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HOW LANDSCAPE FEATURES INFLUENCE ROAD-KILL OF THREE SPECIES OF MAMMALS IN THE BRAZILIAN SAVANNA?

Simone Rodrigues de Freitas[1,*], *Adriana Nepomuceno de Oliveira*[2], *Giordano Ciocheti*[2], *Marcus Vinícius Vieira*[3] and *Dalva Maria da Silva Matos*[2]

[1] *Universidade Federal do ABC, Avenida dos Estados, 5001, Bloco A, sala 631-3, Santo André, SP, Brasil, CEP: 09210-170. E-mail: simonerfreitas.ufabc@gmail.com*
[2] *Departamento de Ecologia e Biologia Evolutiva, CCBS, Universidade Federal de São Carlos, Programa de Pós-Graduação em Ecologia e Recursos Naturais Rodovia Washington Luiz, Km 235, Caixa Postal 676, São Carlos, SP, Brasil, CEP: 13565-905. E-mail: adriana.neoliveira@gmail.com, gciocheti@gmail.com, dmatos@power.ufscar.br*
[3] *Universidade Federal do Rio de Janeiro, Lab de Vertebrados, Depto de Ecologia, CP 68020, Ilha do Fundão, Rio de Janeiro, RJ, Brasil, CEP 21941-590. E-mail: mvvieira@biologia.ufrj.br*

ABSTRACT

Roads are one of the main threats to mammal species conservation. Identifying relationships between landscape and road-kill patterns is necessary to build predictive models and to propose mitigation measures, particularly in heterogeneous landscapes. We choose three species of medium-sized mammals with high dispersal capacity and opportunistic habitat use as representatives to understand which landscape features affect road-kills: the crab-eating fox *Cerdocyon thous*, the maned-wolf *Chrysocyon brachyurus*, and the hare *Lepus europaeus*. The study was done over two consecutive years on the SP-225 highway in the State of São Paulo, southeastern Brazil. Road-kill data were collected on a daily basis, every three hours, by car travelling at 50-60 km/h. We used a logistic regression considering, as dependent variable, the occurrence of road-kills for each species, and as independent variables, the following landscape features: sugarcane fields cover, pasture cover, native vegetation cover, forestry cover, orange groves cover, urban area, and distance to the nearest river. Three buffer sizes were created around each road-kill occurrence to evaluate the effect of spatial scale. Model selection using Akaike Information Criterion with correction for small samples (AICc) showed that the road-kill incidence of *Chrysocyon brachyurus* was positive associated to urban area at larger scale, and for *Cerdocyon thous* and *Lepus europaeus* was found a positive association to forestry cover at different scales. For *C. thous* and *L. europaeus*, some models worth interpreting included water bodies area, distance to the nearest river and sugarcane fields cover. Matrix permeability and river proximity could be used to indicate sites to apply mitigation measures to road-kill for these mammal species in the Brazilian Savanna.
Keywords: conservation, highway, matrix, river, road mortality, Cerrado.

INTRODUCTION

Environmental disruption caused by roads are one of the major concerns for conservationists because mortality caused by collisions with vehicles increases the loss of biodiversity and environmental disruption results in genetic isolation at the population level (Goosem 2007, Benítez-López *et al.* 2010, Roger *et al.* 2011, Van der Ree *et al.* 2011). The risk of being killed is mostly related to the animal agility and traffic volume of the road (Forman *et al.* 2003, Goosem 2007, Laurance *et al.* 2009, Cáceres 2011, Grilo *et al.* 2011). Vulnerability is species dependent and in the case of mammals, body size, reproductive rate, diet and dispersal capacity are important characteristics that help to identify which species are most vulnerable (Grilo *et al.* 2009, Barthelmess and Brooks 2010, Cáceres 2011, Rytwinski and Fahrig 2011). However, high rates of road-kills of a particular species do not necessarily imply a threat to its survival, as it may well indicate that the species is abundant in the area. This is the case of herbivores which typically have higher densities than carnivores and omnivores (Barthelmess and Brooks 2010, Cáceres *et al.* 2010), such as *Cerdocyon thous* (Linnaeus, 1766) and *Hydrochoerus hydrochaeris* (Linnaeus, 1766) (Fahrig and Rytwinski 2009, Cáceres *et al.* 2012, Dornas *et al.* 2012). Contrarily, low rate of road-kill may represent a significant loss in populations of endangered or threatened species, such as *Myrmecophaga tridactyla* (Linnaeus, 1758) and *Puma concolor* (Linnaeus, 1771) (Forman and Alexander 1998, Laurance *et al.* 2009, Dornas *et al.* 2012).

