EFFECTS OF LANDSCAPE CHARACTERISTICS ON ROADKILL OF MAMMALS, BIRDS AND REPTILES IN A HIGHWAY CROSSING THE ATLANTIC FOREST IN SOUTHEASTERN BRAZIL

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ABSTRACT

In North Hemisphere countries, collisions with large-sized mammals could cause serious accidents, including loss of human lives or substantial material damages for the driver. In contrast, in tropics, there is less large-sized wildlife hit by vehicles than small ones and thus the damages and human losses should be lower. However, the diversity of species killed by collisions with vehicles is higher in tropics, and thus the conservation issues become more relevant than security ones, specially near protected areas. Herein we propose a community approach to identify priority sites to apply road kill mitigation measures. This work aims to evaluate the effects of adjacent landscape characteristics on vertebrate roadkills. The study was done during three years in the BR-040 highway, from km 125.2 in Rio de Janeiro State to km 773.5 in Minas Gerais State, Southeastern Brazil. Along this 180.5 km stretch, BR-040 crosses two protected areas through the Brazilian Atlantic Forest mountains, whose main native vegetation cover is composed of tropical rain forest. This stretch of BR-040 is a 4-lane highway under management of a private company, called Concer. The Concer employees were trained by Dr. Cecilia Bueno, through her project, called "Wildlife Paths", to record roadkills 24h a day, resulting from a 50km/h speed on average. The landscape characteristics around each road kill were quantified (urban area, forest cover, herbaceous cover, crop fields) in three distances (1 km, 5 km and 10 km) to evaluate the effect of scale on models. The distance to the nearest river was also measured. Logistic regression models were designed using presence/absence of road kills as dependent variables and landscape characteristics as independent variables, which were selected by Akaike's Information Criterion. Almost three hundred road kills were recorded during the three-year study on the BR-040 highway, representing to 1.50 roadkills/km/year: 58% mammals, 33% birds and 9% reptiles. There were 72 species recorded, 40 species of birds, 24 of mammals and 8 of reptiles. River proximity and herbaceous vegetation cover were associated to most road killed vertebrate groups. For all species and for mammals, road kills were associated with river proximity, whereas for large and arboreal mammals, reptiles and owls, roadkills were associated to higher herbaceous vegetation cover. Birds road kill did not show a clear relation to landscape characteristics. The association between river proximity and road kill of all species and of mammals indicates that rivers may be a preferential route for them. In a mountain, river are located in valleys and represents food and water source, and also an easier way to move in forests. The relationship found between large and arboreal mammals, reptiles and owls with higher herbaceous vegetation cover could represent habitat for some groups and a matrix for others, but for both the highway crosses their habitat or their route in the matrix leading to road kill. Some mitigation measures were suggested and some already done, such as installation of signs, fences and underpasses.

Keywords: Atlantic Forest, conservation, vertebrates, tropics, Latin America.

INTRODUCTION

Collisions between vehicles and vertebrates have been studied in temperate countries for many decades (Forman et al. 2003, Seiler & Helldin 2006). In South America, studies on the impacts of roads have been developed only recently and there are few studies published, mostly in Brazil (for example, Pinowski 2005 in Venezuela, Attademo et al. 2011 in Argentina, and Vieira 1996, Coelho et al. 2008, Cáceres 2011, Dornas et al. 2012, Rosa & Bager 2012 in Brazil). In general, the road-kill vertebrate community in tropics is more diverse and small-sized than from temperate region, therefore the consequences of the collisions may be different, especially regarding security issues (Dornas et al. 2012, Farmer & Brooks 2012). In North Hemisphere countries, collisions with large-sized mammals often cause serious accidents, including loss of human lives or substantial material damages for the driver (Forman et al. 2003, Seiler 2005, Seiler & Helldin 2006, Huijser et al. 2009). On the other hand, there is less large-sized wildlife hit by vehicles in tropics than small ones and thus the damages and human losses should be lower. However, the diversity of species killed in collisions with vehicles is higher in tropics, and thus the conservation issues may become more relevant than security ones, specially in protected areas (Bager & Rosa 2012, Coelho et al. 2012, Dornas et al. 2012, Garriga et al. 2012).

