Volume 25 (July 2015), 141–148

Herpetological Journal

FULL PAPER

Published by the British Herpetological Society

Road mortality of the herpetofauna in a Cerrado ecosystem, central Brazil

Adriano M. Souza, Renan C. Pires, Vitor S. Borges & Paula C. Eterovick

Programa de Pós Graduação em Zoologia de Vertebrados, Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil

Roads have many detrimental effects on natural habitats and their fauna, ranging from altered microclimate to road kills. Animals which move slowly or are attracted to the road surface are particularly threatened. We studied herpetofauna road mortality in a Cerrado ecosystem in central Brazil. We sampled 51 km of state roads during 26 days distributed between dry and wet seasons in 2010 and recorded 109 dead individuals of 34 species of amphibians and reptiles. Including animals found alive on the road, we recorded 159 individuals across 39 species (estimated richness: 48). This number represents about 50% of the herpetofauna species richness expected to occur in a Cerrado site in central Brazil based on a concomitant species inventory. Our study indicates that roads can cause high mortality rates for the Cerrado herpetofauna. We consider that this problem requires urgent attention since economic growth is largely based on agriculture in the Cerrado and construction of more roads is planned to improve harvest transport.

Key words: amphibians, reptiles, wildlife road mortality, wildlife road use

INTRODUCTION

Roads can cause isolation and fragmentation of habitats, and animals which attempt to cross roads are exposed to the risk of collision with vehicles (Vestjens, 1973; Trombulak & Frissell, 2000). Road kills can result in high mortality levels, especially in the case of animals that move slowly, such as amphibians and reptiles (Ashley & Robinson, 1996; Hels & Buchwald, 2001; Gibbs & Steen, 2005). Roads also function as barriers for dispersal, promoting habitat fragmentation and reducing gene flow within populations or among subpopulations (De Maynadier & Hunter, 2000; Dyer et al., 2002; Marsh et al., 2005). Additionally, roads create an edge effect in their vicinity, including temperature changes, wind intensification and humidity alterations, all of which are factors known to reduce populations of sensitive species and alter communities in adjacent habitats (Coffin, 2007).

Despite the rich biodiversity of Brazil, information on road mortality is limited and focused on mammals (Valladares-Padua et al., 1995; Vieira, 1996; Pereira et al., 2006; Cherem et al., 2007), birds (Rosa & Bager, 2012), or the whole vertebrate fauna (Rosa & Mauhs, 2004; Bager & Rosa, 2011). Only two studies have so far focused on road mortality of the herpetofauna in Brazil (Silva et al., 2007; Hartmann et al., 2011). However, ectotherms are expected to be particularly vulnerable because they move slowly and are often attracted by roads to thermoregulate (e.g., Bernardino & Dalrymple, 1992). Furthermore, amphibians and reptiles are likely to cross roads during their movements while foraging or searching for breeding sites (Steen & Gibbs, 2004; Silva et al., 2007; Andrews et al., 2008).

The Cerrado is the second largest biome in Brazil, covering nearly 25% of the country's territory (Ab'Saber, 1977). It is presently one of the most threatened biomes in South America, due to the indiscriminate use of fire, removal of vegetation for agriculture and pastures of introduced grasses (Dias, 1994; Klink & Machado, 2005). It is estimated that only 7% of the area of the Cerrado is preserved, whereas 56% is used for soy monocultures and 37% is classified as anthropogenic landscape (Dias, 1994). The construction of more roads is planned to improve harvest transport (Klink & Machado, 2005). Recent studies on the species composition of the herpetofauna in the Cerrado recorded 213 squamates, 139 amphibians and 24 amphisbaenids (Bastos, 2007; Costa et al., 2007).

In the present study, we quantified the occurrence of amphibians and reptiles (killed or alive) along a 51 km stretch of major roads in the state of Tocantins (central Brazil) crossing a typical Cerrado habitat (*sensu strictu*; Haidar et al., 2011). We tested whether amphibians, lizards or snakes differed in number of dead individuals on the road. We also tested for differences in mortality rates between seasons. Concomitantly, we conducted a species inventory in the vicinity of the road to estimate what proportion of the local species richness is using the road and/or being subject to road kills. Our main goal

Correspondence: Paula C. Eterovick (pceterovick@gmail.com)