In general, larger animals have wide home ranges and consequently are more likely to find roads than smaller animals (Forman and Alexander 1998, Ng *et al.* 2004, Grilo *et al.* 2009). Also, herbivores are attracted by grasses and seeds dropped by trucks along the roadsides while omnivorous are attracted by garbage and carcasses of other hit animals along the highways (Forman *et al.* 2003). In this sense, in heterogeneous and fragmented landscapes large and medium-sized mammals explore the landscape as a whole not restricting their exploration to a single vegetation type. Thus, a landscape approach is needed to understand the spatial pattern of road-kills, and associated environmental factors (Lyra-Jorge *et al.* 2008).

There is a global concern about the threats and urgency of conservation strategies for mammals, and vehicles collisions mortality has a relevant impact on terrestrial vertebrates, particularly in disturbed habitats (Forman and Alexander 1998). However, simple estimates of the number of killed animals do not provide useful information for planning strategies to decrease road-kills. It is important to identify where animals are most likely to be killed (Clevenger *et al.* 2003, Ramp *et al.* 2005, Taylor and Goldingay 2010, Van der Ree *et al.* 2011), and which factors attract animals to these sites. These actions are particularly important in heterogeneous landscapes, such as those found in the tropics, where land use and land cover patterns are diverse and change under influence of roads (Freitas *et al.* 2010).

The Brazilian savanna, hereafter Cerrado, has been threatened for decades by the expansion of urban and agriculture areas, construction of roads and dams (Carvalho *et al.* 2009). Nowadays, there are only small Cerrado fragments scattered into different matrix types (Carvalho *et al.* 2009, Ganem *et al*. 2013). It is well known that fragmentation changes landscape structure by reducing connectivity and persistence of small and isolated populations, especially for species with low matrix tolerance (Henle *et al.* 2004). Dispersal capacity can increase the chances of survival by decreasing isolation and competition in local populations, but also increases mortality risks when a dispersing animal has to deal with roads and traffic. Therefore, understanding how species move through the landscape, and identifying the relationship between landscape and road-kill pattern is necessary to design predictive models and management strategies to minimize the mortality rates of wildlife (Malo *et al.* 2004, Clevenger and Ford 2010, Taylor and Goldingay 2010).

Mammals may respond in different ways to roads and traffic, for example, avoiding roads, atmospheric emissions and disturbances caused by roads; attempting to escape oncoming vehicles; and being attracted to roads (Jaeger *et al.* 2005, Rosa and Bager 2013). Road avoidance behavior decreases the rates of mortality but also decreases connectivity, and the emissions and disturbances reduce the quality of habitats near roads. The ability to avoid vehicles is a behavior that has a positive impact as it decreases the risks of being hit. Finally, the worst situation occurs when animals actually are attracted to roads, which increases the mortality risk. Thus, habitat generalist mammals with high dispersal capacity can be used as a model to understand the most abundant species killed by vehicle collision and its relationship to landscape features.

Considering the high rate of fragmentation of the Brazilian Savanna, locally called Cerrado, and the associated increase in the number of roads with economic development in Brazil, we evaluated the relationship between landscape features and road-kill of medium-sized mammals along a highway. We chose three focal species (*sensu* Lambeck 1997) commonly abundant in the region, with different home range sizes and dispersal capacities: the canid *Cerdocyon thous*, the maned-wolf *Chrysocyon brachyurus* (Illiger, 1815), and the hare *Lepus europaeus* (Pallas, 1778). The highway of study has homogeneous road traffic, so we expect that road-kill could be determined by differences in landscape features and matrix permeability for each species.

