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Mammal-vehicle collisions on toll roads in São Paulo State: implications for wildlife, human safety and costs for society

Fernanda Delborgo Abra

Thesis presented to obtain the degree of Doctor in Science. Area: Applied Ecology

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Bachelor of Science in Biology

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I dedicate my PhD thesis to the wildlife of the State of São Paulo because they persist in inhabiting the remnants of the Cerrado and Atlantic Forest of our State, despite so many different impacts and human disregards.

Dedico a minha tese de doutorado à fauna silvestre do Estado de São Paulo por persistirem em habitar os remanescentes de Cerrado e Mata Atlântica do nosso Estado apesar de tantos diferentes impactos e dos descasos humanos.

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Um doutorado não é fácil.

Não se trata de realizar uma pesquisa inovadora e no final defender o que você fez. Isso, inclusive, pode ser entendido como a parte fácil do processo. O difícil é o processo.

O significado de PhD tem origem do latim “Philosophiæ Doctor”, que significa Doutor em Filosofia, ou aquele que tem amor pelo conhecimento, que domina uma área do conhecimento e se torna referência dentro da sociedade. O PhD vai além de um título, ele é uma marca na sua vida sobre “*noblesse oblige*”. Ouvi essa expressão pela primeira vez em 2015, quando o Dr. Marcel Huijser aceitou me orientar e me contou uma história. A história de quando ele iniciou seu doutorado e o seu orientador também lhe contou uma história. “*Noblesse oblige”* ou a “obrigação nobre” é uma expressão francesa e significa que com um título, prestígio ou qualquer coisa que lhe traga destaque na sociedade, também vem a responsabilidade. No caso sobre ter um doutorado, responsabilidade de servir à sociedade, conhecer seus problemas e resolvê-los. Responsabilidade em ser uma pessoa honesta, ética, simples e capaz de passar o seu conhecimento, também de maneira simples.

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Doing a PhD is not easy.

It's not about conducting an innovative research project and ultimately defending what you've done. This is the easy parto f the process. What is difficult is the process.

The meaning of PhD originates from the Latin "Philosophiæ Doctor", which means Doctor of Philosophy, or one who has a love of knowledge, who dominates their field and becomes a reference within the society. The PhD goes beyond a title, it is a mark in the life on "*noblesse oblige*". I heard this expression for the first time in 2015, when Dr. Marcel Huijser agreed to advise me and told me a story. The story of when he started his doctorate and his advisor also told him a story. "*Noblesse oblige*" or "noble obligation" is a French expression and means that with a title, prestige or anything that brings you prominence in society also comes the responsibility. In the case of having a doctorate, it is the responsibility of serving society, understanding its problems, and solving them. We have the responsibility to being honest, ethical, simple and able to pass on our knowledge in a way that is easy to understand.

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A PhD means intellectual and personal improvement. A hard lesson so that, after obtaining a doctor's degree, we are ready to serve.

At the end of my doctorate, I reflected on all the situations and learning that I experienced during this process and how so many people taught me, each in their own way and in their time, to be a better person, a better researcher and a better citizen. In my personal assessment, I am ready to serve, and I am glad to know that serving society is something I imagine doing in the future for as long as it is physically and intellectually possible.

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“Every individual matters. Every individual has a role to play. Every individual makes a difference.”
— Jane Goodall

“You cannot get through a single day without having an impact on the world around you. What you do makes a difference, and you have to decide what kind of difference you want to make.”
— Jane Goodall

SUMMARY

RESUMO

Colisões envolvendo mamíferos em rodovias sob concessão do Estado de São Paulo: implicações para fauna silvestre, segurança humana e custos para a sociedade.

As rodovias e o tráfego podem afetar o movimento, a capacidade de dispersão dos indivíduos e aspectos populacionais (e.g. aumento de mortalidade não natural). A mortalidade direta causada por atropelamento e o efeito de barreira nas rodovias são tipicamente identificados como uma das maiores ameaças à vida selvagem. Além disso, as colisões com mamíferos de grande porte também são uma ameaça à segurança humana e representam um custo econômico para a sociedade. Os pesquisadores especializados em Ecologia de Estradas de todo o mundo utilizam locais georreferenciados das colisões envolvendo animais para compreender os padrões de distribuição espacial. Os resultados demonstram que as colisões envolvendo animais não são aleatórias, mas são espacialmente agrupadas para espécies de vertebrados. Os pesquisadores também usam novas ferramentas de modelagem, como a Modelagem de Distribuição de Espécie (MDE), para orientar processos de decisão sobre conservação biológica como modelagem preditiva de atropelamentos para determinar variáveis (por exemplo, paisagem, *design* de rodovias, volume de tráfego), que poderiam explicar os atropelamentos. Nesta tese, eu analisei dados sobre atropelamentos oriundos de diferentes concessionárias de rodovias no estado de São Paulo durante o período de 2005 à 2014. No Capítulo 1, investiguei se os inspetores de tráfego das concessionárias identificavam corretamente as espécies de mamíferos silvestres atropelados nessas rodovias. No Capítulo 2, eu estimei o número de atropelamentos de mamíferos silvestres de médio e grande porte para todas as rodovias pavimentadas em São Paulo, com base em dados de atropelamentos de concessionárias (~6.500 km). No Capítulo 3, usei a abordagem MDE para gerar modelos de predição de atropelamentos para oito espécies de mamíferos silvestres em todas as rodovias pavimentadas no estado de São Paulo, e executei análise de pontos críticos de atropelamentos para identificar seções críticas de rodovias para espécies específicas ou grupos de animais. No Capítulo 4, explorei, pela primeira vez no Brasil, os efeitos de acidentes envolvendo animais na segurança humana em rodovias pavimentadas no Estado de São Paulo, bem como calculei os custos desses acidentes para a sociedade e resumi as perspectivas legais em matéria de responsabilidade civil e compensação financeira associada às colisões envolvendo animais em rodovias. Os capítulos foram especificamente planejados e executados para entender, em uma perspectiva ampla, as diferentes implicações relacionadas às colisões envolvendo veículos-automotores e mamíferos em rodovias: i) conservação biológica, ii) segurança humana e, iii) economia. Os resultados de cada capítulo apresentam recomendações práticas para que as agências ambientais e de transporte no estado de São Paulo possam trabalhar com planejamento e prioridade para reduzir colisões envolvendo mamíferos. Isso deve resultar em um sistema rodoviário mais seguro para os usuários, com menores índices de mortalidade de animais, implementação de oportunidades seguras de travessias para a fauna e redução dos custos financeiros para a sociedade.

Palavras-chave: Atropelamento; Mamífero; Rodovia; Estado de São Paulo; Conservação biológica; Segurança humana; Economia

ABSTRACT

Mammal-vehicle collisions on toll roads in São Paulo State: implications for wildlife, human safety and costs for society

Roads can affect animal movement, dispersal and population aspects (i.e., increasing non-natural mortality) of wild species. Direct road mortality and the barrier effect of roads are typically identified as one of the greatest threats to wildlife. In addition, collisions with large mammals are also a threat to human safety and represent an economic cost to society. Road ecologists worldwide, have used available georeferenced locations of wildlife-vehicle collisions to determine spatial distribution patterns along and the outcomes demonstrates that wildlife-vehicle collisions are not at random, but they are spatially clustered for vertebrate species. Researcher also have used new modelling tools, such as the Species Distribution Modelling (SDM), to orient decision processes on biological conservation as predictive roadkill models (RPM) to determine variables (e.g. landscape, road design, road traffic), that could explain the collisions of specific species. I analyzed roadkill data from toll road companies in São Paulo state during 2005 to 2014. In Chapter 1, I investigated whether maintenance personnel from toll roads companies correctly identified the species of the roadkilled wild mammals on these roads. In Chapter 2, I estimated the roadkill numbers of wild medium and large sized mammals for paved roads (~6,500 km) in São Paulo, based on roadkill data from toll road companies. In Chapter 3, I used SDM approach to generate RPM for eight mammal species on all paved roads in São Paulo state, and I ran roadkill hotspot analysis to identify critical road sections for specific species or animal groups. In Chapter 4, I explored, for the first time in Brazil, the effects of animal-vehicle crashes on human safety on paved roads in São Paulo State, and I estimated the costs of these animal-vehicle crashes to society, and summarized the legal perspectives with regard to liability and associated financial compensation for animal-vehicle collisions. The chapters were specifically planned and designed to understand, in a broad perspective, the different implications related to mammal-vehicle collisions: biological conservation, human safety and economics. The outcomes from each chapter show practical recommendations so that environmental and transportation agencies in São Paulo state can work with planning and priority to reduce mammal-vehicle collisions. This should ultimately result in a road system with improved human safety, reduced unnatural mortality for both domestic and wild animal species, safe crossing opportunities for wildlife, and reduced monetary costs to society.

