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SHORT AND NARROW ROADS CAUSE SUBSTANTIAL IMPACTS ON WILDLIFE

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Abstract: Short and narrow roads are generally overlooked when assessing road impacts on biodiversity. However, these roads bisect natural environments and may cause significant impacts on wildlife in local scale. Thus, we monitored roadkills along a short two-lane road (CPM road) in Southeastern Brazil and propose mitigation strategies to reduce wildlife mortality. We monitored roadkilled vertebrates along 5 km of CPM road from 2010 to 2016 and we also compiled data from previous studies along the same road. We conducted a hotspot analysis to identify CPM road areas with significant roadkill aggregation. We recorded 77 roadkilled vertebrates from 14 taxonomic groups along the CPM road. Mammals were the most frequently recorded group (91% of roadkills), which represented 56% of all medium- and large-sized mammal species known to occur in the study area. We identified three roadkill hotspots along the CPM road. Two of them were located at two stream crossings, where the road cut across the associated riparian forests, and the other was at a road section with water drainage from a pond, also connected to a riparian forest. These riparian forests are part of the remaining natural habitat that provides connectivity between the forest remnants in the landscape, and therefore, for wildlife. Our results showed that even short and narrow roads can have considerable roadkill, which may have severe effects for wildlife on a local scale. The results stress the need to carefully look at these types of roads and propose measures to reduce impacts. We propose the creation of safe crossing opportunities in the hotspot zones combined with wildlife fencing to keep the animals off the road and guide them towards the safe crossing opportunities.

Keywords: human-modified landscapes; mammals; mitigation measures; roadkill.

INTRODUCTION

The construction of roads and other linear infrastructure have modified the landscape to the point where it is now uncommon to find areas distant from roads and areas that remain unaffected by them (Forman & Alexander 1998, Coffin 2007). Roads fragment and isolate the remaining natural areas and, as a result, can reduce the viability of wildlife populations (Develey &

Stouffer 2001, Benítez-López *et al.* 2010, Yamada *et al.* 2010, Macpherson *et al.* 2011). They also cause direct wildlife mortality through wildlife-vehicle collisions. For large mammal species this can result in human injuries and fatalities, and property damage (Boves & Belthoff 2012, Huijser *et al.* 2013). Generally, species that are both common and large are a particular concern for human safety (CDC 2004, Langley *et al.* 2006), while those that are rare or threatened, are primarily a biological conservation priority, though there are some exceptions (*e.g.*, Medici *et al.* 2016). For the latter, the loss of only a few individuals can already result in a local population decline, or even local or regional extirpation (Coffin 2007).

Road ecology research has mainly focused on documenting the effects of roads and traffic on wildlife. However, in some cases, it has also evaluated strategies to avoid, reduce or compensate these impacts (Cuperus *et al.* 1999, Trombulak & Frissel 2000, Coffin 2007, Huijser *et al.* 2013). Most of these studies are aimed at the wide and busy highways (Abra 2012, Huijser *et al.* 2013, Freitas *et al.* 2015, Abra *et al.* 2018), presumably because of the danger associated with hitting large mammals at high speed, and the barrier effect associated with wide and high-volume roads. The impacts of narrow roads generally receive far less attention. The state of São Paulo in Brazil, is considered one of the most developed states in Brazil and hosts an extensive network of paved roads (~37,000 km); most of them (83%) narrow two-lane roads (30,700 km; DER 2017).

Generally, these relatively narrow two-lane roads in Brazil (*e.g.*, country roads) are located within human-modified landscapes (HMLs), which may contain remnants of natural or semi-natural vegetation. These roads can bisect these natural areas and streams, while linking cities to housing developments, isolated houses and farms, and other villages and cities. These HMLs may still host high biodiversity (Anjos 2001, Giraudo *et al.* 2008, Dotta & Verdade 2011, Alexandrino *et al.* 2013, Magioli *et al.* 2014a, Magioli *et al.* 2016, Bovo *et al.* 2018). One common characteristic of these landscapes, is that they are highly fragmented, especially in the Atlantic Forest and Cerrado biomes (Klink & Machado 2005, Ribeiro *et al.* 2009), which are the biomes present in the state of São Paulo. In these heavily fragmented landscapes, animals must move across agricultural lands and roads to meet their territorial, reproductive and feeding needs (Fahrig 2007). Thus, roads bisecting HMLs may act as barriers for wildlife, and they can also result in direct wildlife mortality as a consequence of wildlife-vehicle collisions.