MATERIAL AND METHODS

Study area

We carried out this study in the SP-225 highway, from Km 75 to Km 235, between the municipalities of Itirapina (22°15'10" S and 47°49'22" W) and Jaú (22°17'47" S and 48°33'28" W), in the Northeast region of the State of São Paulo, Brazil (Fig. 1). The cities along studied site are small: Jaú has 131,040 inhabitants in 2010; Brotas 21,580 and Itirapina 15,524 inhabitants (IBGE 2014). The SP-225 highway is a two-lane, paved road, often bordered by invasive grasses. The climate has two distinct seasons, a rainy season from October to March, and a dry season from April to September (Durigan *et al.* 2007, Carvalho *et al.* 2009). This road crosses three protected areas: the Experimental Station of Itirapina, the Experimental Station of Jaú, and the Ecological Station of Itirapina. Remnants of the original vegetation comprise about 21.5% of the total sampled area, composed by different vegetation types of the Brazilian Savanna, locally called Cerrado, seasonally semideciduous and riparian forests, where several endemic species persist, such as the birds *Nothura minor* (Spix, 1825), *Rhea americana* (Linnaeus, 1758), *Sicalis flaveola* (Linnaeus, 1766), *Cariama cristata* (Linnaeus, 1766), and the mammals *Chrysocyon brachyurus* (Illiger, 1815), *Ozotoceros bezoarticus* (Linnaeus, 1758) and *Speothos venaticus* (Lund, 1842) (Scariot *et al.* 2005, Motta-Junior *et al.* 2008, Bocchiglieri *et al.* 2010). The matrix where fragments are scattered contain different crops, mostly sugarcane (38.3%), *Pinus* sp. (8.5%), orange (5.2%), as well as pasture for cattle (22.0%) (Fig. 1).

Road-kill Data

Data on mammal road-kills were collected daily, every three hours, by car driving at 50-60