Keywords: Roadkill; Mammal; Road; São Paulo State; Biological conservation; Human safety; Economics

1. INTRODUCTION/INTRODUÇÃO

1.1. English

The global loss of biodiversity loss is especially notable in tropical regions. Many tropical areas have been extensively modified by human activities, including the expansion of urban areas, agriculture and transportation network (GIBBS et al., 2010; FOLEY et al., 2011; LAURENCE, 2014).

Roads have important benefits for society as they allow for the transportation of people and goods. However, we now know that highways and their continuing expansion to the remotest remaining natural areas, results in the severe ecological impacts (TROCME, 2003; LAURANCE et al., 2014). These linear infrastructure projects are among the most severe human-caused impacts on natural landscapes. It is a global problem that has huge implications for the natural environment, including many wildlife species (LODÉ et al., 2000; BOND & JONES, 2008). Highways, both existing and ones that are in the planning or construction phase, represent one of the biggest threats to biodiversity (FORMAN & ALEXANDER, 1998; TROMBULAK & FRISSEL, 2000).

For wildlife, the effects of roads and traffic varies and ranges from habitat loss (FORMAN et al., 2003), reduction in habitat quality in a zone adjacent to the road (e.g. noise, lights, pollution, visual disturbance) (FORMAN et al, 2003; EIGENBROD et al., 2009; PARRIS et al., 2009), barrier effect, including interruption of migration and dispersion (NELLEMANN et al., 2001; VISTNES et al., 2004; LESBARRÈS & FAHRIG, 2012), and direct mortality through collisions with vehicles (FORMAN & ALEXANDER, 1998; FAHRIG & RYTWINSKI, 2009).

Direct road mortality has the potential to alter the demographic structure of wildlife populations (STEEN & GIBBS, 2004) and create local population sinks (NIELSEN et al., 2006). Such changes may alter the structure and function of communities and ecosystems adjacent to the road (TROMBULAK & FRISSELL, 2000). The extent of these impacts depends on the characteristics of the roads such as road density, traffic volume, as well as, landscape features, proximity to protected areas, the wildlife species and their natural history (FAHRIG et al., 1995; AMENT et al., 2008; FRAIR et al., 2008; FREITAS et al., 2015; RYTWINSKI & FAHRIG, 2013).

Loss of individual animals through direct roadkill mortality has been well documented all around the world. Many studies have estimated roadkill numbers. Studies differ in species groups studies, different types of roads, and in the length of the study period. Annual roadkill estimates include 159,000 mammals and 653,000 birds in The Netherlands, seven million birds in Bulgaria, and five million amphibians and reptiles in Australia (ZANDE et al., 1980; BENNETT, 1991; FORMAN & ALEXANDER, 1998). In the United States it has been estimated that 80 million birds are killed on roads each year (ERICKSON et al., 2005), while one million vertebrates are estimated to be roadkilled per day along roads (FORMAN & ALEXANDER, 1998). In Brazil, there are two estimates for vertebrate roadkill: 14.7 (± 44.8) million per year (DORNAS et al., 2012), and 475 million per year (430 million small animals, 40 million medium vertebrates and 5 million large vertebrates) (CBEE, 2019).

Most of these studies are conducted along the wide and high traffic volume highways (HUIJSER et al., 2009; HUIJSER et al., 2013; FREITAS et al., 2015; ABRA et al., 2018). The impacts of narrow roads generally receive far less attention (but see MAGIOLI et al., 2018). Still, the majority of the studies involve medium and large sized mammals. The concern for mammal roadkills is generally greater than for other species groups. There are several reasons for this: large mammals pose the greatest risk to human safety and have the highest economic costs associated with vehicle repair (CONOVER et al., 1995; GROOT BRUINDERINK & HAZEBROEK, 1996; HUIJSER et al., 2009), and there is great concern with the biological conservation of mammals. About 27% of all mammal species are at risk of extinction (CARDILLO et al., 2005; SCHIPPER et al., 2008). Because mammals are generally charismatic (COURCHAMP et al., 2018), they are also often used as “umbrella species” in strategic planning for conservation (JENKINS et al., 2013).

In tropical countries, biodiversity tends to be higher which results in a wider range of species killed by cars (BASKARAN & BOOMINATHAN, 2010; HOBDAY & MINSTRELL, 2008; WANG et al., 2013; MOHAMMADI & KABOLI, 2016). When species are identified by non-experts (e.g. through a citizen science data collection effort), common and large species tend to be more frequently reported than small and rare species (FORD & FAHRIG, 2007; ABRA et al., 2018 - Chaper 1). In addition, in tropical countries, the focus is often on biological conservation rather than human safety, which leads to the inclusion of species with relatively small body sizes (BRAZ & FRANÇA, 2016; BROKIE et al., 2009). However, this does not mean that human safety is not a concern in tropical countries. Large species can also affect human safety in the tropics. For example, in South America: e.g. South American tapir (*Tapirus terrestris*), capybara (*Hydrochoerus hydrochoeris*), brocket deer (*Mazama* spp.), marsh deer (*Blastocerus dichotomus*) (BUENO et al., 2013; HUIJSER et al., 2013; MEDICI et al., 2016), in Africa: e.g. African bush elephant (*Loxodonta Africana*), greater kudu (*Tragelaphus strepsiceros*) (DREWS, 1995; ELOFF & van NIEKERK, 2005), Asia (e.g. Asian elephant (*Elephas maximus*) (VIDYA & THUPPIL, 2010), and in Oceania (e.g. kangaroos, wallaroos, and wallabies (*Macropus* spp.) (BOND & JONES, 2013; KLÖCKER et al., 2006).

In South America, little information is available on the threat that animal-vehicle collisions pose to human safety and the associated costs to society (Chapter 4). However, in 2014, the Brazilian Federal Highway Police reported 3,174 animal-vehicle collisions (AVC) on the Brazilian Federal Highway system (IPEA, 2015). Animal-vehicle collisions represented 1.9% of all reported crashes, of which 40.9% resulted in human injuries, and 2.6% resulted in human fatalities (IPEA, 2015).

Road ecologists worldwide, have used georeferenced locations of wildlife-vehicle collisions to investigate their spatial distribution in relation to road and landscape characteristics (RAMP et al., 2005, 2006; MOUNTRAKIS & GUNSON, 2009). The results show that wildlife-vehicle collisions are not randomly distributed but that they are spatially clustered for many vertebrate species (JOYCE & MAHONEY, 2001; CLEVENGER et al., 2003; RAMP et al., 2006). Researchers have also used new modelling tools to help guide decision processes for biological conservation (ELITH & LEATHWICK, 2009; FRANKLIN, 2010). These tools include predictive roadkill models (MALO et al., 2004 – Chapter 3) to identify variables (e.g. landscape, road design, road traffic), that are associated with collision locations for specific species (FINDER et al., 1999; JOYCE & MAHONEY, 2001; NIELSEN et al., 2003; SAEKI & MACDONALD, 2004; SEILER, 2004; DUSSAULT et al., 2006; GARROTE et al., 2018; WILLIAMS et al., 2019).

Predictable models can be useful for environmental and transportation agencies because they allow for the identification of areas where mitigation measures are needed most (e.g. underpasses, overpasses, fences, animal detection systems). The models can also influence the design of new roads and predict what impacts roads might have on wildlife populations.

The main purpose of this thesis was to understand how mammal roadkill's impact biological conservation, human safety and economy. We also investigate temporal and spatial roadkill patterns and, for the first time in Brazil, the legal perspectives about liability involving road accidents and animals. Below we present how the thesis is organized, followed by a brief description of each chapter.

Chapter 1: How reliable are your data? Verifying species identification of road-killed mammals recorded by road maintenance personnel in São Paulo State, Brazil
Published in Biological Conservation

Reference: Abra, F.D., Huijser, M.P., Pereira, C.S., Ferraz, K.M.P.M.B. How reliable are your data? Verifying species identification of road-killed mammals recorded by road maintenance personnel in São Paulo State, Brazil. Biological Conservation, 2018, 225, 42–52. https://doi.org/10.1016/j.biocon.2018.06.019.

In this chapter, we investigated whether maintenance personnel correctly identified the species of the road-killed wild mammals in a tropical region: São Paulo State, Brazil. We used two different and complementary methods to verify species identification: i) We investigated images of road-killed mammals that were associated with the data collected by road maintenance personnel, and ii) We presented images of alive and dead mammals to road maintenance personnel and asked them to identify the species. Finally, we formulated recommendations to improve the reliability of species identification of road-killed animals by non-experts.

Chapter 2: How many mammals are roadkilled per year in São Paulo State, Brazil? An estimate based on roadkill data collected by toll road companies.

In this study, we estimate the total number of medium and large mammals roadkilled per year along all paved roads of São Paulo State based on roadkill data collected by toll road companies. Our study is the first well documented approach that provides estimates of minimum, maximum, average and median roadkill numbers for medium and large mammals in São Paulo State. We also discuss the implications for biological conservation, specifically threatened and endangered species.

Chapter 3: Where are wild mammals roadkilled? Predictive roadkill models using landscape variables in São Paulo State.