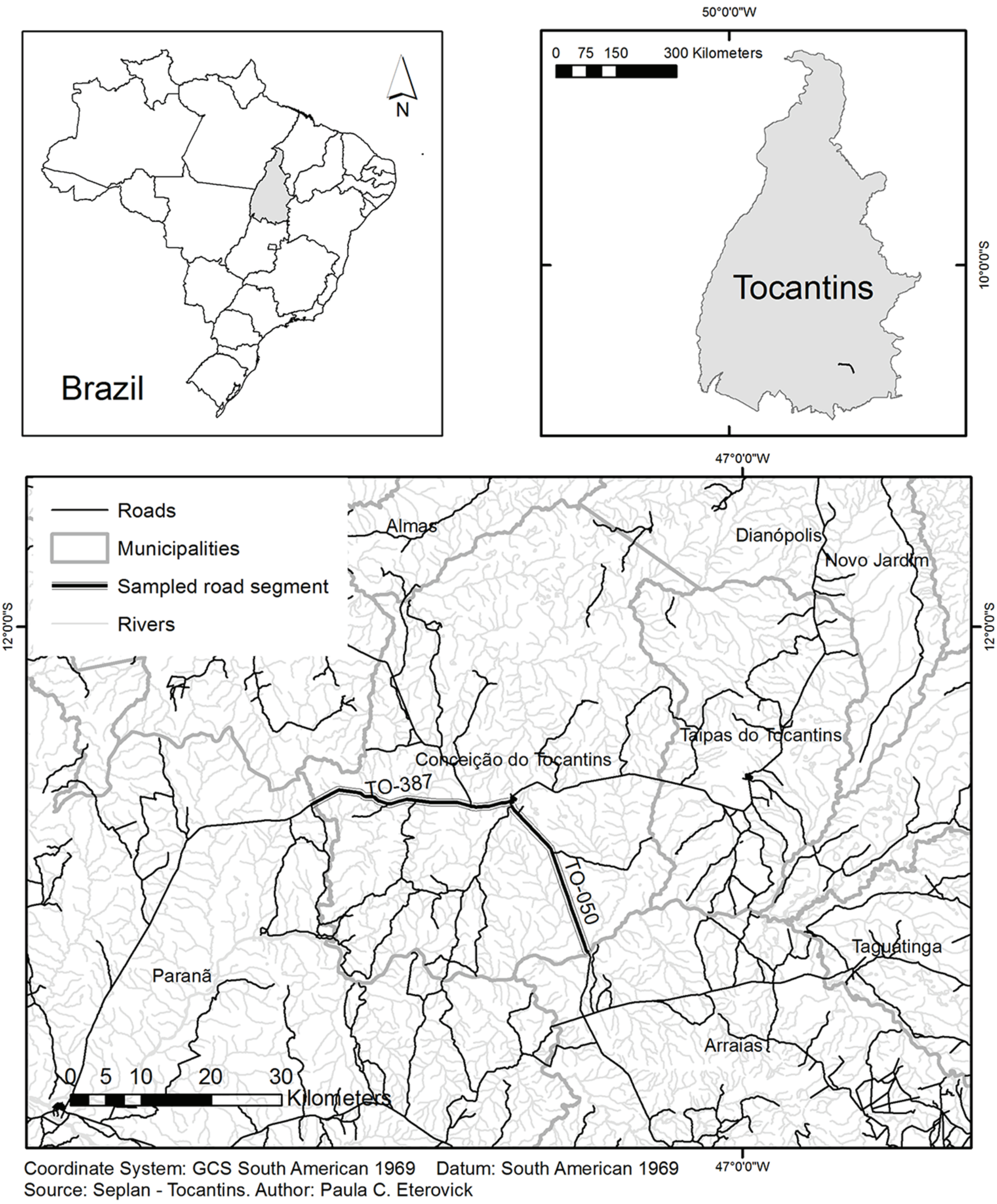

Fig. 1. Road stretches sampled in the state of Tocantins in central Brazil.

was to acquire an insight into the magnitude of road mortality on the herpetofauna of the Cerrado since a rapid expansion of the transportation system is expected.

MATERIALS AND METHODS

The study site encompassed a 29 km stretch of the state road TO-050 connecting to a 22 km stretch of the state road TO-387 between the rivers Paranã and Palma in the southern portion of the state of Tocantins, central Brazil (Fig. 1). The two-lane roads are approximately 10 m wide, with shoulders in some sections. Both roads have the same characteristics and so we use "road stretch" to refer to the whole sampled extent from here on. Through most of its length the road stretch crosses preserved habitats that retain their original cerrado *sensu strictu* vegetation (Veloso, 1963), with a small proportion crossing areas of anthropogenic disturbance. There is no available information on traffic intensity for this road stretch, but our personal observations indicated no noticeable differences between daily sampling periods or seasons. We observed the number of vehicles to be relatively small for a state road (about 40 vehicles per hour, 60% trucks/buses, 20% cars and 20% motorbikes) but a large portion of the road stretch was straight and the speed limit (80 km/h) was not respected.