To assess the impact of short and narrow roads on wildlife, we monitored vertebrate road mortality (especially mammals) along a short two-lane road within an HML in southeastern Brazil. Our results may not only help to develop mitigation strategies along narrow low-volume roads, but they can also serve planners when deciding on the most appropriate routes for roads in HMLs, and how the impacts of these roads on human safety and biological conservation can be best avoided, mitigated, or compensated.

MATERIAL AND METHODS

Study area

Our study road, Comendador Pedro Morganti road (henceforth called CPM road), is located in Piracicaba, state of São Paulo, Brazil (22°43'30" S, 47°38'56" O; Figure 1), and is 5 km long. CPM road runs from the northeastern edge of the urban area of Piracicaba (kilometer zero), bisects the Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ), a campus of the University of São Paulo, and also borders the Instituto de Pesquisas e Estudos Florestais (IPEF). This road provides access to industrial and residential areas, *i.e.*, a high-level housing development and the Monte Alegre neighborhood.

The CPM road is located in the Atlantic Forest biome and borders the Cerrado biome (IBGE 2004) in a region highly modified by human activities. Some small semideciduous forest fragments are still present on the both sides of the road, along with small sections of riparian secondary vegetation. Two of the three streams (*i.e.*, the Piracicamirim River, and a nameless intermittent stream) in the study area are bisected by the CPM road, and the third one (*i.e.*, the Piracicaba River, located just to the north of the road) is in the immediate proximity (Figure 1). The riparian vegetation along the streams connects most of the remaining forest fragments in the area. Four ponds are present in the area on both sides of the road. These ponds also