In this Chapter, we used the SDM approach to predict roadkills, in general and for eight target mammal species, in São Paulo state based on roadkill data from toll road companies from 2005 to 2014. We also identified roadkill hotspots on the same toll roads in

São Paulo State for the same period. Finally, we discussed predictive roadkill modeling and roadkill hotspot results for mitigation planning for existing roads or roads under planning.

Chapter 4: Pay or prevent? Human safety, costs to society and legal perspectives on animal-vehicle collisions in São Paulo state, Brazil
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In this chapter we document and explore the effects of animal-vehicle crashes on human safety in São Paulo State in Brazil. In addition, we estimate the costs of these animal-vehicle crashes to society, and we summarize the legal perspectives with regard to liability and associated financial compensation for animal-vehicle collisions.

1.1. Português

A perda global da biodiversidade é especialmente notável nas regiões tropicais. Muitas áreas tropicais têm sido extensivamente modificadas por atividades humanas, incluindo a expansão de áreas urbanas, agricultura e malha de transporte (GIBBS et al., 2010; FOLEY et al., 2011; LAURENCE, 2014).

As rodovias apresentam importantes beneficios para a sociedade, uma vez que permite o transporte de pessoas e produtos. No entanto, é sabido que as rodovias e sua contínua expansão até as mais remotas áreas naturais resultam em impactos ecológicos severos. (TROCME, 2003; LAURANCE et al., 2014). Esses projetos de infraestrutura lineares estão entre os impactos mais severos causados pelo homem em paisagens naturais. Este é um problema global o qual possui grandes implicações para o ambiente natural, incluindo diversas espécies silvestres (LODÉ et al., 2000; BOND & JONES, 2008). As rodovias, incluindo as existentes e as em fases de planejamento ou instalação, representam uma das maiores ameaças à biodiversidade (FORMAN & ALEXANDER, 1998; TROMBULAK & FRISSELL, 2000).

Para os animais silvestres, o efeito das rodovias e do tráfego variam desde a perda de habitat (FORMAN et al., 2003), redução na qualidade do habitat em zonas adjacentes às rodovias (e.g. ruído, iluminação artificial, poluição e perturbação visual) (FORMAN et al., 2003; EIGENBROD et al., 2009; PARRIS et al., 2009), efeito barreira, incluindo a interrupção de migrações e dispersões (NELLEMANN et al., 2001; VISTNES et al., 2004; LESBARRÈS & FAHRIG, 2012) e mortalidade direta por colisão com veículos (FORMAN & ALEXANDER, 1998; FAHRIG & RYTWINSKI, 2009).

A mortalidade direta tem o potencial de alterar a estrutura demográfica de populações de animais silvestres (STEEN & GIBBS, 2004) e criar sumidouros de populações locais (NIELSEN et al., 2006). Tais mudanças podem alterar a estrutura e a funcionalidade de comunidades e ecossistemas adjacentes às rodovias (TROMBULAK & FRISSELL, 2000). A extensão destes impactos depende de características das rodovias, tais como, densidade rodoviária, volume de tráfego, bem como, estrutura da paisagem, proximidade com áreas protegidas, diferentes espécies de animais e suas histórias naturais (FAHRIG et al., 1995; AMENT et al., 2008; FRAIR et al., 2008; FREITAS et al., 2015; RYTWINSKI & FAHRIG, 2013).

A perda de indivíduos de animais por morte direta de atropelamento tem sido bem documentada em todo o mundo. Muitos estudos têm estimado o número de atropelamentos. Os estudos diferem no grupo de animais, tipos diferentes de rodovias e períodos de estudo. Anualmente, as estimativas de atropelamentos incluem 159.000 mamíferos e 653.000 aves na Holanda, sete milhões de aves na Bulgária a cinco milhões de anfíbios e répteis na Austrália (FORMAN & ALEXANDER, 1998; ZANDE et al., 1980; BENNETT, 1991). Nos Estados Unidos, os atropelamentos têm sido estimados em 80 milhões de aves em rodovias por ano (ERICKSON et al., 2005), enquanto um milhão de vertebrados terrestres são estimados atropelados por ano nas rodovias (FORMAN & ALEXANDER, 1998). No Brasil, existem duas estimativas para vertebrados atropelados, 14.7 (± 44.8) milhões por ano (DORNAS et al., 2012), e 475 milhões por ano (430 milhões de pequenos animais, 40 milhões de médios vertebrados e cinco milhões de grandes vertebrados) (CBEE, 2019).

A maioria dos estudos é realizada em rodovias de grande porte e alto tráfego (HUIJSER et al., 2009; HUIJSER et al., 2013; FREITAS et al., 2015; ABRA et al., 2018). O impacto de rodovias de pequeno porte geralmente recebe menos atenção (veja MAGIOLI et al., 2018). Ainda, a maioria dos estudos envolvem mamíferos de médio e grande porte. A preocupação dos atropelamentos com mamíferos é geralmente maior do que com outros grupos de animais por diversos motivos: grandes mamíferos colocam em risco a segurança humana e apresentam maiores perdas econômicas associadas ao reparo de veículo em caso de colisão (CONOVER et al., 1995; GROOT BRUINDERINK & HAZEBROEK, 1996; HUIJSER et al., 2009), e existe uma grande preocupação com a conservação biológica dos mamíferos. Entorno de 27% de todas as espécies de mamíferos estão em risco de extinção (CARDILLO et al., 2005; SCHIPPER et al., 2008). Ainda, uma vez que os mamíferos são geralmente carismáticos (COURCHAMP et al., 2018), eles frequentemente são usados como “espécies guarda-chuva” em planos estratégicos de conservação (JENKINS et al., 2013).

Em países tropicais, a biodiversidade tende a ser maior o que resulta em uma ampla gama de espécies atropeladas por veículos (HOBDAY & MINSTRELL, 2008; BASKARAN & BOOMINATHAN, 2010; WANG et al., 2013; MOHAMMADI & KABOLI, 2016). Quando as espécies são identificadas por não-especialistas (e.g. coleta de dados por ciência cidadã), as espécies de grande porte e comuns tendem a ser mais frequentemente reportadas do que espécies de pequeno porte e raras (FORD & FAHRIG, 2007; ABRA et al., 2018 - Capítulo 1).

Ainda, em países tropicais, o foco da redução dos atropelamentos geralmente se dá pela conservação da biodiversidade em comparação com segurança humana, o que aumenta a inclusão de espécies de pequeno porte nos estudos (BROKIE et al., 2009; BRAZ & FRANÇA, 2016). No entanto, isso não significa que a segurança humana não é uma preocupação em países tropicais. Espécies de grande porte também podem afetar a segurança humana nos trópicos. Por exemplo, na América do Sul: e.g. anta (*Tapirus terrestris*), capivara (*Hydrochoerus hydrochoeris*), veados (*Mazama* spp.), cervo do pantanal (*Blastocerus dichotomus*) (BUENO et al., 2013; HUIJSER et al., 2013; MEDICI et al., 2016), na África: e.g. elefanta Africano (*Loxodonta Africana*), kudu (*Tragelaphus strepsiceros*) (DREWS, 1995; ELOFF & van NIEKERK, 2005), Ásia (e.g. elefante Asiático (*Elephas maximus*) (VIDYA & THUPPIL, 2010), e na Oceania (e.g. cangurus (*Macropus* spp.) (BOND & JONES, 2013; KLÖCKER et al., 2006).

Na América do Sul, pouca informação é disponível sobre o risco que a colisão envolvendo animais em rodovias causa para a segurança humana e custos financeiros associados (Capítulo 4). No entanto, em 2014, a Polícia Rodoviária Federal Brasileira registrou 3.174 colisões envolvendo animais no Sistema Rodoviário Federal (IPEA, 2015). Colisões envolvendo animais em rodovias representaram 1.9% de todos os acidentes registrados dos quais, 40.9% resultaram em vítimas humanas com ferimentos e 2.6% resultaram em mortes humanas (IPEA, 2015).

Especialistas em Ecologia de Estradas em diversos países têm usado localizações georreferenciadas de colisões envolvendo animais em rodovias para investigar padrões espaciais em relação às características das rodovias e da paisagem (RAMP et al., 2005, 2006; MOUNTRAKIS & GUNSON, 2009). Os resultados mostram que as colisões envolvendo animais não são distribuidas aleatoriamente, mas se mostram espacialmente congregados para diversas espécies de vertebrados (JOYCE & MAHONEY, 2001; CLEVENGER et al., 2003; RAMP et al., 2006). Pesquisadores também têm usado novas ferramentas de modelagens para auxiliar nos processos de tomadas de decisão para conservação da biodiversidade (ELITH & LEATHWICK, 2009; FRANKLIN, 2010). Essas ferramentas incluem modelos de predição de atropelamentos (MALO et al., 2004 – Capítulo 3) para identificar variáveis (e.g. paisagem, *design* da rodovia, tráfego), que são associadas com locais de colisões para espécies específicas (FINDER et al., 1999; JOYCE & MAHONEY, 2001; NIELSEN et al., 2003; SAEKI & MACDONALD, 2004; SEILER, 2004; DUSSAULT et al., 2006; GARROTE et al., 2018; WILLIAMS et al., 2019).