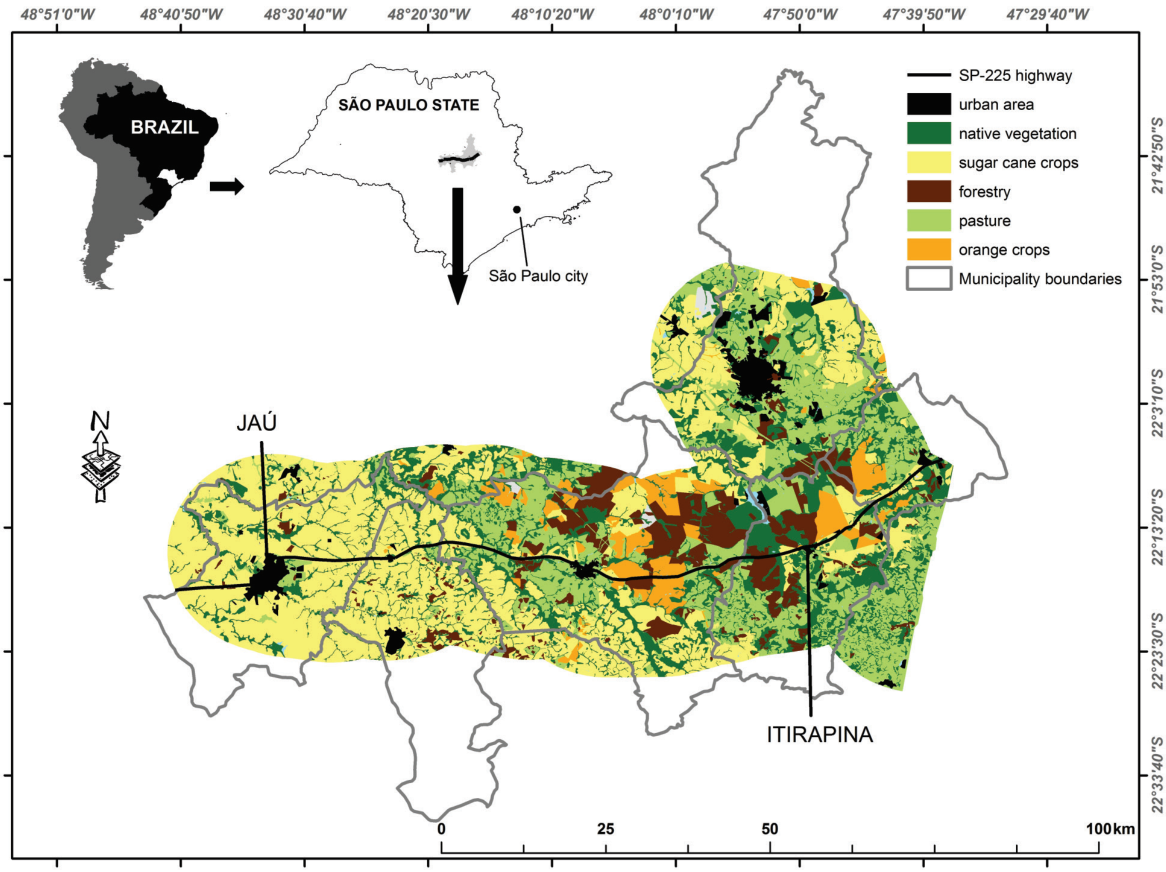

Figure 1. SP-225 highway (black line) in São Paulo State, southeastern Brazil, showing the cities of Jaú and Itirapina, land use and land cover around the highway (15 km).

km/h, from January 2006 to February 2008. These data were collected in partnership with employees of the OHL Group Brazil, a private company responsible for the maintenance of this highway. In each road-kill occurrence they recorded the exact location of the accident (km and geographic coordinates), date, time, common name of the animal, and a photograph of the killed animal was taken, and used later to confirm identification of the species by experts. Animal carcasses were removed from the road after being recorded.

Species description

The three species of medium-sized mammals have high dispersal capacity and are habitat generalists, and thus, they do not avoid roads and are vulnerable to be killed by vehicle collision. *Cerdocyon thous*, the crab-eating fox, is a generalist canid found in different vegetation types of the Cerrado and also in the Atlantic Forest, from grasslands to dense forests (Trovati *et al.* 2007). Its home range area varies from 5 to 10 km^2 (Bueno and Motta-Junior 2004), and the mean longest distance covered was 793 m (Faria-Corrêa et al. 2009). *Chrysocyon brachyurus*, the maned wolf, is an omnivore species typical of open habitats such as grasslands and other open vegetation types of the Cerrado (Dietz 1985, Vynne *et al*. 2011, Massara *et al*. 2012). Its home range area varies from 21.7 to 115 km^2 (Carvalho and Vasconcellos 1995, Bueno and Motta-Junior 2004, 2006, Jácomo *et al*. 2009). Lion *et al*. (2011) showed that some protected areas from the Brazilian Federal District harbor genetically healthy maned wolf populations, i.e. there was no genetic structuring for these populations, indicating a high dispersal capacity. The maned wolf is an endemic species of the Brazilian Savanna biome and is considered threatened by extinction (IUCN 2013). *Lepus europaeus*, the hare, is an exotic, in some places invasive, generalist herbivore, hence persistence of populations and extinction risks are not of concern (Kufner *et al.* 2008, Lantschner *et al.* 2013). However, it can be used to determine if there are common landscape features associated road-kills in mammals in general, native and exotic. Mean home range is 0.21 km^2 (Rühe and Hohmann 2004), and median natal dispersal distances up to 1,615 m (Bray et al. 2007). *Lepus europaeus* is attracted to the edges of the road increasing its risk of road-kill and of hare's predators (Roedenbeck and Voser 2008, Barrientos and Bolonio 2009).

Analysis

Based on a satellite image (CBERS 2, HRC sensor) with 4 meters of spatial resolution, we produced a map of land use and land cover covering 15 km around the highway. We made the landscape classification manually, using the ArcGIS 9.2 software (ESRI 2010), with 87% accuracy comparing field observation to the classified map. The map produced had six classes of landscape features: sugarcane fields, pasture, native vegetation, forestry (*Pinus* sp. plantation), orange groves, and urban area. Native vegetation class included different vegetation types of the Cerrado (grassland, swamp grassland, woody grassland, savanna, woody savanna), seasonally semideciduous and riparian forests because the aim was to evaluate whether there is an association between road-kill and any type of native vegetation.