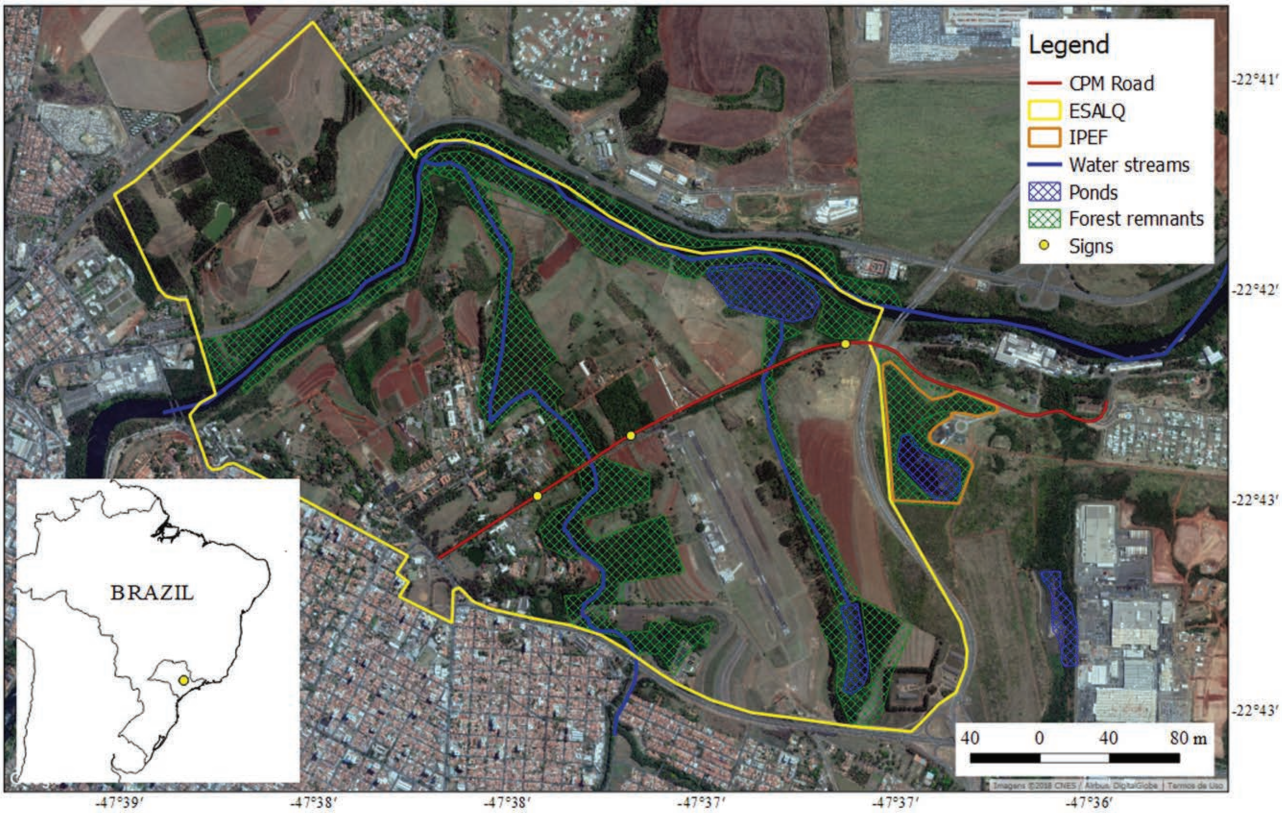

Figure 1. Location of the Comendador Pedro Morganti road (CPM road; in red) in the municipality of Piracicaba, state of São Paulo, Brazil. Streams and ponds (in blue), forest remnants (in green) and wildlife crossing signs (yellow dots) are also highlighted.

serve as wildlife habitat, especially for frogs, birds and semi-aquatic mammals.

There are some fences present along the road, but these were not constructed to contain wildlife, and they are in disrepair at several locations. Three wildlife crossing signs are also present along the road (Figure 1). A drainage culvert (diameter 1.3 m) was built in 2014, which could potentially be used by wildlife, and some capybara (*Hydrochoerus hydrochaeris*; Rodentia, Caviidae) have been observed using the culvert. However, there has been no systematic monitoring of the culvert.

We estimated traffic volume through direct observation and counting vehicles on the CPM road during four days; two hours in the morning (from 09:00 h to 11:00 h), two hours in the afternoon (from 14:00 h to 16:00 h) and two hours in the night (from 19:00 h to 21:00 h) each (16 h in total; 10 in week days and 6 in weekend days). The estimated traffic volume can be considered substantial (167 ± 55 vehicles/h) for a local road, especially because it is relatively narrow (typically 6 m wide, no designated lanes). However, compared to some major highways that are nearby, such as the Bandeirantes highway with five lanes and a much higher traffic volume (~12,000/day; DER 2017), the traffic volume for the CPM road is relatively low.

Roadkill database

We focused on the first 4.35 km of the CPM road, because this area still sustains substantial wildlife populations, especially bird species (N = 205; Alexandrino *et al.* 2013) and mammal species (N = 35; Bovo *et al.* 2018). A high biodiversity is still present, despite the intense human impacts on the landscape (*i.e.*, urban, industrial, and agricultural areas). We compiled roadkill data from previous studies long the CPM road in 2011 and 2012 (Andrade 2012, Nascimento 2012), and we collected additional data through non-standardized observations between 2010 and 2016. When recording roadkill, there were typically at least two observers present in a car with a speed of ~30 km/h. The observers drove the road section in the morning (07:00 h) and afternoon (17:00 pm). Records included date of observation, geographical coordinates, pictures and species identification when possible.

We adopted mammal species nomenclature following Paglia *et al.* (2012) and Vivo & Carmignoto (2015) for Sciuridae. Threatened species classification was based on IUCN (2017), Brazil Red Book of Threatened Species of Fauna (ICMBio 2016) and Decreto 60.133 (São Paulo 2014) red lists, for world, national and regional scales, respectively.