Modelos de predição podem ser úteis para agências de meio ambiente e de transporte porque eles permitem a identificação de áreas onde medidas de mitigação para redução dos atropelamentos são mais necessárias (e.g. passagens inferiores de fauna, viadutos vegetados ou ecodutos, cercas, sistemas de detecção animal). Os modelos também podem influenciar o *design* de novas rodovias e predizer quais impactos as rodovias podem ter em relação às populações silvestres.

O propósito principal desta tese foi entender como os atropelamentos de mamíferos impactam a conservação da biodiversidade, segurança humana e economia. Nós também investigamos os padrões temporais e espaciais dos atropelamentos e, pela primeira vez no Brasil, investigamos as perspectivas legais sobre a responsabilidade envolvendo colisão com animais em rodovias e os custos envolvidos. Abaixo, apresentamos como a tese é organizada, seguido de uma breve descrição de cada capítulo.

Capítulo 1: Quão confiáveis são os seus dados? Verificação da identificação de espécies de mamíferos atropelados registrados por inspetores de tráfego nas Rodovias concedidas do Estado de São Paulo.

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Neste capítulo, nós investigamos se os inspetores de tráfego de rodovias concedidas identificaram corretamente espécies de mamíferos atropeladas em uma região tropical: Estado de São Paulo, Brasil. Nós usamos dois métodos diferentes e complementares para verificar a identificação das espécies: i) nós investigamos imagens de mamíferos atropelados associados a dados coletados por inspetores de tráfego, e ii) nós apresentamos imagens de mamíferos vivos e mortos por atropelamento para os inspetores de tráfego e pedimos para eles identificarem as espécies. Finalmente nós formulamos recomendações para melhorar a confiabilidade da identificação das espécies de animais atropelados feitas por não especialistas.

Capítulo 2: Quantos mamíferos silvestres são atropelados por ano no Estado de São Paulo, Brasil? Uma estimativa baseada em dados de atropelamentos coletados por concessionárias de rodovias.

Neste estudo, nós estimamos os números de atropelamentos de mamíferos de médio e grande porte para todas as rodovias pavimentadas do Estado de São Paulo baseado em dados de atropelamentos coletados em rodovias concedidas. Nosso estudo é a primeira abordagem bem documentada que fornece estimativas de números mínimos, máximos, médios e medianos de atropelamentos para mamíferos de médio e grande porte no Estado de São Paulo. Também discutimos as implicações para a conservação biológica, especificamente espécies ameaçadas de extinção.

Capítulo 3: Onde os mamíferos silvestres são atropelados? Modelos preditivos de atropelamentos utilizando variáveis da paisagem no Estado de São Paulo.

Neste capítulo, utilizamos a abordagem MDE para prever os atropelamentos em geral, e oito espécies de mamíferos alvo, no estado de São Paulo, com base em dados de atropelamentos de rodovias concedidas entre 2005 à 2014. Também identificamos pontos críticos de atropelamentos nas mesmas rodovias São Paulo pelo mesmo período. Finalmente, discutimos os resultados da modelagem de atropelamentos preditivos e do hotspot de atropelamentos para o planejamento de mitigação de rodovias existentes ou em planejamento.

Capítulo 4: Pagar ou prevenir? Segurança humana, custos para a sociedade e as perspectivas legais em colisões envolvendo animais no Estado de São Paulo, Brasil.

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Neste capítulo, nós documentamos e exploramos os efeitos das colisões de animais em rodovias na segurança humana no Estado de São Paulo, Brasil. Ainda, nós estimamos os custos destas colisões para a sociedade e resumimos as perspectivas legais no que diz respeito a responsabilidade compensação financeira associada para colisões com animais.

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2. CHAPTER 1: HOW RELIABLE ARE YOUR DATA? VERIFYING SPECIES IDENTIFICATION OF ROAD-KILLED MAMMALS RECORDED BY ROAD MAINTENANCE PERSONNEL IN SÃO PAULO STATE, BRAZIL

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Capítulo 1: Quão confiáveis são os seus dados? Verificação da identificação de espécies de mamíferos atropelados registrados por inspetores de tráfego nas Rodovias concedidas do Estado de São Paulo.

RESUMO

Ao redor do mundo, muitos estudos com animais silvestres são baseados em dados coletados por voluntários. Estudos de atropelamentos de animais frequentemente são baseados em dados coletados por não-especialistas, incluindo inspetores de tráfegos de rodovias e outros voluntários, mas o controle da qualidade destes dados raramente é aplicado. Nós investigamos se os inspetores de tráfego identificaram corretamente espécies de mamíferos de médio e grande porte atropeladas ao longo das rodovias concedidas do Estado de São Paulo, Brasil. Nós investigamos 3.222 imagens de animais atropelados e comparamos com as descrições originais dada pelos inspetores de tráfego (não-especialistas) com as nossas identificações (especialistas). Nós também apresentamos imagens de animais vivos e atropelados para inspetores de tráfico (n = 179) de cinco concessionárias diferentes e pedimos aos colabores para descrever o nome comum das espécies. Nós vimos que os inspetores de tráfego identificam corretamente certas espécies que são comuns, de grande porte e mais reconhecíveis. No entanto, espécies raras, espécies raramente avistadas ou espécies que se assemelham a outras espécies (e.g. pequenos felideos e canídeos silvestres), ou espécies que não são facilmente reconhecíveis são frequentemente identificadas de forma incorreta, de forma ambígua, ou não identificadas. Nós também encontramos que a habilidade dos inspetores de tráfego em identificar canídeos e felideos mais comuns é independente do contexto. A fim de melhorar a identificação de espécies por não-especialistas, nós recomendamos treinamento sobre identificação, uso de escalas em registros fotográficos para reporte das carcaças e, quando necessário a validação da identificação das espécies feita por especialistas.

Palavras-chave: Ciência cidadã; Rodovias; Identificação de espécies; Ecologia de estradas; Não-especialistas; Atropelamentos

Chapter 1: How reliable are your data? Verifying species identification of road-killed mammals recorded by road maintenance personnel in São Paulo State, Brazil

ABSTRACT

Across the world, many wildlife studies rely on data collected by volunteers. Roadkill studies often rely on data collected by non-experts including road maintenance personnel and volunteers, but data quality control is rarely applied. We investigated whether maintenance personnel correctly identified the species of road-killed mammals along toll roads in São Paulo State, Brazil. We investigated 3,222 images of road-killed animals and compared the original species descriptions by road maintenance personnel ("non-experts") with our identification ("experts"). We also presented images of alive and road-killed mammals to road maintenance personnel (n= 179) and asked them to describe the species. We found that road maintenance personnel typically correctly identified certain common, large, or highly recognizable species. However, rare or rarely seen species, species that resemble other species (e.g. small wild canids and felids), or species that are not highly recognizable were often misidentified, ambiguously described, or not identified at all. We also found that the ability of road maintenance personnel to correctly identify the most common road-killed small wild canids and felids is dependent on the context. When similar species are rare, road maintenance personnel typically correctly identifies the most common road-killed small wild canids and felids. However, common small canids and felids are not reliably identified if similar species are more abundant. To improve the reliability of species identification by non-experts, we recommend training in species identification, including images with a scale to accompany all roadkill records, and verification of the roadkill records and associated images for selected species by experts.

Keywords: Citizen science; Highways; Species-identification; Road ecology; Non-experts; Roadkill

2.1. INTRODUCTION

Across the world, many scientific studies rely on data collected by volunteers. The reasons are varied, but they include a) Project goals that are too ambitious in time or money to be conducted by paid professionals on their own, b) Making use of local knowledge and experience, c) Engaging the public and other stakeholder groups, and d) The public and organized stakeholders taking initiative to document an issue that they would like to see addressed (e.g. HADJ-HAMMOU et al., 2017; NEWSON et al., 2017; STEGER et al., 2017). Despite the growing use of data collected by volunteers and non-experts in science there are often problems or perceived problems with the data quality (JOLLYMORE et al., 2017; MITCHELL et al., 2017; TREDICK et al., 2017).

Many citizen science projects in the biological and ecological sciences require species identification by volunteers or non-experts. However, the ability of volunteers or non-experts to correctly identify the species varies widely between species, and rare species tend to be most difficult to identify correctly (SWANSON et al., 2016; RÜDISSER et al., 2017; VANTIEGHEM et al., 2017). Nonetheless, in the field of road ecology volunteers or non-experts have been found to correctly identify 97% of the reported road-killed animals for which an image was available (WAETJEN & SHILLING, 2017). Species or species groups that were most commonly misidentified were squirrels, other small mammal species, and birds (WAETJEN & SHILLING, 2017). However, volunteers or non-experts, especially those that are only occasional contributors, are also known to report charismatic and easily identifiable species more than other species groups (PAUL et al., 2014; PÉRIQUET et al., 2018). In this article, we further explore the reliability of species identification of road-killed animals by non-experts.

