²). HDI, population size and density were obtained in IBGE (Brazilian Institute of Geography and Statistics) site (IBGE 2012). Normality was tested using Shapiro-Wilk test. The statistical significance level was set at 0.05 for all the tests. The analyses were performed with the software P.A.S.T. version 2.12 (Hammer *et al.* 2001) and R (R Core Team 2016).

RESULTS

We recorded 89 individuals of class Mammalia, 84 of which were identified to the species level. We identified 12 species from six orders and seven families (Table 1). The roadkill rate was 0.025 individual/km/day. The most frequent roadkilled species, *Myrmecophaga tridactyla*, is categorized as vulnerable. Furthermore, there was one record of *Chrysocyon brachyurus*, which is listed under the near threatened category (Table 1).

We did not find a correlation between home range and the number of roadkills ($t = -0.072$, $df = 8$, $p = 0.944$). Similarly, there was no influence of body mass on the number of roadkills ($F = 2.698$, $df = 10$, $p = 0.132$). We did not observe significant differences ($F = 1.0697$, $df = 3$, $p = 0.385$) among the average number of roadkills of the different activity patterns (Figure 2). However, there was a significant difference among food habits (p = 0.003). The numbers of roadkills of herbivores specimens is lower than the omnivores and insectivores.

There's no influence of demographic variables in mammal roadkill (F = 0.45, df = 1, p = 0.52, R^2 = 0.71). The human development index (p = 0.29), human population density (p = 0.34), total area of the municipality (p = 0.82), and human population size (p = 0.46) variables did not influence the numbers of roadkill of mammals per municipality.

DISCUSSION

In recent years, studies that investigated the factors that involve roadkill of vertebrates have been quite common (Astudillo *et al.* 2014, Carvalho *et al.* 2015, Kang *et al.* 2016). However, as mentioned by Cunha *et al.* (2010), it is difficult to compare results because roads have different characteristics and previous studies used different methodological and sampling procedures. Even so, it is known that the frequency of wild animals killed on roads depends on mammal population abundance (Milli & Passamani 2006, Bager et al. 2007, Cáceres 2011). Usually animals killed on roads are the most abundant and widespread species (Rosa & Mauhs 2004, Grilo 2012).

The five species most affected by roadkills in this study (*Myrmecophaga tridactyla, Tamandua tetradactyla, Lycalopex vetulus, Cerdocyon thous*, and *Nasua nasua*) were also the most impacted ones in other surveys (Prado *et al.* 2006, Tumeleiro *et al.* 2006, Bueno & Almeida 2010, Cunha *et al.*

Table 1. Records of roadkilled specimens of medium- and large-sized mammals on the GO-060 highway, between the municipalities of Goiânia and Piranhas, in the State of Goiás, Brazil. Int = insectivorous; Onv = omnivorous; Hb = herbivorous; AP = activity patterns; Dn = diurnal; Nt = nocturnal; Ct = cathemeral; CrN = crepuscular/nocturnal; IUCN (2017-3) = International Union for Conservation of Nature categories; VU = vulnerable; LC = Least concern; NT = Near threatened.

Species	Common name	Absolute frequency (relative frequency)	Food habit	Activity pattern	Body mass (g)	Home range size (ha)	IUCN	References
ORDER PILOSA								
Family Myrmecophagidae								
Myrmecophaga tridactyla	Giant anteater	21 (0.24)	Int	Ct	30.5 kg	1080	VU	Desbiez & Medri 2010, Paglia *et al.* 2012
Tamandua tetradactyla	Southern tamandua	18 (0.20)	Int	Nt	5.2 kg	100	LC	Desbiez & Medri 2010, Hayssen 2011, Paglia *et al.* 2012
ORDER CARNIVORA								
Family Canidae								
Lycalopex vetulus	Hoary fox	11 (0.12)	Onv	CrN	4.0 kg	456	LC	Dalponte 2009, Paglia *et al.* 2012
Cerdocyon thous	Crab-eating fox	10 (0.11)	Onv	CrN	6.5 kg	280	LC	Pedó *et al.* 2006, Hirsh 2009, Tortato & Althoff 2009, Paglia *et al.* 2012