In Brazil, there are estimates of 8.65 (±26.37) vertebrate road-kill/km/year, representing 14.7 (±44.8) million road-kill/year throughout Brazil's territory (Dornas et al. 2012). The vertebrate species more hit by vehicles are usually those more abundant (Cáceres 2011, Bager & Rosa 2012, Dornas et al. 2012), such as, the crab-eating fox (*Cerdocyon thous* Linnaeus, 1766) and the capybara (*Hydrochoerus hydrochaeris* Linnaeus, 1766; Dornas et al. 2012). Some of the largest road-killed mammals are the maned wolf (*Chrysocyon brachyurus* Illiger, 1815) and the jaguar (*Panthera onca* Linnaeus, 1758; Bueno & Almeida 2010; Dornas et al. 2012), which are included in the IUCN red list of threatened species (IUCN, 2012). The high species diversity usually found dead on roads in tropics is also a conservation concern, especially when threatened species are included. Most species have few road-kill records and thus may not represent a significant mortality rate in the population level. However, for rare species, some deaths on the road in a fragmented landscape may represent a threat of local extinction (Laurance et al. 2009).

Roads may affect wildlife populations through barrier effects, leading to reduction of local genetic diversity and isolating populations (Lesbarrères et al. 2006, Balkenhol & Waits 2009, Laurance et al. 2009). Wildlife crossings are one of the measures used to mitigate barrier effects and reduce wildlife road-kill, improving connectivity between habitats fragmented by roads (Corlatti et al. 2009, Laurance et al. 2009, Beckmann et al. 2010, Lesbarrères & Fahrig 2012). Thus, these crossings should not lead to ecological "dead-ends", but must link to a larger functional landscape and habitat complex that allows wildlife to disperse, move freely, and meet their daily and life needs now and in the future, including projected land-use changes (Clevenger & Ford 2010). Maps, road-kill data and GIS tools are useful to identify where to locate wildlife crossings and other types of mitigation (Clevenger et al. 2003, Clevenger & Ford 2010). Road-kill data alone is not enough to estimate wildlife movement areas and should be combined with habitat linkage mapping to improve this evaluation in order to choose the places where mitigation measures should be built (Clevenger et al. 2003, Clevenger & Ford 2010). Usually, considerations of wildlife crossing placement begin by determining the focal species or group (Clevenger & Ford 2010, Gunson et al. 2011). There are some differences in tropical landscapes that raise the need of some methodology changes to identify the crossings placement. In a high species richness and low abundance condition, it is necessary a community level approach gathering many species with different behavior and dispersal capacity. In tropics, land use and land cover changes in decades representing habitat loss and expansion of crops, pasture or urban areas (Soares-Filho et al. 2004, Carvalho et al. 2009, Freitas et al. 2010, Dobrovolski et al. 2011, Lira et al. 2012, Onojeghuo & Blackburn 2012, Southworth et al. 2012, Rosa et al. 2012) and then, there is a risk of building a wildlife crossing where in a near future could be an ecological "dead-end".

Herein we propose a community approach to identify priority sites to apply road kill mitigation measures. This work aims to evaluate the effects of adjacent landscape characteristics on vertebrate roadkills.

MATERIAL AND METHODS

Study area

The study was carried out in highway BR-040, in the 180.4 km section from km 125.2 in Rio de Janeiro State (22°48'02"S and 43°17'26"W) to km 773.5 in Minas Gerais State (21°38'34"S and 43°26'10"W), Southeastern Brazil (Figure 1). The surveyed section crosses nine municipalities: six in the state of Rio de Janeiro (Rio de Janeiro, Duque de Caxias, Petrópolis, Areal, Três Rios and Comendador Levy Gasparian), and three in Minas Gerais state (Simão Pereira, Matias Barbosa and Juiz de Fora).