We sampled the road stretch in pairs, road-cruising by car (at a speed of 50 km/h) six times a day, driving along the road in both directions in the morning, afternoon, and evening, during 13 consecutive days in

Table 1. The number of species records of amphibians and reptiles found dead (Road/Dead) or alive (Road/Alive) on a 51 km stretch of the roads TO-050 and TO-387 between the Paraná and Palmas rivers in the southern portion of the state of Tocantins in central Brazil, and the number of records from two different sampling methods (Pitfalls and Transects) used to inventory amphibians and reptiles in the vicinity of the road stretch (Outside the road). Taxonomy is according to Frost (2013) for amphibians and Bérnils & Costa (2012) for reptiles. Species with a single or double asterisk are considered as Data Deficient or Vulnerable by the IUCN (2013), respectively. Species without an asterisk are considered Least Concern or have not been assessed by the IUCN Red List of Threatened Species (IUCN, 2013).

Taxon	Road		Outside the road		
	Dead	Alive	Pitfalls	Transects	Total
Amphibia – Siphonopidae					
Siphonops sp.	0	0	0	1	1
Amphibia – Bufonidae					
Rhinella granulosa (Spix, 1824)	0	0	0	9	9
R. jimi (Stevaux, 2002)	0	0	0	8	8
R. schneideri (Werner, 1894)	0	1	0	21	22
Amphibia - Hylidae					
Dendropsophus decipiens (Lutz, 1925)	0	0	0	9	9
D. melanargyreus (Cope, 1887)	0	0	0	4	4
D. minutus (Peters, 1872)	0	0	0	62	62
D. nanus (Boulenger, 1889)	0	0	0	8	8
D. rubicundulus (Reinhardt and Lutken, 1862)	0	0	0	35	35
Hypsiboas raniceps Cope, 1862	11	4	0	16	31
H. cf. *multifasciatus* (Gunther, 1859)	0	0	0	7	7
**Phyllomedusa azurea* Cope, 1862	0	0	0	4	4
P. hypochondrialis (Daudin, 1800)	5	3	0	21	29
Pseudis tocantins Caramaschi and Cruz, 1998	0	0	0	16	16
Scinax eurydice (Bokermann, 1968)	0	0	0	8	8
S. fuscomarginatus (Lutz, 1925)	0	0	0	30	30
S. fuscovarius (Lutz, 1925)	2	2	0	41	45
S. cf. *perereca* Pombal, Haddad and Kasahara, 1995	0	0	0	2	2
Trachycephalus typhonius (Linnaeus, 1758)	1	1	0	2	4
Amphibia – Leptodactylidae					
Eupemphix nattereri Steindachner, 1863	0	0	0	6	6
Leptodactylus fuscus (Schneider, 1799)	0	1	0	32	33
L. labyrinthicus (Spix, 1824)	1	0	0	3	4
L. latrans (Steffen, 1815)	1	1	0	35	37
L. syphax Bokermann, 1969	0	0	0	2	2
L. troglodytes Lutz, 1926	0	0	0	5	5
Physalaemus cuvieri Fitzinger, 1826	0	0	22	23	45
P. centralis Bokermann, 1962	0	0	12	16	28
**P. obtectus* Bokermann, 1966	0	0	0	2	2
Pseudopaludicola falcipes (Hensel, 1867)	0	0	18	12	30
P. saltica (Cope, 1887)	0	0	15	7	22
Amphibia – Odontophrynidae					
Odontophrynus cultripes Reinhardt and Lütken, 1862	0	0	5	2	7
Proceratophrys goyana (Miranda-Ribeiro, 1937)	0	0	0	10	10
Amphibia - Microhylidae					
**Chiasmocleis mehelyi* Caramaschi and Cruz, 1997	0	0	1	0	1
Dermatonotus muelleri (Boettger, 1885)	0	0	0	5	5
Elachistocleis ovalis (Schneider, 1799)	0	0	7	2	9
Eusuchia – Alligatoridae					
Caiman crocodilus (Linnaeus, 1758)	0	0	0	3	3
Paleosuchus palpebrosus (Cuvier, 1807)	0	0	0	3	3
Chelonia – Chelidae					
Phrynops geoffroanus (Schweigger, 1812)	0	0	0	4	4
Chelonia – Podocnemididae					
Podocnemis cf. *expansa* (Schweigger, 1812)	0	0	0	1	1
Chelonia – Testudinidae					
Chelonoidis carbonaria (Spix, 1824)	0	0	0	2	2
***C. denticulata* (Linnaeus, 1766)	0	1	0	1	2
Squamata – Amphisbaenidae					
Amphisbaena alba Linnaeus, 1758	0	0	0	2	2
Leposternum microcephalum Wagler, 1824	0	0	0	2	2
Squamata – Diploglossidae					
Ophiodes striatus (Spix, 1825)	0	0	0	3	3
Squamata – Gekkonidae					
Hemidactylus mabouia (Moreau de Jonnès, 1818)	0	0	0	8	8
Squamata – Gymnophthalmidae					
Micrablepharus maximiliani (Reinhardt and Luetken, 1862)	0	0	4	1	5
Squamata – Iguanidae					