Data analysis

To identify road sections that may need mitigation along the CPM road, we conducted a cluster analysis of roadkilled animals using the 'Siriema' software (Coelho *et al.* 2014). First, we used the 2-D Ripley's K statistic, which identifies non-random spatial distribution of roadkilled animals across multiple scales (Coelho *et al.* 2008) and which takes the sinuosity of the road into account. Then we conducted a 2-D Hotspots analysis using the following parameters: radius = 10 m, number of simulations = 1000, confidence interval = 99%, for a random distribution of the roadkill locations.

RESULTS

Roadkills

We recorded 77 roadkilled animals from 14 taxonomic groups along the CPM road, including

Table 1. Taxonomic identification of roadkilled species, threat categories, and number of individuals (N) recorded along the Comendador Pedro Morganti road (CPM road), state of São Paulo, Brazil. *Domesticated/non-native species; Worldwide: IUCN (2017); Brazil: Brazil Red List (ICMBio 2016); State of São Paulo: Decreto 60.133 (São Paulo 2014).

Taxon	N	Threat category		
		Worldwide	Brazil	São Paulo
MAMMALS	**(70)**			
DIDELPHIMORPHIA				
Didelphidae				
Didelphis albiventris Lund, 1840	11	LC	LC	LC
CINGULATA				
Dasypodidae				
Dasypus novemcinctus Linnaeus, 1758	15	LC	LC	LC
LAGOMORPHA				
Leporidae				
Lepus europaeus (Linnaeus, 1758) *	1	-	-	-
PRIMATES				
Callitrichidae				
Callithrix penicillata (É. Geoffroy, 1812)	1	LC	LC	LC
CARNIVORA				
Felidae				
Felis catus (Linnaeus, 1758) *	3	-	-	-
Canidae				
Canis lupus familiaris (Linnaeus, 1758) *	2	-	-	-
Cerdocyon thous (Linnaeus, 1766)	1	LC	LC	LC
Mustelidae				
Galictis cuja (Molina, 1782)	1	LC	LC	LC
Lontra longicaudis (Olfers, 1818)	1	NT	LC	LC

Table 1. Continued on next page…

Table 1. ...Continued

Taxon	N	Threat category		
		Worldwide	Brazil	São Paulo
Procyonidae				
Nasua nasua (Linnaeus, 1766)	13	LC	LC	LC
RODENTIA				
Erethizontidae				
Coendou spinosus (F. Cuvier, 1823)	9	LC	LC	LC
Caviidae				
Hydrochoerus hydrochaeris (Linnaeus, 1766)	12	LC	LC	LC
BIRDS	**(3)**			
Unidentified bird	3	-	-	-
REPTILES	**(4)**			
Salvator merianae (Duméril & Bibron, 1839)	2	LC	LC	LC
Oxyrhopus sp.	2	-	-	-
TOTAL	**77**			