The topography varies from the lowlands near Duque de Caxias city (19 m high, 22°47'09"S, 43°18'43"W), through the mountain range (about 1,000 m high) and Petrópolis city (838 m high, 22°30'18"S, 43°10'44"W) up to Juiz de Fora city (715 m high, 21°41'20"S, 43°20'40"W). Within this entire range, the road has paved 2-lane in each direction, and for the stretch crossing the mountain range, the 2-lane going up and the 2-lane going down run separately. Thus, the road is divided in 2-lane going up and 2-lane going down from km 102 at Duque de Caxias municipality up to km 72 at Petrópolis municipality, where it crosses the Biodiversity Corridor of Serra do Mar. In addition, from km 125.2 to km 102 in Rio de Janeiro State, the road has 2-lane in each direction. Similarly to the last stretch from km 72 to km 0 (in Rio de Janeiro State) and km 828 to km 773.5 (in Minas Gerais State) with 2-lane in each direction.

The larger tropical rain forest remnants constitutes the Biodiversity Corridor of Serra do Mar, encompassing two natural reserves: Petrópolis Protected Area (Área de Proteção Ambiental de Petrópolis) and Tinguá Biological Reserve (Reserva Biológica do Tinguá). Most adjacent landscape of BR-040 is composed by herbaceous cover (pasture and grasslands, 42.7%), followed by forest cover (29.9%) and urban areas (21.6%, **FIGURE 1**).

The BR-040 stretch between Petrópolis and Juiz de Fora was constructed in 1861 by Brazil's Emperor Dom Pedro II (Neto, 2001). The stretch between the cities of Petrópolis and Rio de Janeiro was constructed in 1928 by President Washington Luís, and in 1931, it was the first paved road in Brazil. Since 1996, the BR-040 stretch from Rio de Janeiro to Juiz de Fora has been under the authority of a private company, Concer. The mean traffic volume on the BR-040 is more than 39,046 vehicles/day (Céu-Aberto/Concer 2010).