To evaluate the effect of spatial scale on road-kill occurrence for each species, three buffer sizes were created around each road-kill occurrence using distances of 1 km, 5 km, and 10 km. Buffer distances were based on the ecology and behavior of the particular species (Ramp *et al.* 2005). The estimates of home range area for the studied species were considered to select the buffer distances. We expect that species with larger home range use larger areas of the landscape and thus larger buffer size could represent the scale and grain perceived by the species. We considered that 10 km around the road-kill event is the larger distance encompassing the landscape feature that could influence the animal route to the crossing site along the highway.

We modeled the effect of landscape features on incidence of road-kills using a logistic regression for each species, with presence/absence of road-kills as the dependent variable. Absence points of road-kills were obtained by randomly selecting points along the highway, in the same number as the number of presence points. The random selection was done converting lines (highway) in points, extracting the coordinates of these points, randomly sorting these points, and then selecting the first absence points up to the same amount of presence points. Landscape features were measured within each buffer, both in presence and absence points. We used the relative area (%) of each class of landscape cover within each buffer (1, 5 and 10 km), and the distance to the nearest river as independent variables, totalizing 22 models (Table 1). The generalized linear models (GLM) were fitted assuming a binomial distribution and logit as a link-function, in R 2.14.1 (R Development Core Team. 2011). Model selection was performed using Akaike's Information Criterion with correction for small samples (AICc; Burnham and Anderson 2002). To rank the best models and evaluate their performance, we used the AICc weight (*w*AICc) and the evidence ratio (wi_max / wi_i; Burnham and Anderson 2002). The best model has the lower evidence ratio (Evidence = 1.0). Some models with higher evidence ratio will be considered and discussed if they differ from the best model by at least 2 AICc units (ΔAICc $\leq$ 2.0). We included one null model with only a constant (intercept = 1) as independent variable, representing factors that are not directly related with landscape features (Table 1).

RESULTS

From January 2006 to February 2008, 32 *Cerdocyon thous*, 22 *Lepus europaeus* and 10 *Chrysocyon brachyurus* were killed by vehicle collisions on the SP-225 highway, between Km 75-235. The landscape characteristic selected to explain road-kill events for each species was different: a positive association to urban area for *Chrysocyon brachyurus*, and a positive association to forestry cover for *Cerdocyon thous* and for *Lepus europaeus* (Table 2). However, all selected landscape characteristics represent that road-kill events are more likely to occur in matrix types, such as forestry or urban area, and do not represent habitat of these species, such as native vegetation (Table 2). In addition, the best models included different scales: for *Chrysocyon brachyurus* and *Cerdocyon thous* included the large scale (10 km), whereas for *Lepus europaeus* included the intermediate scale (5 km; Table 2).

For *Cerdocyon thous* and *Lepus europaeus*, some models had much less support, but still worth interpreting because they differ from the best model by at least 2 AICc units (ΔAICc $\leq$ 2.0; Table 2). *Cerdocyon thous* road-kill events were also positively associated to water bodies area at large scale and negatively to distance to the nearest river (Table 2). *Lepus europaeus* road-kill events were negatively associated to distance to the nearest river and also negatively associated to sugarcane fields cover in the large scale (Table 2).

DISCUSSION

The landscape analysis revealed that road-kill records were related to matrix use by species,

Table 1. Competing models of the effect of landscape features on the incidence of road-kills of three species of mammals along SP-225 highway, Brazil. Presence/absence of road-kills was the dependent variable in all models. The buffer sizes used were 1, 5 e 10 km.

Independent variables	Unity
Distance to the nearest river	m
Native vegetation cover for each buffer size	%
Pasture cover for each buffer size	%
Orange groves cover for each buffer size	%
Sugarcane fields cover for each buffer size	%
Forestry cover for each buffer size	%
Water bodies area for each buffer size	%
Urban area for each buffer size	%
Null model (Intercept = 1)	-

Table 2. Ranking of the models for road-kill incidence of *Chrysocyon brachyurus* (n=10), *Cerdocyon thous* (n=32) and *Lepus europaeus* (n=22) as a function of landscape features, based on Akaike Information Criterion corrected for small samples (AICc). The best model is marked by an asterisk. Only models with ΔAIC ≤ 2.0 and the null model are showed. The positive or negative sign before independent variable indicates the effect direction.