Wildlife-vehicle collisions are a concern around the world and it affects human safety, property and wildlife (CONOVER et al., 1995). Many roadkill studies focus on large common mammal species (usually mainly ungulates), as they pose the greatest threat to human safety in Europe (e.g.; GROOT BRUINDERINK & HAZEBROEK, 1996), Africa (e.g. DREWS, 1995; ELOFF & van NIEKERK, 2005), North America (e.g. HUIJSER et al., 2009), South America (e.g. BUENO et al., 2013; HUIJSER et al., 2013; MEDICI et al., 2016), Asia (VIDYA & THUPPIL, 2010), and Oceania (e.g. KLÖCKER et al., 2006; BOND & JONES 2013). However, if the focus is also on biological conservation or biological diversity in general, then rare, threatened, or endangered species, or all species are important, independent of their body size (e.g. BROKIE et al., 2009; BRAZ & FRANÇA, 2016). Since biodiversity in the tropics tends to be higher than in temperate regions, roadkill studies in the tropics tend to report a wide range of species including relatively rare and small species (HOBDAY & MINSTRELL, 2008; BASKARAN & BOOMINATHAN, 2010; WANG et al., 2013; MOHAMMADI & KABOLI, 2016).

For non-experts, it is typically easier to correctly identify large mammals that are hit by vehicles than smaller sized species as it is more likely that at least some portion of a large animal has remained intact (SANTOS et al., 2016). Furthermore, in areas with high biodiversity, species identification is typically more challenging because there are often multiple species that have similar appearance, for example small wild Felids from genus *Leopardus*. For these reasons, it may be harder for non-experts to correctly identify road-killed mammals in the tropics than, for example, in North America or Europe. Non-experts also tend to use species descriptions based on common names which can be confusing and may result in unclear data that is excluded from further analyses (FORD & FAHRIG, 2007; SWANSON et al., 2016). Species descriptions based on common names can relate to more than one species, or the same common name may be associated with different species depending on the region. Yet, many roadkill studies, including those from the tropics, rely on data collected by non-experts (HUIJSER et al., 2013; VERCAYIE & HERREMANS, 2015; BÍL et al., 2017).

Non-experts include law enforcement personnel (e.g. crash reports), road maintenance personnel (carcass removal data), and volunteers (carcass observation data) (LEE et al., 2006; HUIJSER et al., 2007; HEIGL et al., 2017). The most severe wildlife-vehicle crashes, e.g. those with at least an estimated US$1,000 in vehicle repair costs and those that include human injuries and human fatalities, are reported by law enforcement personnel and are included in crash databases (HUIJSER et al., 2007). It is typically a standard task of road maintenance personnel to remove and report carcasses of large mammals on or near the highway as they present a safety hazard for the traveling public (HUIJSER et al., 2007). Large mammal-vehicle collision data collected by road maintenance personnel or law enforcement personnel are typically readily available, they tend to have (the potential for) similar search and reporting effort in time and space, and they often relate to large geographical areas. However, the data may still have varying spatial accuracy, especially when cross-roads or other landscape features are used as a location description rather than mile reference posts or coordinates based on a Global Positioning System (HUIJSER et al., 2007). In some cases, citizens (or volunteers) are asked to submit observations of road-killed wildlife. These observations are typically incidental and lack documented search or reporting effort. Such citizen science programs are sometimes targeted at rare or small species that are not well represented in the data collected by road maintenance crews or law enforcement personnel (e.g. MCCLINTOCK et al., 2015; HEIGL et al., 2017). Citizen science data can relate to specific highway sections, but they can also relate to much larger geographical areas (e.g. LEE et al., 2006 vs. SHILLING & WAETJEN, 2015). Though citizen science data typically have undocumented search and reporting effort, they can still have spatial similarity to data collected by researchers or others that used consistent search and reporting effort (PAUL et al., 2014).

While many roadkill studies rely on data collected by non-experts, data quality control is often lacking (but note these exceptions: PAUL et al., 2014; DWYER et al., 2016; SWANSON et al., 2016; PÉRIQUET et al., 2018). In this study, we investigated whether road maintenance personnel ("non-experts") correctly identified the species of the road-killed wild mammals in a tropical region: São Paulo State, Brazil. We used two different and complementary methods to verify species identification: i) We investigated images of road-killed mammals that were associated with the data collected by road maintenance personnel, and ii) We presented images of alive and dead mammals to road maintenance personnel and asked them to identify the species. Finally, we formulated recommendations to improve the reliability of species identification of road-killed animals by non-experts. We believe the findings and recommendations do not only apply to our study area, but that they are also useful elsewhere throughout the world where wildlife data, specifically roadkill data, are collected by people who are not experts in species identification.

2.2. MATERIALS AND METHODS

2.2.1. Datasets

We investigated the reliability of species identification by road maintenance personnel of road-killed animals. We used two different methods, each with their corresponding data sets and analyses:

2.2.1.1. Data set 1: Roadkill records and associated images collected by road maintenance personnel

We received 3,222 records of road-killed mammals observed by road maintenance personnel from five different toll roads companies: Autovias, Cart, Centrovias, Intervias and SPVias (Appendix A). One expert (i.e. a researcher) viewed each image associated with the records and identified the species or species group independent from the original Portuguese species description provided by road maintenance personnel. In case the expert was uncertain of the species, a second researcher examined the image as well. We tested the reliability of species identification in roadkill data collected by road maintenance personnel by comparing the original species descriptions by road maintenance personnel (non-experts) to our species identification (experts).

2.2.1.2. Data set 2: Classroom species identification test

We visited five different offices of toll road maintenance personnel in São Paulo State. The five locations were at the most 130 km apart (Jundiaí, São Carlos, Sertãozinho, Araras, Itatiba). The meetings took place in a classroom setting. We presented images of 34 wild mammal species (dead and alive) known to occur in São Paulo State to the road maintenance personnel and asked them to write down the names of the species on a form (Table 1). In total, 179 people participated in the identification tests (Table 1). Identifying road-killed species was part of the daily task of the participants. We only presented images of adult animals and each image had a scale included in the image so that the participants were aware of the true size of the animal in each image. All images showed the animals (dead and alive) from the side and all images (dead and alive) clearly showed the most important species characteristics. Because we did not use images of heavily mutilated road-killed animals, the results represent an optimistic scenario for the species identification skills of road maintenance personnel. Each image was shown for 20 seconds during which the participants were asked to write down the species name.

We prepared three different versions of the test. Each test had different sets of images to reduce potential effects associated with an individual image (i.e. a particular image may be harder or easier to identify by the participants, independent of how well they can identify the species involved). We selected eight species for which multiple images were presented in each test (typically 5 alive, 5 dead, 15 different alive and 15 different dead images in total for the three tests). For other species only one image (1 alive, 3 different alive images in total) was presented in each test (Table 1). See Appendix B and C for which Portuguese species descriptions we deemed to be correct for the individual species.

Table 1. Number of species images showed for each test. *Images of the species *Eira barbara*, *Conepatus semistriatus*, *Leopardus guttulus* and *Puma yagouaroundi* were presented to fewer participants because the images were added later after the first groups of participants had already taken Test 1, 2 or 3.

Species	Participants (n)	Test 1 (n = 78) Alive	Test 1 (n = 78) Dead	Test 2 (n = 62) Alive	Test 2 (n = 62) Dead	Test 3 (n = 39) Alive	Test 3 (n = 39) Dead
Capybara (*Hydrochoerus hydrochaeris*)	179	5	5	5	5	5	5
Maned wolf (*Chrysocyon brachyurus*)	179	6	4	6	4	6	4
Hoary fox (*Lycalopex vetulus*)	179	5	5	5	5	5	5
Crab-eating fox (*Cerdocyon thous*)	179	5	5	5	5	5	5

Table 1. Number of species images showed for each test. *Images of the species *Eira barbara*, *Conepatus semistriatus*, *Leopardus guttulus* and *Puma yagouaroundi* were presented to fewer participants because the images were added later after the first groups of participants had already taken Test 1, 2 or 3.