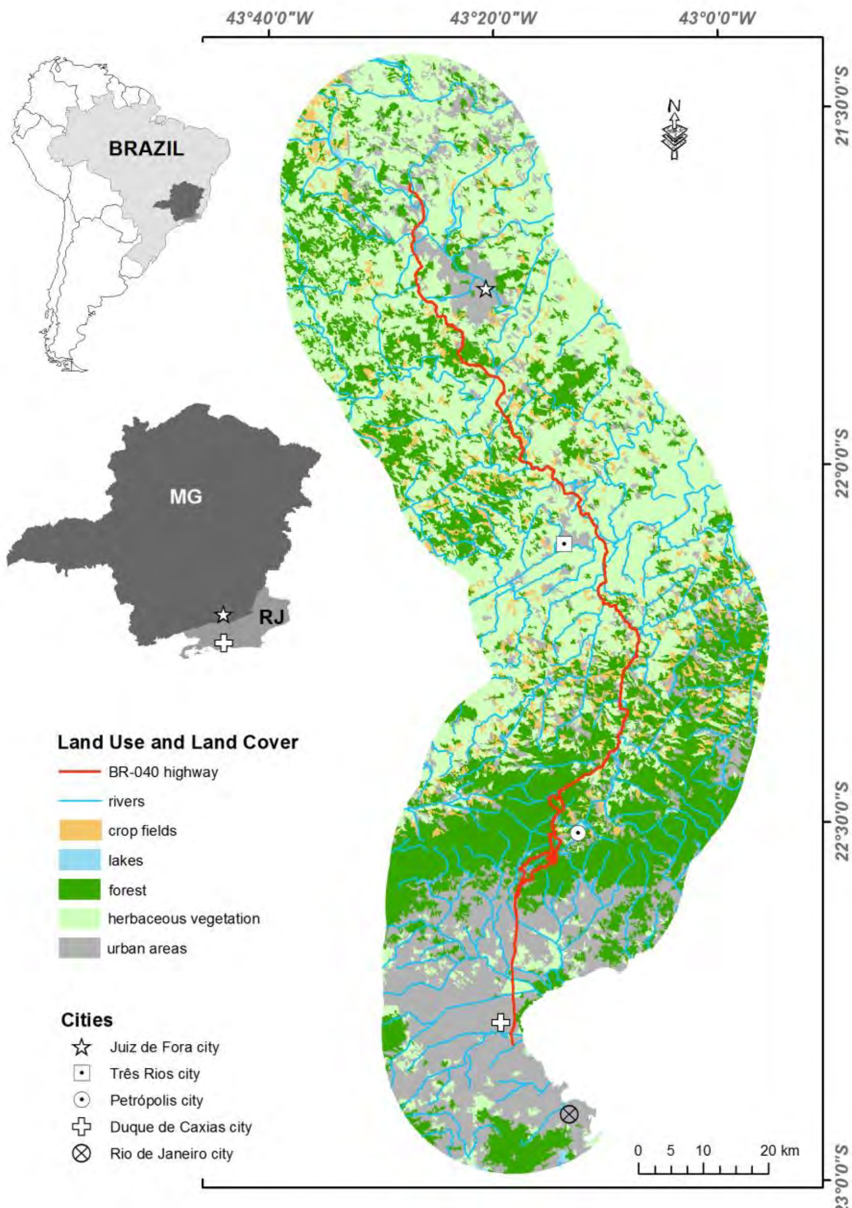

FIGURE 1. Study area: BR-040 highway from the km 125.1, near Duque de Caxias city in Rio de Janeiro State (RJ) to the km 773.5, near Juiz de Fora city in Minas Gerais State (MG), Southeastern Brazil. Landscape characteristics 20-km around BR-040 highway are shown in detail.

Data collection

We recorded wildlife killed on the road daily, for 3 years (from April 2006 to April 2009), along 180.4 km on BR-040 between the cities of Rio de Janeiro and Juiz de Fora. We do not analyzed temporal variation in this study and decided to aggregate all 3 years data because of sample size matters. After training, CONCER workers collected road-kill animals found on the highway in 24/7 basis, with an estimated average speed of 50 km/h. After taxonomic identification, carcasses were deposited on National Museum of Rio de Janeiro collection.

Data analysis

A map of land use and land cover of the studied area was made by means of Landsat images of 2002, with a 1:250,000 scale and accuracy of 86.39% (IESB, 2007). Considering the scale used, the landscape did not change significantly in a decade, thus the landscape map represents well the time when road-kill data was collected. The landscape characteristics around each road-kill were quantified: urban area, forest cover, herbaceous cover, and crop fields. In order to evaluate the effect of scale on models, we used three distances from road-kill to measure landscape characteristics at 1 km, 5 km and 10 km. The distance to the nearest river was also measured. We sorted out the same number of road-kill along the highway to represent absences in logistic regression models. The same landscape characteristics were measured up to 1 km, 5 km and 10 km from each absence point. All landscape measures were done using ArcGIS version 9.3.1. Logistic regression models were generated using presence/absence of road-kill as dependent variables and landscape characteristics as independent variables (**TABLE 1**) and model selection was performed using Akaike's Information Criterion (AIC; Burnham & Anderson, 2002). This landscape analysis was done for all species together and for the following groups and sub-groups: mammals, large mammals, arboreal or volant mammals, reptiles, all birds, and owls (**TABLES 2, 3 and 4**).

TABLE 1. Competing models used in Akaike's Information Criterion (AIC) selection, where dependent variables were presence or absence of road-kill in the BR-040 highway.