Table 1. Continued on next page…

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Species	Common name	Absolute frequency (relative frequency)	Food habit	Activity pattern	Body mass (g)	Home range size (ha)	IUCN	References
Chrysocyon brachyurus	Maned wolf	1 (0.01)	Onv	CrN	22 kg	11500	NT	Jácomo *et al.* 2004, Rodrigues *et al.* 2007, Paula *et al.* 2013, Paula & Matteo 2015
Family Procyonidae								
Nasua nasua	South-american coatí	8 (0.09)	Onv	Dn	5.1 kg	755	LC	Gompper & Decker 1998, Beisiegel & Mantovani 2006, Paglia *et al.* 2012
Procyon cancrivorus	Crab-eating raccoon	6 (0.07)	Onv	Nt	5.4 kg	695	LC	Arispe *et al.* 2008, Paglia *et al.* 2012
ORDER CINGULATA								
Family Dasypodidae								
Euphractus sexcinctus	Six-banded armadillo	2 (0.02)	Onv	Ct	5.4 kg	958	LC	Redford & Wetzel 1985, Dalponte & Tavares-Filho 2004, Paglia *et al.* 2012
Dasypus novemcinctus	Nine-banded armadillo	1 (0.01)	Int	CrN	3.5 kg	20.3	LC	McBee & Baker 1982, Paglia *et al.* 2012
ORDER PRIMATES								
Family Cebidae								
Sapajus libidinosus	Bearded capuchin monkey	2 (0.02)	Onv	Dn	4.0 kg	293	LC	Vilela 2007, Paglia *et al.* 2012
ORDER DIDELPHIMORPHIA								
Family Didelphidae								
Didelphis albiventris	White-eared opossum	3 (0.03)	Onv	CrN	2.7 kg	7.04	LC	Alessio *et al.* 2005, Paglia *et al.* 2012, Sanches *et al.* 2012

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Species	Common name	Absolute frequency (relative frequency)	Food habit	Activity pattern	Body mass (g)	Home range size (ha)	IUCN	References
ORDER RODENTIA								
Family Erethizonthidae								
Coendou prehensilis	Brazilian porcupine	1 (0.01)	Hb	Nt	5.3 kg	30	LC	Santos-Júnior 1998, Paglia *et al.* 2012

2010, Hegel *et al.* 2012, Gomes *et al.* 2013). The only exceptions were the members of order Cingulata that, unlike other works (Cherem *et al.* 2007, Cáceres *et al.* 2010, Cáceres *et al.* 2012, Santana 2012, Silva-Neto *et al.* 2015), were less frequent in the present study. Moreover, here were few roadkills of primates and Erethizontidae rodents, which corroborates the findings of other surveys (Melo & Santos-Filho 2007, Coelho *et al.* 2008, Gumier-Costa & Sperber 2009, Santos *et al.* 2012).

Apparently, body mass is not a determinant factor for roadkill, which has also been reported by other authors (Hobday & Minstrell 2008, Cunha *et al.* 2010). We commonly presume that large mammals are most affected by roads than small mammals, however, differently from the African savanna, where large-sized mammals prevail (De Vivo & Carmignotto 2004), more than 80% of the mammals in the Cerrado are medium- and small-sized animals (Marinho-Filho *et al.* 2000). Thus, the probability of a lower body mass animal being killed on a road in the Cerrado is higher than the probability of a large-sized animal, even thought it was not significant in this study.

Furthermore, in this biome, most mammal species are omnivorous and have a generalist and opportunist behavior (Paglia *et al.* 2012), resulting in a lower influence of diet leading to roadkills, and explains why herbivorous were less roadkilled than another guilds. We expected that, since herbivorous mammals probably travel in a larger area than omnivorous and insectivorous to obtain food