Dependent variable	Independent variable	k	AICc	ΔAICc	wAICc	Evidence
Chrysocyon	+ Urban area for 10 km buffer	3	23.05	0.00	0.762	1.0*
	null	2	31.44	8.39	0.011	66.5
Cerdocyon	+ Forestry cover for 10 km buffer	3	85.89	0.00	0.302	1.0*
	+ Water bodies area for 10 km buffer	3	87.18	1.29	0.159	1.9
	- Distance to the nearest river	3	87.80	1.91	0.116	2.6
	null	2	91.14	5.25	0.022	13.8
Lepus	+ Forestry cover for 5 km buffer	3	60.18	0.00	0.271	1.0*
	- Distance to the nearest river	3	61.48	1.30	0.141	1.9
	- Sugarcane fields cover for 10 km buffer	3	62.03	1.85	0.108	2.5
	null	2	63.63	3.45	0.048	5.6

where: intercept = 1 (the null model); k = number of parameters; ΔAICc = difference between the AICc of a given model and that of the best model; *w*AICc = Akaike weights (based on AIC corrected for small sample sizes); Evidence = the evidence ratio.

identifying their preferential routes across more permeable matrix types, and the scale is relevant. For *Chrysocyon brachyurus*, the maned wolf, urban area in the large scale (10 km) was associated to road-kill indicating the use of the urban matrix. For *Cerdocyon thous*, forestry was the most relevant parameter to explain road-kill, followed by water bodies, both in the large scale, and proximity of river, highlighting the importance of water source and use of forestry matrix. For *Lepus europaeus*, forestry in the intermediate scale (5 km) was the most relevant to its road-kill, followed by proximity of river and a negative association to sugarcane in the large scale indicating the importance of water source, use of forestry matrix and avoidance to sugarcane matrix. The association to different scales, particularly between different matrix types for the same species, showed that landscape analysis should consider different scales not only considering species dispersal capacity but also different relations between species and landscape features.

The association between road-kills of *Chrysocyon brachyurus* and urban matrix is unexpected because this endangered species usually inhabits the grasslands and scrub forests of central South America (Dietz 1985). It is important to consider that the studied area is manly rural, covered by agriculture and pasture, and urban areas are small-sized cities. Thus, this positive association between road-kill of *Chrysocyon brachyurus* to urban areas may have a threshold for larger cities, that is, we expect a negative association in landscapes where urban areas are a predominant feature or there are larger cities. In a rural landscape context, maybe the maned wolf uses urban matrix only for dispersal, which may provide more resources surrounding parks (Vynne et al. 2011). The maned wolf is considered a generalist species occurring in different land cover types, especially open vegetation types of Cerrado, and different land use types, such as near buildings and roads at night, but avoiding tropical forest remnants (Coelho *et al.* 2008, Massara *et al.* 2012). In a Cerrado landscape, *C. brachyurus* showed an association with edge density of native vegetation, indicating its low sensitivity to landscape change or disturbance (Lyra-Jorge *et* *al.* 2010). On a geographic scale, *C. brachyurus* has been expanding its distribution due to forest fragmentation and conversion of forest to open vegetation for different land uses (Santos *et al.* 2003, Coelho *et al.* 2008, Queirolo *et al.* 2011).

Forestry seems to be a permeable matrix for *Cerdocyon thous* and *Lepus europaeus*. That may indicates that *Cerdocyon thous* may prefer more forested habitat than previously thought. Other studies showed that *C. thous* is well adapted to agricultural, forestry and areas at different successional stages (Juarez and Marinho-Filho 2002, Lyra-Jorge *et al.* 2008, Ferraz *et al.* 2010), and *C. thous* is described as habitat generalist and opportunistic in general. However, it occurs more often in forested habitats, even secondary forests, and on long trails (Goulart *et al.* 2009). *Cerdocyon thous* is also frequently recorded in agroforestry systems, especially in *cabrucas* (cacao plantations shaded by native trees; Cassano *et al.* 2012), and even in Eucalyptus plantations (Lyra-Jorge *et al.* 2008). In a dry forest in Bolivia, *C. thous* preferred riparian forests over Chacoan and montane forest habitats, even where the riparian forest was less available (Maffei and Taber 2003).