		Test 1 (n = 78)		Test 2 (n = 62)		Test 3 (n = 39)	
Species	Participants (n)	Alive	Dead	Alive	Dead	Alive	Dead
Puma (*Puma concolor)*	179	5	5	5	5	5	5
Ocelot (*Leopardus pardalis*)	179	5	5	5	5	5	5
Southern tamandua (*Tamandua tetradactyla*)	179	4	5	4	5	4	5
Giant anteater (*Myrmecophafa tridactyla*)	179	6	4	5	5	5	5
Jaguar (*Panthera onca*)	179	1		1		1	
South American tapir (*Tapirus terrestris*)	179	1		1		1	
South American coati (*Nasua nasua*)	179	1		1		1	
Crab-eating raccoon (*Procyon cancrivorus*)	179	1		1		1	
Spotted paca (*Cuniculus paca*)	179	1		1		1	
Azara´s agouti (*Dasyprocta azarae*)	179	1		1		1	
Coypu (*Myocastor coypus*)	179	1		1		1	
Brown-throated sloth (*Bradypus variegatus*)	179	1		1		1	
Brazilian cottontail (*Sylvilagus brasiliensis*)	179	1		1		1	
European hare (*Lepus europaeus*)	179	1		1		1	
Neotropical otter (*Lontra longicaudis*)	179	1		1		1	
Lesser grison (*Galictis cuja*)	179	1		1		1	
Gray brocket (*Mazama gouazoubira*)	179	1		1		1	
Feral pig (*Sus scrofa*)	179	1		1		1	
Brazilian porcupine (*Coendou prehensilis*)	179	1		1		1	
Collared peccary (*Pecari tajacu*)	179	1		1		1	
White-lipped peccary (*Tayassu pecari*)	179	1		1		1	
Nine-banded armadillo (*Dasypus novemcintus*)	179	1		1		1	
Brazilian squirrel (*Guerlinguetus ingrami*)	179	1		1		1	
White-eared opossum (*Didelphis albiventris*)	179	1		1		1	
Domestic dog (*Canis lupus familiaris*)	179	1		1		1	
Domestic cat (*Felis catus*)	179	1		1		1	
Tyra (*Eira barbara*)*	60	1		1		1	
Striped hog-nosed skunk (*Conepatus semistriatus*)*	60	1		1		1	
Southern tiger cat (*Leopardus guttulus*)*	60	1		1		1	
Jaguarundi (*Puma yagouaroundi*)*	60	1		1		1	

2.2.1.3. Portuguese species description, species names, and species identification

Road maintenance personnel ("non-experts") always used Portuguese names to describe the species. In this paper, Portuguese names always relate to the species descriptions by road maintenance personnel which can be "correct", "incorrect" or ambiguous. English common names or scientific names always relate to animals whose species or species group was identified by the researchers ("experts") based on images. Consequently, English common names or scientific names are always considered "correct".

2.2.2. Analyses

2.2.2.1. Data set 1: Roadkill records and associated images collected by road maintenance personnel

We went back to the common names that were recorded by toll road maintenance personnel ("non-experts"). For each Portuguese common name or each variation in Portuguese common name recorded by the "non-experts", we tallied what species or species group the common name actually related to (based on the images associated with each record). We then classified which Portuguese common names were associated with which species (based on the images) for ≥ 70%, ≥ 80% and ≥ 90% of the records.

2.2.2.2. Data set 2: Classroom species identification test

For all species that we showed images of to the toll road maintenance personnel ("non-experts"), we calculated the percentage of the Portuguese species descriptions that was "correct", "maybe correct", and "incorrect". recorded by the "non-experts". We considered a Portuguese species descriptions identification "incorrect" when the Portuguese species description was not associated with the actual species shown on an image. The latter category also included records that were left blank by the participants.

For the eight species (maned wolf (*Chrysocyon brachyurus*), crab-eating fox (*Cerdocyon thous*), hoary fox (*Lycalopex vetulus*), puma, (*Puma concolor*), ocelot (*Leopardus pardalis*), capybara (*Hydrochoerus hydrochaeris*), southern tamandua (*Tamandua tetradactyla*), and giant anteater (*Myrmecophaga tridactyla*), we showed about five images dead and alive for, we made boxplots to visualize the percentage of "correct" and "correct +

maybe correct" species descriptions. We plotted the data for alive and dead images separately. We made separate boxplots for canids, felids, and anteater species. For these species we also conducted a Man-Whitney-U non-parametric test (2-sided) to investigate if there were differences between identification of images that showed the same species alive versus dead ("correct" and "correct + maybe correct").

For the remaining 26 species that we only showed live images for, we summarized the results with descriptive statistics only. This still allowed for a general evaluation of the participants ability to identify those species. The ability of the participants to correctly identify individual species was classified as excellent (≥ 80-100%), good (≥ 60-<80%), moderate (≥ 40-<60%), poor (≥ 20-<40%) and very poor (≥ 0-<20%).

2.3. RESULTS

2.3.1. Which Portuguese common names for road-killed animals relate to what species?

For data set 1, Portuguese common names for road-killed mammals that had the highest reliability (≥ 90%) with being associated with a particular species and that had a sample size of at least 15, were "lobo-guará" and "lobo" for maned wolf (*Chrysocyon brachyurus*), "cachorro-do-mato" for crab-eating fox (*Cerdocyon thous*), "coelho" and "lebre" for European hare (*Lepus europaeus*), "capivara" for capybara (*Hydrochoeris hydrochaeris*), and "tamanduá-mirim" for southern tamandua (*Tamandua tetradactyla*) (Table 2, Fig. 1). The following species names were less reliably (≥ 80%) associated with a certain species: "onça" and "onça-parda" for puma (*Puma concolor*), "jaguatirica" for ocelot (*Leopardus pardalis*), "tamanduá" for southern tamandua (*Tamandua tetradactyla*), and "tamanduá-bandeira" for giant anteater (*Myrmecophaga tridactyla*). The following species names were even less reliably (≥70%) associated with a certain species: "raposa" and "cachorro" for crab-eating fox (*Cerdocyon thous*) and "veado" for gray brocket (*Mazama gouazoubira*).

All Portuguese species descriptions for the 34 species that were reported by road maintenance personnel are summarized in Appendix B and C. For data set 2, Portuguese species descriptions for road-killed animals that had the highest reliability (≥ 90%) with being associated with a particular species and that had a sample size of at least 20, were "capivara" for capybara (*Hydrochoeris hydrochaeris*), "gato-do-mato", "jaguatirica", and "onça-pintada" for ocelot (*Leopardus pardalis*), "onça-parda", "puma", and "suçuarana" for puma (*Puma *concolor*), and "tamanduá-mirim" for southern tamandua (*Tamandua tetradactyla*) (Table 3, Fig. 1). The following species names were less reliably associated with a certain species: "lobo-guará" for maned wolf (*Chrysocyon brachyurus*) and "tamanduá-bandeira" for giant anteater (*Myrmecophaga tridactyla*) (all ≥ 80%), and "onça" for puma (*Puma concolor*) (≥ 70%). Note that the analyses for data set 2 were limited to the eight species that had multiple images for each road-killed species in each test (typically 5 images, 15 different "dead" images in total).

Table 2. Data set 1: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these descriptions relate to. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%. Only species with percentages ≥ 5% were included in the table.

Portuguese species description	**N**	***H. hydrochaeris* (N, %)**	***M. coypus* (N, %)**	***S. villosus* (N, %)**	***Ouriço ni* (N, %)**	***C. villosus* (N, %)**	***L. europaeus* (N, %)**	***C. paca* (N, %)**	***C. aperea* (N, %)**	***D. novemcinctus* (N, %)**	***T. tetradactyla* (N, %)**	***Didelphis* sp. (N, %)**
Capivara	1234	1230 (99.6)						1 (0.08)				
Castor	3		3 (100)									
Cutia	1										1 (100)	
Ouriço	46			18 (39.13)	18 (39.13)	8 (17.40)						
Paca	3							3 (100)				
Preá	2								1 (50.00)			1 (50.00)
Ratão-do-banhado	9		9 (100)									
Rato-do-banhado	4		4 (100)									
Roedor	7	1 (14.28)	1 (14.30)				4 (57.15)			1 (14.28)		

		***C. thous* (N, %)**	***C. brachyurus* (N, %)**	***L. vetulus* (N, %)**	***P. cancrivorus* (N, %)**	***Didelphis* sp. (N, %)**	***D. albiventris* (N, %)**	***H. hydrochaeris* (N, %)**	***L. europaeus* (N, %)**	***Leopardus* sp. (N, %)**	***M. gouazoubira* (N, %)**
Cachorro	19	14 (73.68)			1 (5.30)			2 (10.52)	1 (5.26)		1 (5.26)
Cachorro-do-mato	191	174 (91.09)									
Cachorro-doméstico	6	4 (66.66)				1 (16.66)		1 (16.66)			

Table 2. Data set 1: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these descriptions relate to. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%. Only species with percentages ≥ 5% were included in the table.