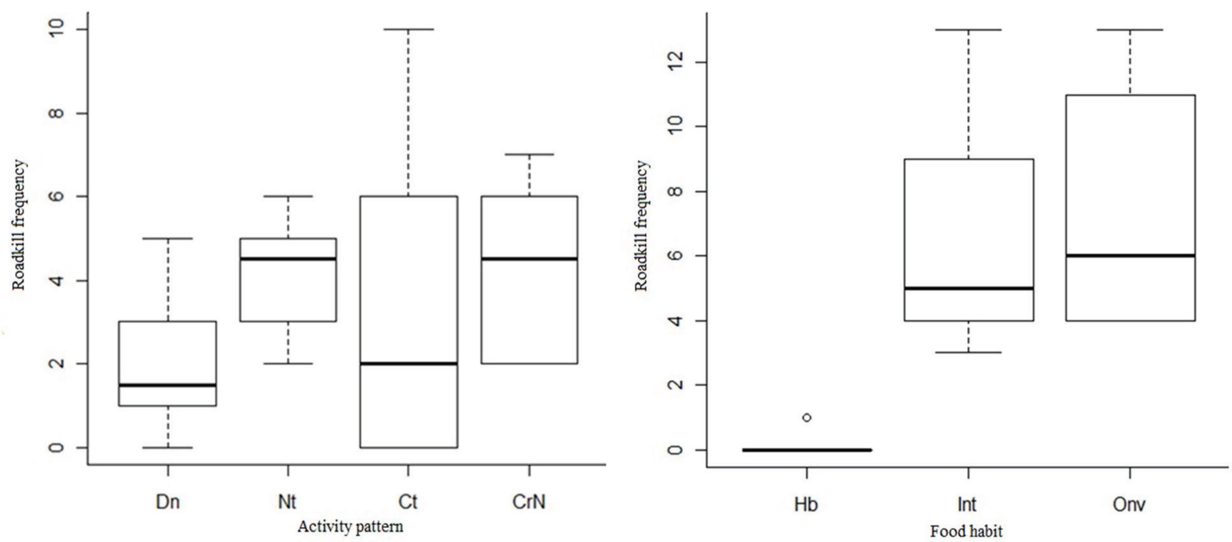

Figure 2. Boxplots with average number of roadkills of medium- and large-sized mammals on the GO-060 highway, between the municipalities of Goiânia and Piranhas, in the State of Goiás, Brazil, in relation to activity pattern and food habits (Dn = diurnal, Nt = nocturnal, Ct = cathemeral, CrN = crepuscular/nocturnal, Hb = herbivore, Int = insectivore, Onv = omnivore).

(Tucker *et al.* 2014), they should be more prone to be roadkilled. However, in both cases, our results show the opposite pattern.

Members of the order Pilosa have poorly developed vision and hearing (Medri *et al.* 2011), making them more prone to being affected by headlights and noise of vehicles (Outen 2002). Thus, this could be a predisposing factor to the high number of roadkills of these animals (Freitas *et al.* 2014). Moreover, the two species of order Pilosa recorded in this study are cathemeral (Medri & Mourão 2005), have large home ranges (*M. tridactyla* up to 1,190 ha and *T. tetradactyla* up to 380 ha) (Medri & Mourão 2005, Hayssen 2011), and use a broad variety of habitats, from savanna formations to woodlands (Desbiez & Medri 2010). Despite there were no significant results when testing the effects of activity pattern and home range size on number of roadkills, these characteristics can lead these two species of order Pilosa to move long distances and cross roads and make them more likely to be roadkilled.

The three members of Canidae family (*C. brachyurus*, *C. thous* and *L. vetulus*) recorded in the present study are omnivorous and opportunistic, and even feed on carcasses (Pedó *et al.* 2006, Rodrigues *et al.* 2007). Thus, these animals are sometimes attracted to roads due to the availability of food, such as carcasses of run over animals, which increases their chances of being killed (Bueno & Almeida 2010, Leite *et al.* 2012, Freitas *et al.* 2015). Besides this, these species have crepuscular and nocturnal habits (Jácomo *et al.* 2004, Dalponte 2009, Tortato & Althoff 2009, Paula *et al.* 2013) and can easily adapt to human-altered environments (Trovatti *et al.* 2007, Lyra-Jorge *et al.* 2008, Bocchiglieri *et al.* 2010, Paula *et al.* 2013), which increases their chances of crossing roads at night and, consequently, of being run over.

The generalist and omnivorous habit of *N. nasua* (Hirsch, 2009) could be one of the factors that influences its roadkill rate, since individuals of this species feed on carcasses, like the canids (Gompper & Decker 1998). Moreover, *N. nasua* forms large groups, that may have more than 30 individuals (Gompper & Decker 1998, Beisiegel & Mantovani 2006). When they are foraging or moving around, this bigger groups can spread all over the highway when they cross, making it difficult for drivers to avoid collisions. Thus, the chances of one *N. nasua* being run over when crossing a road in a group may be larger than that of a solitary animal.