Table 1. *Continued.*

Taxon	Road		Outside the road		
	Dead	Alive	Pitfalls	Transects	Total
Squamata – Mabuyidae					
Notomabuya frenata (Cope, 1862)	0	0	2	1	3
Squamata – Phyllodactylidae					
Gymnodactylus darwinii (Gray, 1845)	0	0	2	0	2
G. geckoides Spix, 1825	0	0	3	0	3
Squamata – Polychrotidae					
Polychrus acutirostris Spix, 1825	1	1	0	2	4
Squamata – Teiidae					
Ameiva ameiva (Linnaeus, 1758)	0	0	0	18	18
Ameivula ocellifera (Spix, 1825)	2	1	0	15	18
Salvator merianae Duméril and Bibron, 1839	3	1	0	3	7
Tupinambis quadrilineatus Manzani and Abe, 1997	4	0	0	4	8
Squamata – Tropiduridae					
Tropidurus cf. *hispidus* (Spix, 1825)	0	0	0	18	18
Tropidurus cf. *itambere* Rodrigues, 1987	2	0	0	3	5
T. oreadicus Rodrigues, 1987	1	0	0	26	27
Squamata – Aniliidae					
Anilius scytale (Linnaeus, 1758)	1	0	0	1	2
Squamata – Boidae					
Boa constrictor Linnaeus, 1758	4	2	0	4	10
Epicrates cenchria (Linnaeus, 1758)	1	1	0	0	2
E. crassus Cope, 1862	0	0	0	1	1
Eunectes murinus (Linnaeus, 1758)	0	0	0	1	1
Squamata – Colubridae					
Chironius exoletus (Linnaeus, 1758)	3	2	0	4	9
C. flavolineatus (Jan, 1863)	2	0	0	4	6
C. fuscus (Linnaeus, 1758)	2	0	0	5	7
Drymarchon corais (Boie, 1827)	0	0	0	1	1
Oxybelis aeneus (Wagler, 1824)	0	0	0	1	1
Spilotes pullatus (Linnaeus, 1758)	0	0	0	1	1
Tantilla melanocephala (Linnaeus, 1758)	0	0	0	1	1
Squamata - Dipsadidae					
Apostolepis cearensis Gomes, 1915	0	0	0	1	1
Apostolepis sp.	2	0	0	0	2
Atractus pantostictus Fernandes and Puorto, 1994	9	6	0	7	22
Clelia clelia (Daudin, 1803)	1	0	0	0	1
Echinanthera cyanopleura (Cope, 1885)	1	0	0	2	3
Helicops modestus Günter, 1861	1	0	0	1	2
Lygophis meridionalis (Schenkel, 1901)	2	0	0	3	5
L. paucidens (Hoge, 1953)	2	0	0	3	5
Erythrolamprus poecilogyrus (Wied, 1825)	8	3	2	10	23
Oxyrhopus trigeminus Duméril, Bibron and Duméril, 1854	9	9	0	9	27
O. guibei Hoge and Romano, 1978	0	0	0	11	11
Phimophis guerini (Duméril, Bibron and Duméril, 1854)	5	0	0	3	8
Philodryas nattereri Steindachner, 1870	0	0	0	2	2
Philodryas olfersii (Lichtenstein, 1823)	0	0	0	4	4
Philodryas varia (Jan, 1863)	0	0	0	2	2
Pseudoboa nigra (Duméril, Bibron and Duméril, 1854)	9	0	0	9	18
Psomophis joberti (Sauvage, 1884)	0	0	0	1	1
Sibynomorphus mikanii (Schlegel, 1837)	3	4	0	9	16
S. neuwiedi (Ihering, 1911)	4	4	0	8	16
Xenodon merremii (Wagler, 1824)	3	0	0	4	7
Squamata – Typhlopidae					
Typhlops brongersmianus Vanzolini, 1976	2	0	0	1	3
Squamata – Viperidae					
Bothrops moojeni Hoge, 1966	0	0	0	2	2
B. neuwiedi Wagler, 1824	1	0	0	3	4
Crotalus durissus Linnaeus, 1758	0	0	0	2	2

the dry season (July 2010) and 13 consecutive days in the rainy season (November 2010). Sampling intervals were regular and intended to spot animals with different activity periods. We had good visibility of the road surface during road cruising in both directions and recorded all specimens on it, marking their position with a GPS. Since we sampled the road six times a day, we minimised the probability of carcasses being removed from the road by scavengers before detection (see Hels & Buchwald, 2001). We removed specimens found to avoid replicate observations.