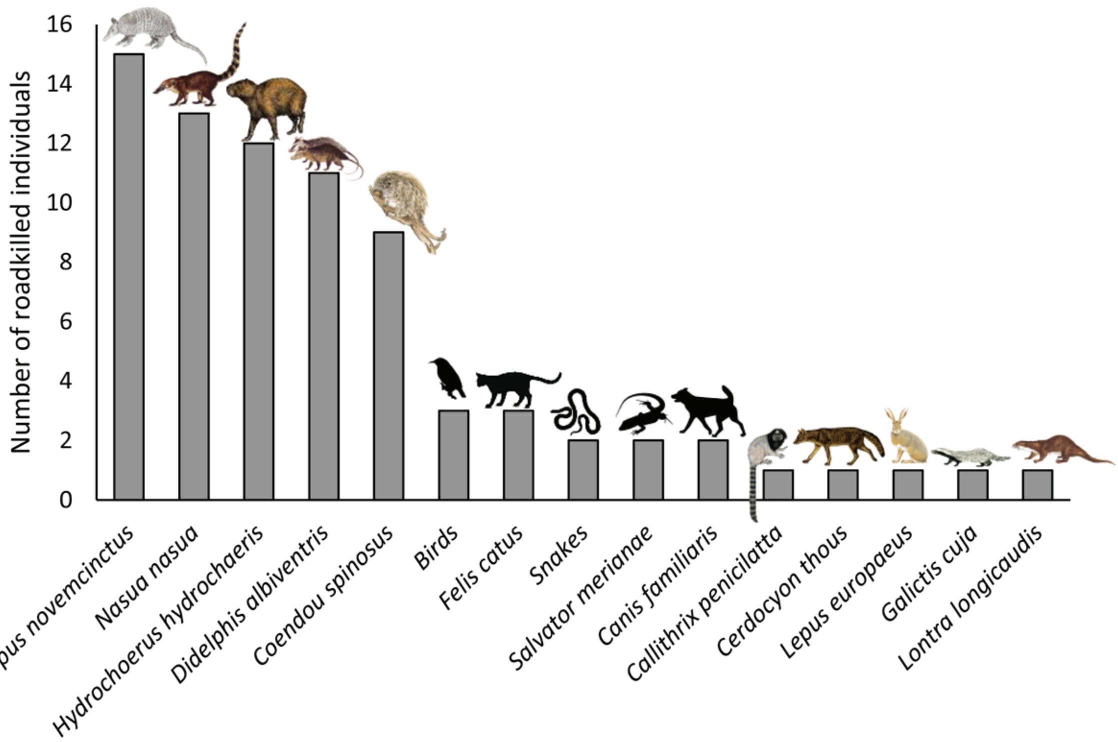

Figure 2. Frequency of the roadkilled vertebrates along the Comendador Pedro Morganti road (CPM road) in the municipality of Piracicaba, state of São Paulo, Brazil.

mammals (N = 70), birds (N = 3) and reptiles (N = 4) (Table 1). No threatened species were recorded as roadkill. Mammals were the most frequently recorded species group (91%), with 10 species (eight native and two exotic). The most frequently roadkilled mammals were *Dasypus novemcinctus* (Cingulata, Dasypodidae), *Nasua nasua* (Carnivora, Procyonidae), *H. hydrochaeris*, *Didelphis albiventris* (Didelphimorphia, Didelphidae) and *Coendou spinosus* (Rodentia, Erethizontidae) (Figure 2). During the survey period, we observed the following species crossing the road alive: *Didelphis* spp., *N. nasua*, *Cerdocyon thous* (Carnivora, Canidae), *C. spinosus*, *D. novemcinctus*, *H. hydrochaeris*, *Puma*