Members of order Cingulata have short and heavy forelimbs adapted for digging (Vizcaíno & Milne 2002), which can result in lower mobility . The combination of this characteristic and their poor vision (Redford & Wetzel 1985) can be extremely prejudicial when crossing roads. Furthermore, the scavenger habit of *E. sexcinctus* (Dalponte & Tavares-Filho 2004) can lead it to feed on roadkill, which increases its chances of being run over.

Primates and Erethizontidae rodents, such as *S. libidinosus* and *C. prehensilis*, respectively, are hardly affected by roadkill, mainly because they are arboreal animals and usually, spend more time on the ground in fragmented areas (Santos *et al.* 2014, Abreu *et al.* 2017), which is the case of our study area, and this could increase the chance of being roadkilled. Furthermore, *C. prehensilis* is herbivorous (Santos-Junior 1998) and *S. libidinosus* is omnivorous, and there are no records of scavenging habits for them (Vilela 2007, Freitas *et al.* 2008, Sabbatini *et al.* 2008). Even so, these animals can be drawn to the roads by external factors, such as food that falls from vehicles (mostly from cargo trucks).

Didelphis species have both arboreal and scansorial habits (Aléssio *et al.* 2005, Sanches *et al.* 2012) and spend considerable time on the ground. These characteristics, associated with the predisposition to feed on garbage disposed near roads (Bueno & Almeida, 2010) and their nocturnal habit (Oliveira-Santos *et al.* 2008), may explain why these animals are frequently run over. However, in this study, we recorded the roadkill of only three individuals of *D. albiventris*. Population density of *D. albiventris* might be small in the study area, therefore this could explain why we recorded this species only three times. Cunha *et al.* (2010) have recorded a significant number of roadkilled *D. albiventris* in the same area, but they sampled for a year and a half, three times more than we did. So it would have been possible to increase this number if we had had more sampling time. On the other hand, some studies suggest *D. albiventris* is not so affected by roadkill in Cerrado comparing to another mammals (Cáceres *et al.* 2010, Cáceres *et al.* 2012). Besides, in this study, we considered *D. albiventris* as a medium species, he is the smaller when compared to another species registered in this study, therefore, another reason could be that it is more difficult to detect smaller mammals from a moving car. Also, small mammals are easily removed of the road, therefore small mammals numbers in roadkill research can be underestimated (Teixeira *et al.* 2013).

Myrmecophaga tridactyla is the only species recorded in this study which is threatened with extinction, categorized as vulnerable according to the IUCN (International Union for Conservation of Nature). The vulnerable status of *M. tridactyla* is even more concerning because this was the most run-over species in the present study. However, *C. brachyurus* that is globally classified as near threatened, but regionally classified as vulnerable (Paula *et al.* 2013), is the only species for which roadkill is a proven risk factor to the maintenance of its populations (Freitas *et al.* 2014, Paula & DeMatteo 2015). Even though we recorded only one occurrence of this species, the roadkill of *C. brachyurus* is a concern because it naturally occurs in low densities (Paula *et al.* 2013). Thus, even though roadkill is not directly connected to its extinction rate, it is relevant and should be considered in future studies that investigate the causes of local and global extinction of this species (Ribeiro *et al.* 2017).

Despite all the problems that building and maintaining roads cause to the environment and natural resources, roads play an important role in the transportation of goods and people in Brazil. Therefore, the implementation of measures to reduce roadkill of wild mammals is imperative. Fauna signage and speed reducers could help drivers to pay attention is slower animals, like anteaters, armadillos and porcupines. Also, in a slower speed, drivers can see small animals better. Wildlife crossings could help animals who used to travel long distances to obtain food, like carnivores and herbivores, and suspended crossings could provide safety to arboreal and scansorial animals, such as coatis and monkeys. Also, according to Miranda *et al.* (2017), including environmental education in preparatory courses given by driving schools could be a useful tool to reduce fauna roadkill. For the establishment of fauna crossings, it is necessary to evaluate the characteristics of local populations to better understand the most appropriate structures to use. Furthermore, we believe this evaluation must consider not only the biological and behavioral characteristics of the species, but also traffic variables (*e.g.*, average speed).

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