In order to assess herpetofauna species richness in the vicinity of the road stretch we used transect sampling and pitfall traps (Heyer et al., 1994; Cechin & Martins, 2000). We distributed 8 transects of 100 m on each side of the road stretch spaced by 2 to 3 km among them and 500 to 1000 m from the road. On each side, three transects were placed close to streams (parallel to and 3 m from

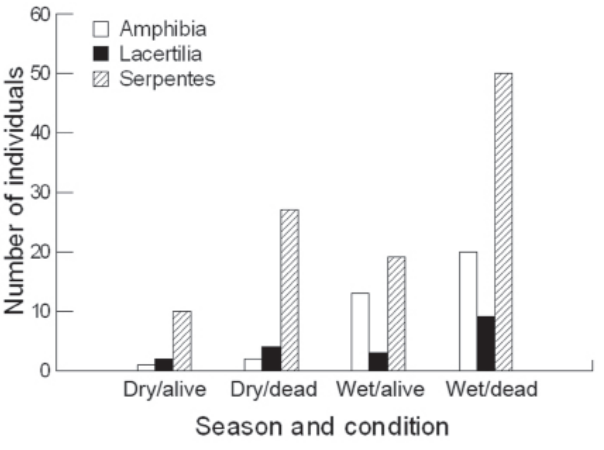

Fig. 2. Number of individuals of the studied taxa (Amphibia, Lacertilia, and Serpentes) found dead or alive during sampling in the dry and wet seasons along the road stretch sampled in the state of Tocantins in central Brazil.

them) and five were placed away from water bodies. Three people walked each transect for one hour and recorded specimens observed within a distance of 5 m to each side and to 3 m height. We inspected any structure that could shelter amphibians or reptiles, including the leaf litter, trunks, cavities, and vegetation. We walked each transect both during the day and at night once during each sampling period, totaling 192 person hours. We installed six series of pitfall traps connected by drift fences along the road stretch, three on each side. We placed the pitfall trap series far from water bodies (at least 500 m) to avoid the flooding of traps. Each trap series consisted of a line of ten 60 l buckets connected by drift fences made of resistant plastic. Drift fences were 1 m high and had their bottom buried 20 cm in the soil. Pitfall traps remained open during the entire sampling period (i.e., 1560 trap days).

We selected models based on Akaike criteria (SYSTAT, 2007) for an analysis of variance to test whether the number of individuals spotted on the road stretch (both dead and alive) was influenced by season (dry, wet) or taxon (amphibians, lizards and snakes). We tested for differences between the proportions of individuals found dead or alive with paired *t*-tests. Numbers of records were log transformed to achieve normal distribution. We also conducted a Chi-square test on the variation in the proportions of dead or alive individuals among taxonomic groups (amphibians, lizards and snakes). To infer the proportion of species of the local herpetofauna directly affected by the road in terms of roadkills, we estimated species richness based on (i) records obtained on the road, and (ii) records obtained in the vicinity of the road with all sampling methods combined. We used the Jackknife I species richness estimator (1000 simulations) in the software EstimateS v.8.0 (Colwell, 2006), considering days as sample units (26 samples). Jackknife I has been shown to perform well even with small data sets (Walther & Morand, 1998).

RESULTS

We recorded a total of 39 species of amphibians and reptiles on the road, 34 of them represented by dead individuals, and 21 represented by live individuals. The sample encompassed nine amphibians (one considered as Data Deficient; IUCN, 2013), one tortoise (considered as Vulnerable; IUCN, 2013), seven lizards and 22 snakes (Table 1). We recorded a total of 159 individuals (109 dead and 50 alive); 114 individuals were recorded during the rainy season, and 45 during the dry season (Table 1, Fig. 2). The estimated species richness was 48.37±3.31 species based on individuals found on the road, and the species accumulation curve did not approach an asymptotic value.

The best model (AIC=27.355) for the analysis of variance included both season (MS=4.492, df=1, p=0.012) and taxon (MS=7.445, df=2, p=0.011) without significant interaction (MS=1.098, df=2, p=0.120; Fig. 2). The number of animals of all groups recorded on the road was higher during the rainy season. Snakes had the higher number of species and individuals on roads (Fig. 2). A significantly higher number of records corresponded to dead individuals for all groups combined (paired t=7.960, p =0.001). We found no significant differences in the proportions of individuals found dead or alive among the three taxonomic groups considered (χ^2=1.932, df=5, p=0.858).

In the vicinity of the road, we obtained records of 35 species of amphibians (27 of which were not found on the road), 17 species of lizards (10 of which were not found on the road), 36 species of snakes (14 of which were not found on the road), two species of caimans (none found on the road) and four species of turtles (three of which were not found on the road, Table 1). Estimated species richness was 109.27±3.81, and stabilised after 19 samples.