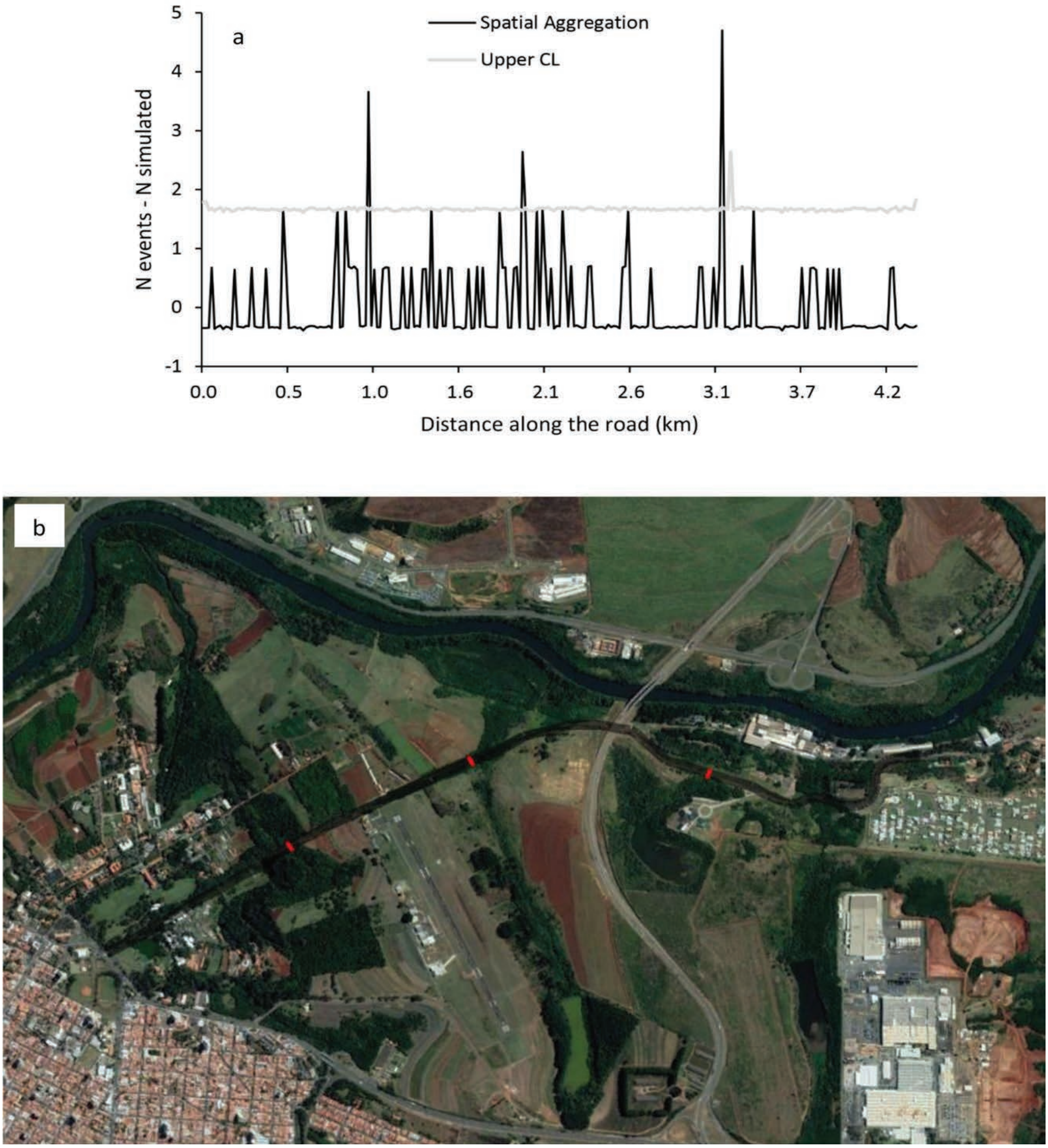

Figure 3. (a) Roadkill hotspots along the Comendador Pedro Morganti road (CPM road), municipality of Piracicaba, state of São Paulo, Brazil. The grey line represents the upper 99% confidence limit (upper CL), and the black line represents the spatial aggregation of the roadkill data from which were subtracted of the data points simulated by the Siriema software (N events – N simulated; Coelho *et al.* 2014). Values that exceeded the upper CL indicate the hotspots. (b) Location of the three roadkill hotspots (in red) at CPM road.

concolor (Carnivora, Felidae), and domestic cats and dogs. *Hydrochoerus hydrochaeris* was often foraging in the vegetation alongside the road. We also found several burrows of *D. novemcinctus* along the road, and tracks of mammals such as *C. thous*, *H. hydrochaeris* and *D. novemcinctus*.

Roadkill hotspots

While roadkill was widespread along the CPM road, the hotspot analysis identified three road segments with considerable roadkill aggregation. Two were exactly where the road crosses the intermittent stream and the Piracicamirim River. The other one was where there was drainage from a pond in IPEF's area (Figure 3).

DISCUSSION

Despite the CPM road being narrow and short, it had a relatively high number of roadkilled mammals. Though small roads are usually overlooked, this research highlights that this type of road may have significant impacts on biodiversity. Because of the linear nature of roads, they bisect a wide variety of environments, especially in HMLs. The CPM road bisects an HML, but where forest remnants are still present, direct road mortality and habitat connectivity are an issue.