The positive association between *Lepus europaeus* and forestry was unexpected. In Europe, *L. europaeus* is usually found in open native vegetation, agricultural fields and non-intensively managed landscapes (Ferretti *et al.* 2010, Farfán *et al.* 2012). As an exotic and opportunistic species, *Lepus europaeus* may occur in different land uses and cover types depending on food availability, but also on predator avoidance. Thus, in our fragmented Cerrado *L. europaeus* used forestry as a permeable matrix, maybe to avoid predators as these matrices would provide more protective cover. Accordingly, in South America it can benefit greatly from the expansion of agricultural areas, are often found in open areas and in cropland (Auricchio and Olmos 1999, Kufner *et al.* 2008), and clearing and forest fragmentation for agriculture provides *L. europaeus* with a potential advantage (Kufner *et al.* 2008). However, it also occurs in more diverse vegetation types in South America than in Europe (Lantschner *et al.* 2013). In northwest Patagonia, the occurrence of *L. europaeus* did not differ between pine plantations and native vegetation (composed of a transition between *Austrocedrus chilensis* forest and arid grassland) (Lantschner *et al.* 2013). In addition, *L. europaeus* prefer moderately grazed pastures than lightly and ungrazed ones, probably to combine herbage density and predator avoidance (Karmiris and Nastis 2007). Thus, predator avoidance seems to be a general important factor for *L. europaeus* in fragmented landscapes, which would explain its association with forested matrices.

Scale was relevant to predict road-kill of three mammal species. The best models of *Chrysocyon brachyurus* and *Cerdocyon thous* included the large scale, whereas for *Lepus europaeus* included the intermediate scale. The dispersal capacity may explain this association because *C. brachyurus* and *C. thous* have larger home ranges than *L. europaeus*. Thus, as expected landscape features nearer of *L. europaeus* are more relevant, whereas for *C. brachyurus* and *C. thous* a broader area is perceived by them. However, for *L. europaeus* other model that still worth interpreting included a negative association to sugarcane fields cover in the large scale. The same species showed an association with two landscape features in different scales, which may indicate that depending on the landscape feature, the scale may be different. In our context, sugarcane could be a broader influence on *L. europaeus* because it is the dominant landscape feature in the studied area. Thus, we recommend include different scales on landscape analysis for predicting road-kill of one or many species, not only to consider species dispersal capacity but also different relations between species and landscape features in each scale (Zeller *et al.* 2012).

Some models with less support, but still worth interpreting, showed that river proximity contributed to explain road-kill of *Cerdocyon thous* and *Lepus europaeus*. *C. thous* road-kill events were also positively associated to water bodies. In a highway in the Brazilian Atlantic Forest, proximity of rivers was a relevant landscape feature to explain road-kill events of capybaras (*Hydrochoerus hydrochaeris*, Linnaeus 1766), a semi-aquatic Brazilian mammal (Bueno *et al.* 2013) and other vertebrate species (Bueno *et al. in press*). In addition of using as water supply in the Cerrado landscape, *C. thous* and *L. europaeus* are likely to use rivers and their riparian vegetation as preferential routes for reaching their habitat, and for protection and foraging during dispersal. In fragmented landscapes, riparian forests work as dispersion corridors for animals, connecting rainforest populations of the neighboring biomes such as the Atlantic Forest and Amazon Forest (Johnson *et al.* 1999, Wiens 2002). Besides increasing landscape permeability, rivers and riparian forest are very important to biodiversity conservation and ecosystem services supply (Gregory *et al*. 1991, Sweeney *et al*. 2004). Thus, native vegetation in riparian zones must be kept and restored, following the Brazilian Forest Code (Law 12.651/2012), particularly on Areas of Permanent Preservation, to improve landscape permeability and ecosystem services supply.