DISCUSSION

We showed that the numbers of species and individuals killed on the studied road stretch are very high compared to other biomes in Brazil (restinga and Atlantic Forest: Silva et al., 2007; Bager & Rosa, 2011; Amazon: Gumier-Costa & Sperber, 2009; Turci & Bernarde, 2009). Although the inventory in the vicinity of the road was conducted in a short period of time, our sampling effort resulted in 94 species, close to the total species richness estimated to occur at the site (109 species). A few thorough herpetofaunal inventories have been conducted at other Cerrado areas in central Brazil and these can provide additional examples of the expected diversity of amphibians and reptiles in the study area (a little over 100 species; Vitt et al., 2005; Vaz-Silva et al., 2007; Valdujo et al., 2009). So then, to the degree that the species richness estimated in our own inventory and the available inventories for other Cerrado localities are accurate, the species we found using the road stretch in our study may approach at least 50% of the species in the region.

The amount of preserved habitat that a road crosses and the presence of water bodies alongside roads are important in determining the impacts on frogs, snakes and turtles (Langen et al., 2009; Gunson et al., 2011). Although we did not measure it quantitatively, we found more individual frogs, lizards and snakes on the road near the vicinity of adjacent water bodies. It is also important to consider that movement patterns, speed, reaction to vehicles, and use of habitats by roads are all determinants of road kill rates (Hels & Buchwald, 2001; Andrews & Gibbons, 2005; Andrews et al., 2008) and may vary among species, sex, and size (Andrews & Gibbons, 2008).

The number of individuals found was significantly higher in the rainy season, when the studied taxa are searching for breeding sites or foraging more actively (Daltry et al., 1998; Martins & Oliveira, 1998; Marques et al., 2000). As pointed-out by Coffin (2007) and Andrews et al. (2008), roads may function as an "ecological trap" for these animals by bisecting their migration routes or territories, offering food (e.g., carrion, insects, and other animals attracted by the road), and habitat for thermoregulation.

The number of individuals found dead was higher than the number of individuals found alive, as also recorded by Andrews & Gibbons (2008) for eight species of snakes. The higher encounter rate of dead compared to live animals on the road is probably due to the long time corpses remain in place compared to the amount of time a living individual spends on the road. Snakes had the highest number of records both alive and dead, due to their high mobility and propensity to cross the road (see Hels & Buchwald, 2001) or attraction to the warmth of the road pavement (Bernardino & Dalrymple, 1992). A high proportion of snakes among herpetofaunal road kills was also observed in the Amazon (Pará state, Gumier-Costa & Sperber, 2009). While snakes may be killed on purpose by drivers because of their unpopularity (Rudolph et al., 1999), intense use of the road seems to be the main mortality cause.

The extant knowledge on herpetofauna road mortality in Brazil is scarce. We reported the results of the first inventory of road mortality on amphibians and reptiles in a Cerrado biome and revealed a high number of species and individuals using the road (and consequently killed). Our results point to the need for additional information on road impacts in the Cerrado for better planning of road construction and impact mitigation. Information on areas with more intense use by native species can be used to plan road construction on areas of potentially less impact (Benayas et al., 2006). It is also important to know what factors influence road kill rates in habitats of interest (see Gunson et al., 2011) and what are the effects of different road features (e.g., paved or unpaved, high or low traffic; see Van Langevelde et al., 2009). Road ecology is an incipient field in Brazil, and more studies on the influence of roads on the herpetofauna are urgently needed to clarify the magnitude of their overall impact, to identify mitigation strategies, and to raise concern for the protection of the native fauna.

ACKNOWLEDGEMENTS

We are thankful to R.S. Santana from Nativa Meio Ambiente for providing infra-structure and financial support for this study, E.R. Wild for revision of the English and suggestions on the manuscript, and CNPq for providing a Research Productivity grant (301077/2010-0) to P.C. Eterovick.

REFERENCES

Ab'Saber, A.N. (1977). Os domínios morfoclimáticos na América do Sul: primeira aproximação. *Geomorfologia* 53, 1–23.

Andrews, K.M. & Gibbons, J.W. (2005). How do highways influence snake movement? Behavioral responses to roads and vehicles. *Copeia* 2005, 772–782.

Andrews, K.M. & Gibbons, J.W. (2008). Roads as catalysts of urbanization: Snakes on roads face differential impacts due to inter- and intraspecific ecological attributes. Pp. 145–153. In Mitchell, J.C., Jung Brown, R.E., Bartholomew, B. (eds.). In *Urban Ecology*. The Society for the Study of Amphibians and Reptiles, USA.

Andrews, K.M., Gibbons, J.W. & Jochimsen, D.M. (2008). Ecological effects of roads on amphibians and reptiles: A literature review. Pp. 121–143. In Mitchell, J.C., Jung Brown, R.E., Bartholomew, B. (eds.). In *Urban Ecology*. The Society for the Study of Amphibians and Reptiles, USA.