Roadkills

The roadkilled native species represented ~56% of all medium- and large-sized mammals that are known to occur in the study area (N = 16; Bovo *et al.* 2018). The most frequently roadkilled species – *D. novemcinctus*, *N. nasua*, *H. hydrochaeris*, *D. albiventris* and *C. spinosus* – are commonly recorded in HMLs (Dotta & Verdade 2011, Reale *et al.* 2014; Magioli *et al.* 2016), and in other road ecology studies (Coelho *et al.* 2008, Cáceres *et al.* 2010, Dornas *et al.* 2012, Huijser *et al.* 2013). Species such as *C. spinosus*, *D. novemcinctus* and *H. hydrochaeris* are known to thrive in agricultural areas (Magioli *et al.* 2014b), and are very common, apparently with abundant populations, which can explain the high roadkill numbers. However, *C. thous*, a common species in HMLs (Ferraz *et al.* 2010) and frequently roadkilled (Coelho *et al.* 2008, Cáceres *et al.* 2010, Cáceres *et al.* 2012, Dornas *et al.* 2012, Bueno *et al.* 2013, Huijser *et al.* 2013, Freitas *et al.* 2015), was recorded only once in our study. Species such as *Galictis cuja* (Carnivora, Mustelidae) and *Lontra longicaudis* (Carnivora, Mustelidae), can be expected to be present in HMLs (Reale *et al.* 2014, Magioli *et al.* 2016), but they only occur in low densities, similar to other carnivore species (Cardillo *et al.* 2004, Ripple *et al.* 2014, Grilo *et al.* 2015). For such species, the loss of a single individual may have severe consequences for their population (Srbek-Araújo *et al.* 2015).

Amongst the most roadkilled mammals, *H. hydrochaeris* is the largest and heaviest species (Ojasti 1973, Ferraz *et al.* 2005), and can be considered of substantial risk to human safety, as also pointed out by other studies (Bueno *et al.* 2013, Huijser *et al.* 2013). *Hydrochoerus hydrochaeris* is considered a resilient species that thrives with certain level of human disturbance in the landscape (Ferraz *et al.* 2007). The studied area has a very substantial population of this species, with high density (Verdade & Ferraz 2006, Bovo *et al.* 2016). This rodent benefits from nearby food sources (crops and forest plantations at ESALQ and IPEF), suitable habitat (ponds and rivers) and low abundance of predators (Bovo *et al.* 2016). In addition, there is a substantial amount of vegetation growing in the road shoulders, particularly grasses, which is an attractive food source to this species. Other large mammals such as *Mazama gouazoubira* (Artiodactyla, Cervidae) and *P. concolor*, are also known to occur in the adjacent forest remnants (Bovo *et al.* 2018), and wildlife-vehicle collisions with these species may also result in human injuries and fatalities (Huijser *et al.* 2013). One individual of *Mazama* spp. was roadkilled in CPM road before the study period.

Although not recorded as roadkill, three threatened mammal species are known to occur in the study area: *Leopardus guttulus* (Carnivora, Felidae), *P. concolor* and *Puma yagouaroundi* (Carnivora, Felidae) (Bovo *et al.* 2018). These felids face a similar situation as *G. cuja* and *L. longicaudis*; the loss of a single individual can not only have a severe impact on their local population, but they can also affect ecosystem dynamics and trophic structure at a local scale (Rheingantz & Trinca 2015), since they are among the few remaining predators.

The few records of small-bodied vertebrates such as birds, reptiles and amphibians, are probably related to low detectability especially when surveys are conducted by car and/or the high disappearance rate for small species (Teixeira *et al.* 2013, Santos *et al.* 2016). Thus, we think that the roadkilled birds and reptiles (few records) and amphibians (not detected) were underrepresented in the roadkill data from the CPM road. In addition, some animals may end up in the tall vegetation immediately adjacent to the road, where they may not be detected. Wounded animals may also die further away from the road (Coelho *et al.* 2008).