Model type	Model code	Independent variables
Habitat	H1	Forest cover
	H2	Herbaceous vegetation cover
	H3	Distance of the nearest river
Land use	L1	Agriculture area
	L2	Urban area
Road	R1	Road density
Reference	A1	1
	A2	Buffer distance

RESULTS

We recorded 297 road-kill vertebrates during the three-year study on the BR-040 highway, representing 0.518 road-kill/km/year (**TABLE 2**). Most of them were mammals (60%), followed by birds (31%) and reptiles (9%; Table 2). There were 70 species recorded, most of them birds (37 species, 53%), followed by mammals (24, 34%) and reptiles (9, 13%; Table 2). The most road-killed species were the opossum *Didelphis aurita* (36 individuals), the capybara *Hydrochoerus hydrochaeris* (30), the sloth *Bradypus variegates* (14), the porcupine *Sphiggurus insidiosus* (14), and the owls *Tyto alba* (14) and *Rhinoptynx clamator* (12; **TABLES 2, 3 and 4**).

Herbaceous vegetation has showed a high negative correlation to forest (**TABLE 5**). River proximity and herbaceous vegetation cover were associated to the most road-killed vertebrate groups (**TABLE 6**). For all species and for mammals separately, road-kill was associated with river proximity, whereas for large and arboreal mammals, reptiles and owls, road-kills were associated to higher herbaceous vegetation cover (**TABLE 6**). The best models of almost all groups showed a better performance than the reference model (intercept). The exception was the model to explain bird road-kill that the reference model showed the best performance, indicating that birds road-kill did not show a clear relationship with landscape characteristics. For birds, other models were also considered relevant, the ones including: (1) less road density, and (2) less urban area (**TABLE 6**).

TABLE 2. Road kill records of mammal species (n = 178) during three years on BR-040.

Sub-groups	Species	Records
Large mammals (records = 64)	*Hydrochoerus hydrochaeris*	30
	Bradypus variegatus	14
	Cerdocyon thous	10
	Chrysocyon brachyurus	6
	Leopardus pardalis	2
	Myocastor coypus	1
	Puma yagouaroundi	1
Arboreal or Volant mammals (records = 20)	*Callithrix jacchus*	11
	Alouatta guariba	3
	Callithrix penicillata	3
	Artibeus lituratus	2
	Guerlinguetus aestuans	1
Other mammal species (records = 94)	*Didelphis aurita*	36
	Sphiggurus insidiosus	14
	Sphiggurus villosus	10
	Galictis cuja	7
	Sylvilagus brasiliensis	7
	Tamandua tetradactyla	6
	Procyon cancrivorus	5
	Cuniculus paca	3
	Dasypus novemcinctus	2
	Philander frenatus	2
	Cavia aperea	1
	Nasua nasua	1

Classification based on Reis et al. (2010).

TABLE 3. Road kill records of bird species (n = 92) during three years on BR-040.

Sub-groups	Species	Records
Owls (records = 34)	*Tyto alba*	14
	Rhinoptynx clamator	12
	Athene cunicularia	2
	Otus athicapillus	2
	Pulsatrix koeniswaldiana	2
	Ciccaba virgata	1
	Otus choliba	1
Other birds (records = 58)	*Piaya cayana*	6
	Columba livia	5
	Aratinga leucophthalmus	4
	Coragyps atratus	4
	Crotophaga ani	3
	Selenidera maculirostris	3
	Tyrannus savana	3
	Buteo magnirostris	2
	Colaptes campestris	2
	Crypturellus parvirostris	2
	Molothrus bonariensis	2
	Penelope obscura	2
	Streptoprocne zonaris	2
	Turdus rufiventris	2
	Aramides saracura	1
	Baryphthengus ruficapillus	1
	Cariama cristata	1
	Colaptes melanochloros	1
	Columbina talpacoti	1
	Gallinula chloropus	1
	Leptotila rufaxilla	1
	Micrastur ruficollis	1
	Milvago chimachima	1
	Nictydromus albicollis	1
	Polyborus plancus	1
	Ramphastus vitellinus	1
	Rupornis magnirostris	1
	Tangara cayana	1
	Tersina viridis	1
	Tyrannus melancholicus	1

Classification based on Reis et al. (2010).