Other less relevant model showed the negative association between sugarcane fields cover and *Lepus europaeus* road-kill events, indicating this kind of matrix as a potential barrier or avoidance to hares. In Brazil, sugarcane production usually includes burning process before harvest, which results in air pollution, wildlife dispersal or death, and other environmental impacts (Goldemberg *et al.* 2008). As a dominant landscape feature in our study area and a degraded area due their intensive use, sugarcane is a less permeable matrix for hares, and probably, for other species. In highly modified landscapes, we expect that dominant land use types may work as barriers to wildlife movement, and thus, more permeable matrix types should be conserved or restored in the landscape to improve connectivity and ecosystem services supply.

Neverthless, high connectivity represents higher road-kill risks when wildlife crosses highways. Thus, safe crossings should be applied on the specific sites along the highways (Forman *et al*. 2003, Beckmann *et al*. 2010). Defining landscape features associated with road-kills allows a more informed and objective selection of locations to best implement mitigation measures (Gunson *et al.* 2011). The relationship found between more permeable matrix types and road-kills of the three focal species, including an exotic and a flag species, suggests that native vegetation may not be the preferential route for many medium to large mammals in the highly fragmented Cerrado. Forestry and rivers should be considered to connect populations fragmented by highways, particularly in Brazilian Savanna domined by agriculture and pasture. Urban areas, including small and medium cities, may be considered mitigation measures that reduce vehicles speed for human and wildlife security. Culverts are usually included in highway projects for water drainage, and a change in culvert design is cheaper than building a new structure, such as fauna overpasses (Huijser *et al.* 2009). Therefore, adapting culverts to be used also as fauna underpasses could be the best economical solution. Fences are necessary to indicate the way to culverts in order to reduce road-kill and increase connectivity between populations possibly fragmented by the highway. Culverts can function as faunal underpasses when their entryway is wider than their overall length because the animal should see the end of the tunnel, and when they have dry platforms or walkways constructed on the lateral interior walls of the bridge and above the high-water mark (Laurance *et al.* 2009, Clevenger and Ford 2010). Modified culverts also should be a multiuse underpass and thus are generally at least 7 m wide and 3.5 m high (Clevenger and Ford 2010). Proximity of protected areas could be used as an additional criterion to select which highway stretches should have priority to receive first mitigation measures.

Chrysocyon brachyurus could be used to call attention to road-kill consequences on wildlife populations. Despite the number of *Chrysocyon brachyurus* road-kills was lower than the other two species, it is much larger in size and is included in Red List of threatened species by extinction (IUCN 2013). Large size also mean low reproductive rate, two or three offspring a year, but good dispersal capacity, a suit of characteristics that make *C. brachyurus* a more vulnerable species to road-kill (Coelho *et al.* 2008, Fahrig and Rytwinski 2009, Cáceres 2011, Lion *et al.* 2011, Rytwinski and Fahrig 2011). As an endemic and endangered species, *C. brachyurus* represents a conservation concern, and may be used as a flagship species (Simberloff 1998, Hoffmann *et al.* 2010, Smith *et al.* 2012). Additionally, as a large species *C. brachyurus* provides a strong argument for mitigation measures because of the human casualties and material damage caused by wildlife-vehicle collisions, and the extinction threats of a species (Huijser *et al.* 2009).

A challenge in the tropics is to find the most suitable mitigation measure in a setting of high species diversity, budget constraints, and economic development as a major priority. Landscape features associated with road-kills would provide ability to predict where these limited resources and efforts should be allocated. More permeable matrix types and proximity to rivers may be such landscape features, potentially suitable for South America in a multi-species conservation approach, implementing road-kill mitigation measures suitable for many species, similarly used in Australia (Laurance *et al.* 2009, Taylor and Goldingay 2010). Proximity of rivers allows the use of culverts, which may be useful to other Brazilian mammals associated with aquatic habitats, for instance, capybaras (*Hydrochoerus hydrochaeris*, Linnaeus 1766) (Bueno *et al.* 2013). To a lesser extent, presence of habitats that provide protective cover from predators may also provide additional predictive ability. The present study demonstrates that some landscapes features can be used to identify highway stretches were road-kill incidence is more likely, for mammals of variety of sizes and habits, allowing a multi-species approach to mitigate road-kills.

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