Our study has some limitations, particularly with regard to the opportunistic nature of the collection of the roadkill data. Nonetheless, we obtained a significant number of records of roadkilled animals over the years, especially mammals, illustrating the substantial impacts that a short and narrow road can have on wildlife.

Roadkill hotspots

Even though the roadkill records were widespread along most of the CPM road, the significant spatial aggregations were mainly associated with riparian forest corridors along streams. The remaining forest cover, similar to most HMLs in the Atlantic Forest and Cerrado, is mainly associated with streams, which are essential structures for mammals persistence (Lees & Peres 2008, Zimbres *et al.* 2017). The small forested patches and corridors are critical for the survival of many native species (Zimbres *et* al. 2017, Fialho *et al.* in press). In the study area, these corridors are the only structural and possibly also functional connectivity remaining.

Freitas *et al.* (2015), Bueno *et al.* (2013) and Bueno et al. (2015) found that proximity to rivers best explained most of the roadkill occurrence, suggesting that these areas are a mitigation priority. Cáceres *et al.* (2012) also pointed out the importance of riparian forests for species crossing, which can result in a higher incidence of roadkills when these forest fragments are bisected by roads. These areas are especially important for semi-aquatic species such as *H. hydrochaeris* and *L. longicaudis*, and for *Myocastor coypus* (Rodentia, Myocastoridae) and *Lutreolina crassicaudata* (Didelphimorphia, Didelphidae), which are known to occur in the study area (Bovo *et al.* 2018). Cáceres *et al.* (2011), Cáceres *et al.* (2012), Bueno *et al.* (2013), Huijser *et al.* (2013) and Bueno *et al.* (2015) found a high number of *H. hydrochaeris* roadkilled close to water streams. In addition, other mammals inhabiting these areas, in particular those with large home ranges, need to move between forest remnants to fulfil dietary, territorial and reproductive requirements, and can thus not function in small isolated habitat fragments (Lyra-Jorge *et al.* 2010, Dotta & Verdade 2011, Miotto *et al.* 2011, Miotto *et al.* 2012, Magioli *et al.* 2016). Moving between different habitat fragments often means crossing roads and exposure to potential mortality.

However, we stress that results concerning roadkill hotspots have to be carefully interpreted. Teixeira *et al.* (2017) showed that hotspot locations may shift in place with time. Therefore, continued monitoring may be required, even if road sections with a hotspot in road mortality have been mitigated.

Final considerations and mitigation measures

The impacts of narrow and short roads such as the one in this study need to be looked more carefully. In this particular case, the CPM road is target of a Civil Inquiry (IC 4235/15 MA) with potential to become a Public Civil Action by the Public Prosecution of Piracicaba Municipality. This civil process was triggered because of the high roadkill numbers, and our study allows for better insight in the extent and location of road mortality, as well as potential mitigation measures. We showed that places where the road bisects streams flanked by riparian forests, hold the largest concentration of roadkills. Thus, we propose implementing wildlife fences in combination with safe crossing opportunities (*e.g.*, underpasses and potentially also overpasses), focusing on the roadkill hotspot zones (Beckmann *et al.* 2010, Huijser *et al.* 2016, Rytwinski *et al.* 2016). Note that the fences may need to extend beyond the roadkill hotspots as short fenced road sections suffer from fence end effects and have lower effectiveness in reducing collisions (Huijser *et al.* 2016). Additionally, reducing design speed may help reduce wildlife-vehicle collisions. Standard or enhanced wildlife warning signs may increase public awareness and they may help gain public support for fences and wildlife crossing structures, but these signs do not reduce collisions (Huijser *et al.* 2015). In HMLs that sustain forest remnants connected by riparian forests, planners should avoid bisecting streams and associated riparian forests. These streams and riparian forests are the main structural connectivity remaining in these heavily altered landscapes. However, if roads do cross streams and riparian forests, we suggest the implementation of a combination of safe crossing opportunities and wildlife fences to improve human safety, reduce unnatural direct wildlife mortality, and to maintain a certain degree of habitat connectivity.

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