Ashley, E.P. & Robinson, J.T. (1996). Road mortality of amphibians and other wildlife in the Long Point Causeway, Lake Erie, Ontario. *The Canadian Field Naturalist* 110, 403–412.

Bager, A. & Rosa, C.A.. (2011). Influence of sampling effort on the estimated richness of road-killed vertebrate wildlife. *Environmental Management* 47, 851–858.

Bastos, R.P. (2007). Anfíbios do Cerrado. Pp. 87–100 in L.B. Nascimento and M.E. Oliveira (Eds.). In *Herpetologia no Brasil II*. Sociedade Brasileira de Herpetologia, Brazil.

Benayas, J.M.R., De La Montaña, E., Belliure, J., Eekhout, X.R. (2006). Identifying areas of high herpetofauna diversity that are threatened by planned infrastructure projects in Spain. *Journal of Environmental Management* 79, 279–289.

Bernardino Jr., F.S. & Dalrymple, G.H. (1992). Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. *Biological Conservation* 62, 71–75.

Bérnils, R.S. & Costa, H.C. (2012). Brazilian reptiles: List of species. Version 2012.2. Sociedade Brasileira de Herpetologia. Available at <http://www.sbherpetologia.org.br>. Accessed: 5 July 2014.

Cechin, S.Z. & Martins, M. (2000). Eficiência de armadilhas de queda (pitfall traps) em amostragens de anfíbios e répteis no Brasil. *Revista Brasileira de Zoologia* 17, 729–740.

Cherem, J.J., Kammers, M., Ghizoni-Jr, I.R., Martins, A. (2007). Mamíferos de médio e grande porte atropelados em rodovias do Estado de Santa Catarina, Sul do Brasil. *Biotemas* 20, 81–96.

Coffin, A.W. (2007). From roadkill to road ecology: a review of the ecological effects of roads. *Journal of Transport Geography* 15, 396–406.

Colwell, R.K. (2006). EstimateS, Version 8.0: Statistical Estimation of Species Richness and Shared Species from Samples (Software and User's Guide). Available at <http://

viceroy.eeb.uconn.edu/EstimateS>. Accessed: 4 July 2013.

Costa, G.C., Nogueira, C., Machado, R.B., Colli, G.R. (2007). Squamate richness in the Brazilian Cerrado and its environmental-climatic associations. *Diversity and Distributions* 13, 714–724.

Daltry, J.C., Ross, T., Thorpe, R.S., Wuster, W. (1998). Evidence that humidity influences snake activity patterns: a field study of the Malayan pit viper *Calloselasma rhodostoma*. *Ecography* 21, 25–34.

De Maynadier, P.G. & Hunter, M.L. (2000). Road effects on amphibian movements in a forested landscape. *Natural Areas Journal* 20, 56–65.

Dias, B. (1994). Conservação da natureza no cerrado brasileiro. Pp. 607–663 in M.N. Pinto (Ed.). In *Cerrado: Caracterização, Ocupação e Perspectivas*. Editora da Universidade de Brasília e Secretaria do Meio Ambiente, Ciência e Tecnologia do Distrito Federal, Brazil.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., Boutin, S. (2002). Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology* 80, 839–845.

Frost, D.R. (2013). Amphibian Species of the World: an Online Reference. Version 5.6 (9 January 2013). Available from: <http://research.amnh.org/herpetology/amphibia/index.html>. American Museum of Natural History, USA. Accessed: 5 July 2013.

Gibbs, J.P. & Steen, D.A. (2005). Trends in sex ratios of turtles in the United States: implications of road mortality. *Conservation Biology* 19, 552–556.

Gumier-Costa, F. & Sperber, C.F. (2009). Atropelamentos de vertebrados na Floresta Nacional de Carajás, Pará, Brazil. *Acta Amazonica* 39, 459–466.

Gunson, K.E., Mountrakis, G., Quackenbush, L.J. (2011). Spatial wildlife-vehicle collision models: a review of current work and its application to transportation mitigation projects. *Journal of Environmental Management* 92, 1074–1082.

Haidar, R.F., Dias, R.R.; Pereira, E.Q., Santana, I.T., Reis, J.S. (2011). Mapeamento e reconstituição dos ambientes fitoecológicos para o sul do estado do Tocantins por meio de imagens Landsat MSS e TM, e dados geoambientais. Pp. 2059–2066, Anais do XV Simpósio Brasileiro de Sensoriamento Remoto, Brazil.

Hartmann, P.A., Hartmann, M.T., Martins, M. (2011). Snake road mortality in a protected area in the Atlantic Forest of Southeastern Brazil. *South American Journal of Herpetology* 6, 35–42.

Hels, T. & Buchwald, E. (2001). The effect of road kills on amphibian populations. *Biological Conservation* 99, 331–340.