TABLE 4. Road kill records of reptile species (n = 27) during three years on BR-040.

Sub-groups	Species	Records
Crocodiles (records = 2)	*Caiman latirostris*	2
Lizards (records = 10)	*Tupinambis merianae*	10
Snakes (records = 15)	*Oxyrhopus clathratus*	5
	Bothrops jararacussu	3
	Erythrolamprus aesculapii venustissimus	2
	Spilotes pullatus	2
	Bothrops jarara	1
	Caudisona durissa	1
	Chironius bicarinatus	1

Classification based on Reis et al. (2010).

TABLE 5. Pearson correlation coefficients among independent variables, using all road-kill records: herbaceous vegetation cover, agriculture area, urban area, forest cover, distance of the nearest river and road density.

	Agriculture	Urban area	Forest	Distance of the nearest river	Road density
Herbaceous vegetation	0.159**	-0.441**	-0.882**	0.022	-0.087**
Agriculture		-0.339**	-0.197**	-0.092**	-0.016
Urban area			0.006	0.061*	-0.103**
Forest				0.013	0.154**
Distance of the nearest river					-0.004

* $p < 0.05$; ** $p < 0.01$

DISCUSSION

The road-kill rate was lower than found by the average estimated to Brazil, 8.65 (±26.37) road-kill/km/year (Dornas et al. 2012). However, the species richness was higher than the average found in other Brazilian studies (mean = 39.30, SD = 26.63), but lower than one study done in Pampa (83 species, Santana 2012) and in Atlantic Forest (92 species, Coelho et al. 2008), both in southern Brazil. This high species diversity hit by vehicles is a great concern for conservation, especially in tropics where land use expansion for food and energy production is a priority for economical development issues, leading to road expansion and improvement of the older roads, especially in Amazon (Soares-Filho et al. 2004, Fearnside 2007). In general, the most road-killed species are the most abundant and with broad distribution (Cáceres 2011, Bager & Rosa 2012, Dornas et al 2012). A few large mammals (although smaller than large North American and European mammals) were killed by collision with vehicles, such as *Hydrochoerus hydrochaeris*, *Cerdocyon thous* and *Chrysocyon brachyurus*, and could cause serious accidents, including loss of human lives or substantial material damages for the driver (Forman *et al*. 2003, Huijser *et al*. 2009).

The association between river proximity and road-kill of all species and of mammals indicates that rivers may be a preferential route for them. In a mountain, rivers located in valleys represent food and water source, and also an easier way to move in forests. Elongated stream passages seem to be a more effective mitigation measure for multi-species approach (Lesbarreres & Fahrig 2012), and thus could be a solution to improve connectivity and reduce road-kill in mountain tropical forests, where rivers may be a preferential route. Forest cover was not related to road-kill. Probably, river as a preferential route work as an attractor to individuals crossing the highway, and thus forest cover become less relevant to explain road-kill. However, in forests located in landscapes with less relief variation we expect that forest cover could be more relevant as preferential routes and thus to predict road-kill events.

The positive relationship of large and arboreal mammals, reptiles and owls with herbaceous vegetation cover could be due to its use as habitat for some groups and as matrix for others. Grasslands and open herbaceous vegetation are habitat for some species of large mammals, such as *Chrysocyon brachyurus* and *Hydrochoerus hydrochaeris*.

However, since forest is the habitat of arboreal mammals the herbaceous vegetation is a matrix for them. Arboreal mammals can cross matrix to reach other forest fragment and when cross the highway are vulnerable to be hit by vehicles. Owls and bats, even those forest species, can move through matrix and when flying at lower heights, they can be hit by vehicles, especially in highway stretches with less curves and relief variation where vehicles could reach higher speed. Reptiles use open areas with higher temperatures for thermoregulation and they could find this condition in areas with higher herbaceous vegetation cover.