Canino	5	3 (60 %)					1 (20.00)			1 (20.00)	
Lobinho	1	1 (100)									
lobo	30	2 (2.67)	27 (90)								
lobo-do-mato	1				1 (100)						
Lobo-guará	103	7 (6.80)	96 (93.20)								
Raposa	265	200 (75.50)		32 (12.10)	23 (8.70)						
Raposa-do-campo	1			1 (100)							
		***P. cancrivorus* (N, %)**	***D. albiventris* (N, %)**	***N. nasua* (N, %)**	***Didelphis* sp. (N, %)**	***G. cuja* (N, %)**	***C. semistriatus* (N, %)**	***L. longicaudis* (N, %)**	***Mamiferoni* (N, %)**	***M. coypus* (N, %)**	***E. barbara* (N, %)**
Mão-pelada	12	12 (100)									
Lontra	6							4 (66.66)		2 (33.33)	
Guaxinim	6	6 (100)									
Quati	35	21 (60)		12 (34.30)					2 (5.71)		
Furão	3					2 (66.66)					1 (33.33)
Gambá	35	3 (8.60)	13 (37.15)		9 (25.70)	3 (8.50)	5 (14.30)				
		***P. concolor* (N, %)**	***L. pardalis* (N, %)**	***Leopardus* sp. (N,**	***P. yagouaround***	***C. thous* (N, %)**	***C. brachyurus***	***E. barbara* (N, %)**	***L. europaeus***		

Table 2. Data set 1: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these descriptions relate to. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%. Only species with percentages ≥ 5% were included in the table.

				%)	***i* (N, %)**		**(N, %)**		**(N, %)**
Felino	2			1 (50)			1 (50.00)		
Filhote de jaguatirica	2			2 (100)					
Gato	7		1 (14.30)	1 (14.30)	2 (28.60)	1 (14.30)		1 (14.28)	1 (14.28)
Gato do mato	2			1	1 (50)				
Jaguatirica	37		33 (89.20)	2 (5.40)					
Leopardo	1	1 (100)							
Onça	43	35 (81.4)	7 (16.30)						
Onça-parda	16	14 (87.5)			2 (12.50)				
		***H. hydrochaeris* (N, %)**	***C. thous* (N, %)**	***L. europaeus* (N, %)**	***P. cancrivorus* (N, %)**	***C. brachyurus* (N, %)**			
Não identificado	352	109 (30.96)	74 (21.00)	27 (7.70)	21 (5.96)	18 (5.11)			
		***D. novemcinctus* (N, %)**	***E. sexcinctus* (N, %)**	***Tatu ni* (N, %)**	***Dasypus* sp. (N, %)**	***T. tetradactyla* (N, %)**			
Tatu	196	93 (47.45)	60 (30.60)	22 (11.22)	20 (10.20)				

Table 2. Data set 1: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these descriptions relate to. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%. Only species with percentages ≥ 5% were included in the table.

Xenarthra	2					2 (100)
		***A. caraya* (N, %)**	***Callitrix* sp. (N, %)**	***S. apela* (N, %)**		
Macaco	12	5 (41.66)	4 (33.33)	3 (25)		
		***T. tetradactyla* (N, %)**	***M. tridactyla* (N, %)**			
Tamanduá	117	102 (87.18)	13 (11.11)			
Tamanduá-mirim	45	43 (95.55)	2 (4.44)			
Tamanduá-bandeira	24	3 (12.5 %)	21 (87.50)			
		***M. gouazoubira* (N, %)**	***Mazama* sp. (N, %)**			
Cervo	3	2 (66.66)	1 (33.33)			
Veado	79	58 (73.40)	21 (26.60)			
Veado-campeiro	1	1 (100)				
		S. scrofa				

Table 2. Data set 1: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these descriptions relate to. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%. Only species with percentages ≥ 5% were included in the table.

		(N, %)
Javali	1	1 (100)
Porco-do-mato	1	1 (100)
suino	1	1 (100)
		***L. europaeus* (N, %)**
Coelho	33	33 (100)
Lebre	215	212 (98.6)
		***T. terrestris* (N, %)**
Anta	2	2 (100)

Table 3. Data set 2: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these species descriptions relate to for imaged of road-killed animals. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%.

Common name	**N**	***C. thous* (N, %)**	***L. vetulus* (N, %)**	***C. brachyurus* (N, %)**	***P. concolor* (N, %)**	***L. pardalis* (N, %)**	***T. tetradactyla* (N, %)**	***M. trydactyla* (N, %)**	***H. hydrochaeris* (N, %)**
Anta	1								1 (100)
Bicho preguiça	10						8 (80,00)	2 (20,00)	
Cachorro	87	41 (47,13)	42 (48,28)	3 (3,45)			1 (1,15)		
Cachorro do mato	564	330 (58,51)	220 (39,01)	13 (2,30)		1 (0,18)			
Cachorro filhote	3	3 (100)							
Cachorro vinagre	1	1 (100)							
Capivara	891								891 (100)
Cervo	1			1 (100)					
Filhote de onça	2					2 (100)			
Filhote de onça pintada	2					2 (100)			
Gambá	16						14 (87,50)	2 (12,50)	
Gato	26	5 (19,23)				21 (80,77%)			
Gato doméstico	1					1 (100)			
Gato do mato	107	3 (2,80)	1 (0,93)		1 (0,93)	102 (95,33)			
Guará	13	1 (7,69)		12 (92,31)					
Guaxinim	2	1 (50,00)		1 (50,00)					
Guepardo	1				1 (100)				
Jaguatirica	466				2 (0,43)	464 (99,57)			
Jaguar	1				1 (100)				
Javali	1		1 (100)						

Table 3. Data set 2: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these species descriptions relate to for imaged of road-killed animals. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%.

Common name	**N**	***C. thous*** **(N, %)**	***L. vetulus*** **(N, %)**	***C. brachyurus*** **(N, %)**	***P. concolor*** **(N, %)**	***L. pardalis*** **(N, %)**	***T. tetradactyla*** **(N, %)**	***M. trydactyla*** **(N, %)**	***H. hydrochaeris*** **(N, %)**
Left blank	225	50 (22,22)	70 (31,11)	22 (9,78)	6 (2,67)	23 (10,22)	40 (17,78)	12 (5,33)	2 (0,89)
Leopardo	3				2 (66,67)	1 (33,33)			
Leoa	3				3 (100,00)				
Lobo	462	86 (18,61)	126 (27,27)	250 (54,11)					
Lobinho	3	2 (66,67)	1 (33,33)						
Lobo do mato	8	2 (25,00)		6 (75,00)					
Lobo guará	609	24 (3,94)	42 (6,90)	542 (89,00)				1 (0,16)	
Onça pintada	178				1 (0,56)	177 (99,44)			
Onça	325	1 (0,31)	1 (0,31)		230 (70,77)	93 (28,62)			
Onça do mato	5				2 (40,00)	3 (60)			
Onça malhada	1					1 (100)			
Onça parda	536		1 (0,19)		531 (99,07)	4 (0,75)			
Onça suçuarana	3				3 (100)				
Preguiça	7				1 (14,29)		5 (71,43)	1 (14,29)	
Puma	21				21 (100)				
Quati	5	2 (40,00)		1 (20,00)				2 (40,00)	
Raposa	771	342 (44,36)	386 (50,06)	42 (5,45)			1 (0,13)		
Raposa do mato	2	1 (50,00)	1 (50,00)						
Suçuarana	91		1 (1,10)		90 (98,90)				
Tamanduá	881						518 (58,80)	362 (41,09)	1 (0,11)

Table 3. Data set 2: Portuguese species descriptions (by road maintenance personnel) and the actual species (scientific names) these species descriptions relate to for imaged of road-killed animals. Darkest shade = ≥ 90%, medium shade = ≥ 80%, lightest shade = ≥ 70%.

Common name	**N**	***C. thous*** **(N, %)**	***L. vetulus*** **(N, %)**	***C. brachyurus*** **(N, %)**	***P. concolor*** **(N, %)**	***L. pardalis*** **(N, %)**	***T. tetradactyla*** **(N, %)**	***M. trydactyla*** **(N, %)**	***H. hydrochaeris*** **(N, %)**
Tamanduá bandeira	397						73 (18,39)	324 (81,61)	
Tamanduá mirim	245			1 (0,41)			232 (94,69)	12 (4,90)	
Tigre	1							1 (100)	
Veado	3		2 (66,67)	1 (33,33)					