Heyer, W.R., Donnelly, M.A., McDiarmid, R.W., Hayek, L.A.C., Foster, M.S. (1994). *Measuring and Monitoring Biological Diversity – Standard Methods for Amphibians*. Smithsonian Institution, USA.

IUCN 2013. *The IUCN Red List of Threatened Species. Version 2013.2*. Available from: <http://www.iucnredlist.org>. Accessed: 5 May 2014.

Klink, C.A., Machado, R.B. (2005). Conservation of the Brazilian Cerrado. *Conservation Biology* 19, 707–713.

Langen, T.A., Ogden, K.M., Schwarting, L.L. (2009). Predicting hot spots of herpetofauna road mortality along highway networks. *Journal of Wildlife Management* 73, 104–114.

Marques, O.A.V., Eterovic, A., Endo, W. (2000). Seasonal activity of snakes in the Atlantic forest in southeastern Brazil. *Amphibia Reptilia* 22, 103–111.

Marsh, D.M., Milam, G.S., Gorham, N., Beckham, N.G. (2005). Forest roads as partial barriers to terrestrial salamander movement. *Conservation Biology* 19, 2004–2008.

Martins, M. & Oliveira, M.E. (1998). Natural history of snakes in forests in the Manaus region, Central Amazonia, Brazil. *Herpetological Natural History* 6, 78–150.

Pereira, G.F.P.A., Andrade, G.A.F., Fernandes, B.E.M. (2006). Dois anos de monitoramento dos atropelamentos de mamíferos na rodovia PA-458, Bragança, Pará. *Boletim do Museu Paraense Emílio Goeldi* 1, 77–83.

Rosa, C.A. & Bager, A. (2012). Seasonality and habitat types affect roadkill of neotropical birds. *Journal of Environmental Management* 97, 1–5.

Rosa, O. & Mauhs, J. (2004). Atropelamentos de animais silvestres na rodovia RS-040. *Caderno de Pesquisa, Série Biologia* 16, 35–42.

Rudolph, D.C., Burgdorf, S.J., Conner, R.N. & Schaefer, R.R. (1999). Preliminary evaluation of the impact of roads and associated vehicular traffic on snake populations in eastern Texas. In Proceedings of Third International Conference on Wildlife Ecology and Transportation. Tallahassee, p. 129–136.

Silva, M.O., De Oliveira, I.S., Cardoso, M.W., Graf, V. (2007). Road kills impact over the herpetofauna of Atlantic Forest (PR-340, Antonina, Paraná). *Acta Biológica Paranense* 36, 103–112.

Steen, D.A & Gibbs, J.P. (2004). Effects of roads on the structure of freshwater turtle populations. *Conservation Biology* 18, 1143–1148.

SYSTAT Software Inc., (2007). SYSTAT 12 for Windows. SYSTAT Software Inc., San Jose.

Trombulak, S.C. & Frissell, C.A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14, 18–30.

Turci, L.C.B. & Bernarde, P.S. (2009). Vertebrados atropelados na Rodovia Estadual 383 em Rondônia, Brazil. *Biotemas* 22, 121–127.

Valladares-Padua, C., Cullen Jr., M.L., Padua, S. (1995). A pole bridge to avoid primate road kills. *Neotropical Primates* 3, 13–15.

Van Langevelde, F., van Dooremalen, C., Jaarsma, C.F. (2009). Traffic mortality and the role of minor roads. *Journal of Environmental Management* 90, 660–667.

Vaz–Silva, W., Guedes, A.G., Azevedo–Silva, P.L., Gontijo, E.F., et al. (2007). Herpetofauna, Espora Hydroelectric Power Plant, state of Goiás, Brazil. *Check List* 3, 338–345.

Valdujo, P.H., Nogueira, C.C., Baumgarten, L., Rodrigues, F.H.G., et al. (2009). Squamate reptiles from Parque Nacional das Emas and surroundings, Cerrado of Central Brazil. *Check List* 5, 405–417.

Veloso, H.P. (1963). Os grandes clímaces do Brasil. III – Considerações gerais sobre a vegetação da região centro-oeste. *Memórias do Instituto Oswaldo Cruz* 61, 357–370.

Vestjens, W.J.M. (1973). Wildlife mortality on a road in New South Wales. *Emu* 73, 107–112.

Vieira, E.M. (1996). Highway mortality of mammals in Central Brazil. *Ciência e Cultura* 48, 270–272.

Vitt, L.J., Caldwell, J.P., Colli, G.R., Garda, A.A., et al. (2005). Uma

atualização do guia fotográfico dos répteis e anfíbios da região do Jalapão no Cerrado brasileiro. *Special Publications in Herpetology, Sam Noble Oklahoma Museum of Natural History* 2, 1–24.
Walther, B.A. & Morand, S. (1998). Comparative performance of species richness estimation methods. *Parasitology* 116, 395–405.

Accepted: 20 August 2014