TABLE 6. Regression models selected by AICc (Evidence ≤ 2) to explain road-kill of each species sub-group. Results of reference model (A1) is also showed.

Dependent Variables	Independent Variables	k	N	AICc	ΔAIC	wAIC	Evidence
All species	- distance of the nearest river	1	1704	2318.3	0.0	0.997	1.0
	intercept	1	1704	2364.2	45.9	0.000	9.3E+09
Mammals	- distance of the nearest river	1	975	1321.7	0.0	1.000	1.0
	intercept	1	975	1353.6	31.9	0.000	8.5E+06
Large mammals	+ herbaceous vegetation cover	1	306	300.1	0.0	1.000	1.0
	intercept	1	306	426.2	126.2	0.000	2.5E+27
Arboreal or Volant mammals	+ herbaceous vegetation cover	1	114	113.9	0.0	0.997	1.0
	intercept	1	114	160.1	46.2	0.000	1.1E+10
Reptiles	+ herbaceous vegetation cover	1	144	150.1	0.0	1.000	1.0
	intercept	1	144	201.7	51.5	0.000	1.6E+11
All birds	intercept	1	558	775.6	0.0	0.237	1.0
	- road density	1	558	776.2	0.6	0.173	1.4
	- urban area	1	558	776.9	1.3	0.124	1.9
Owls	+ herbaceous vegetation cover	1	204	166.6	0.0	1.000	1.0
	intercept	1	204	284.8	118.3	0.000	4.8E+25

where: All birds excluded owls (see Table 2); k = number of parameters; AICc = Akaike Information Criterion for small samples; ΔAIC = difference between the AICc of a given model and that of the best model; wAICc = Akaike weights (based on AIC corrected for small sample sizes).

Birds do not show a clear relationship between road-kill and landscape characteristics. This group included many species with different habitat and matrix perception, some forest species and others occur in open vegetation areas. Due to high diversity and low abundance of road-killed birds it becomes difficult to find a clear relationship with landscape characteristics. However, a weak relationship was found with less road density and less urban area near highway. Thus, road-kill of birds occurred far from cities and in a highway stretch with less curves. Many bird species do not occur in urban areas leading to a low diversity of birds in cities (Chace & Walsh 2006, McKinney 2008). Lesser curves lead to higher speed and higher chance of collision to birds flying at low height crossing the highway.

The low aggregation of road-kill events and the association between river proximity and road-kill of all species indicate that underpasses when rivers cross the highway may be a good mitigation measure. However, there are some restrictions to apply this proposal related to Brazilian transportation and environment agencies, and to additional costs to highway manager. Culverts modified to wildlife underpasses were proposed in the report of environmental impact assessment (EIA); however the Brazilian environment agency did not allow them. For them, the effectiveness of this mitigation measure is unknown and could be a risk for wildlife because hunting pressure. The highway manager agreed to install some fences where were many capybaras killed by vehicle collision. Fences are cheaper than underpasses, especially because they were installed some hundred of meters of fences near the river blocking capybaras when they tried to cross the road. Some preliminary analysis showed that capybaras road-kill events were reduced in this small stretch of the highway. Another mitigation measure suggested in the EIA report and agreed by highway manager was speed bumps and traffic enforcement camera to prevent wildlife-vehicles collision where there were more human causalities. However, the transport agency took some years to allow the installation of speed limit devices. Thus, bureaucracy was the other restriction to implement mitigation measures. Road ecology in Brazil is a novelty in academic studies and there is a great effort to spread the news to government agencies, transportation and environment companies, and the public in general. Differently to temperate regions, tropics have smaller animals than large ones that cause more severe accidents with many human causalities and financial damages (Huijser et al. 2009). We believe that the community approach focusing in biodiversity loss combined to risk of severe accidents due collisions to some large vertebrate species could be a way to get attention to decision makers and groups associated to transport and environment.

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