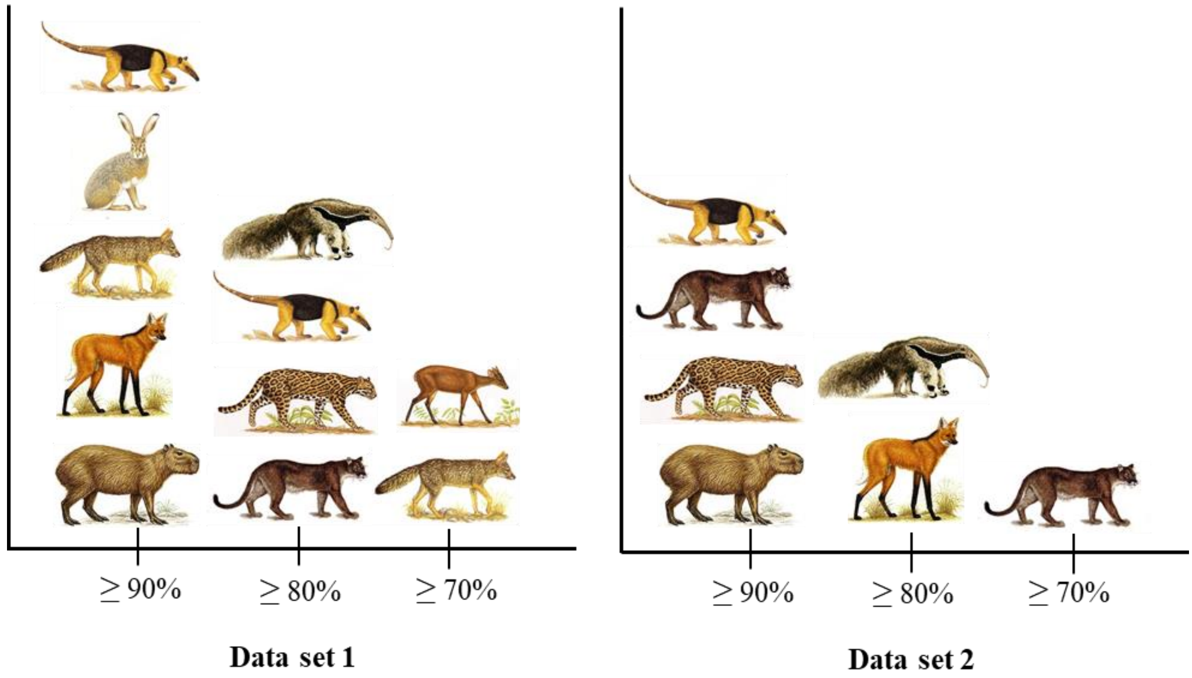

Figure 1. Reliability of species identification by road maintenance personnel based on Data set 1 and Data set 2. Note that same species can occur more than once in the same graph because of variations in the Portuguese species description.

2.3.2. Are species correctly identified based on images that show them alive?

For dataset 2, we calculated the percentages of "correct" and "maybe correct" identification for all 34 species ("alive" individuals only) (Table 4; Appendix D). The species that were most often correctly identified ("correct category") were South American tapir (*Tapirus terrestris*), brown-throated sloth (*Bradypus variegatus*), domestic cat (*Felis catus*), domestic dog (*Canis lupus familiaris*), Brazilian porcupine (*Coendou prehensilis*), Brazilian squirrel (*Guerlinguetus ingrami*), and capybara (*Hydrochoerus hydrochaeris*). In addition, jaguar (*Panthera onca*), European hare (*Lepus europaeus*), gray brocket (*Mazama gouazoubira*), feral pig (*Sus scrofa*), nine-banded armadillo (*Dasypus novemcintus*), maned wolf (*Chrysocyon brachyurus*), puma (*Puma concolor*), southern tamandua (*Tamandua tetradactyla*), and giant anteater (*Myrmecophaga tridactyla*) were most often correctly identified when the "maybe correct" category was included.

Table 4. The ability of road maintenance personnel to correctly identify 34 mammal species based on images of alive individuals. If a species had a similar score for correct vs. correct and maybe correct, it was only listed in the correct column.

Knowledge about the species (% of average identification)	"Correct"	"Correct and maybe correct"
Very good (>80-100%)	*Tapirus terrestris, Bradypus variegatus, Felis catus, Canis lupus familiaris, Coendou prehensilis, Guerlinguetus ingrami, Hydrochoerus hydrochaeris*	*Panthera onca, Mazama gouazoubira, Sus scrofa, Dasypus novemcintus, Chrysocyon brachyurus, Puma concolor, Tamandua tetradactyla, Myrmecophaga tridactyla*
Good (≥60-79%)	*Didelphis albiventris, Nasua nasua, Procyon cancrivorus, Cuniculus paca, Panthera onca, Lontra longicaudis, Chrysocyon brachyurus, Puma concolor, Lepus europaeus*	*Lepus europaeus, Leopardus pardalis*
Moderate (≥40-59%)	*Sus scrofa, Leopardus gutullus, Lycalopex vetulus, Leopardus pardalis, Myrmecophaga tridactyla*	*Dazyprocta azarae, Myocastor coypus, Sylvilagus brasiliensis, Tayassu peccari, Puma yagouaroundi*
Poor (≥20-39%)	*Galictis cuja, Myocastor coypus, Dazyprocta azarae, Cerdocyon thous, Tamandua tetradactyla*	*Pecari tajacu*
Very poor (0-19%)	*Pecari tajacu, Puma yagouaroundi, Conepatus semistriatus, Dasypus novemcintus, Tayassu pecari, Mazama gouazoubira, Sylvilagus brasiliensis*	

2.3.3. Are species shown alive more easily identified than road-killed animals?

For dataset 2, we summarized the "correct" and "correct and maybe correct" species descriptions for the eight species we presented multiple images for in each test in boxplots and tested for potential differences between the identification of "alive" and "dead" individuals (Fig. 2 and 3, Table 5). In general, the ability of road maintenance personnel to correctly identify the species was not significantly different between images of animals that were "dead" versus "alive". However, the following species were significantly ($p \leq 0.05$) more frequently correctly identified based on "alive" images compared to "dead" images: hoary fox

(*Lycalopex vetulus*), giant anteater (*Myrmecophaga tridactyla*), and for maned wolf (*Chrysocyon brachyurus*) this trended towards significance (p=0.064; Table 5).

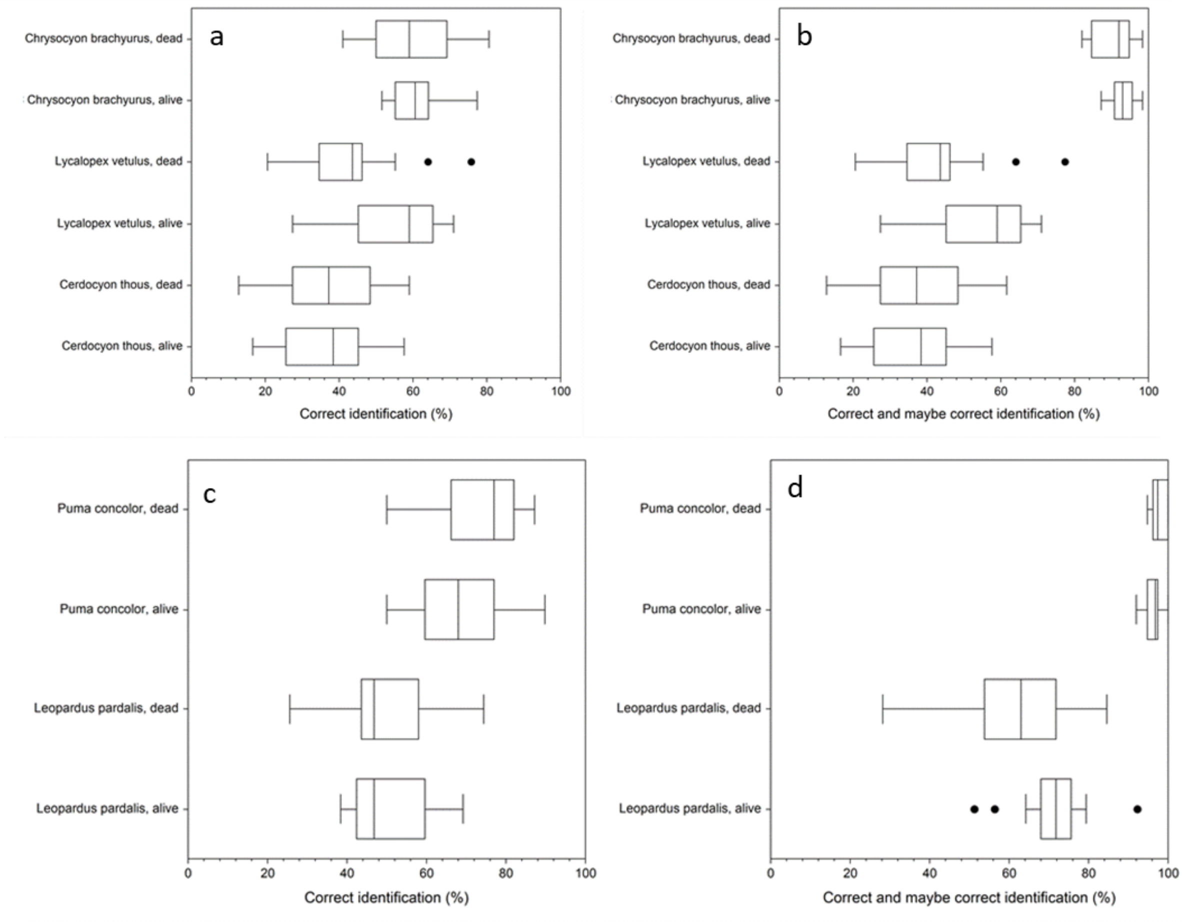

Figure 2. Box plots of the percentages of "correct" and "correct" and "maybe correct" identification for canids (a and b) and felids (c and d). Box: middle 50% of the data (25–75 quartile); vertical line: median; whisker boundaries: 1.5 times inter-quartile range; dots: outliers.

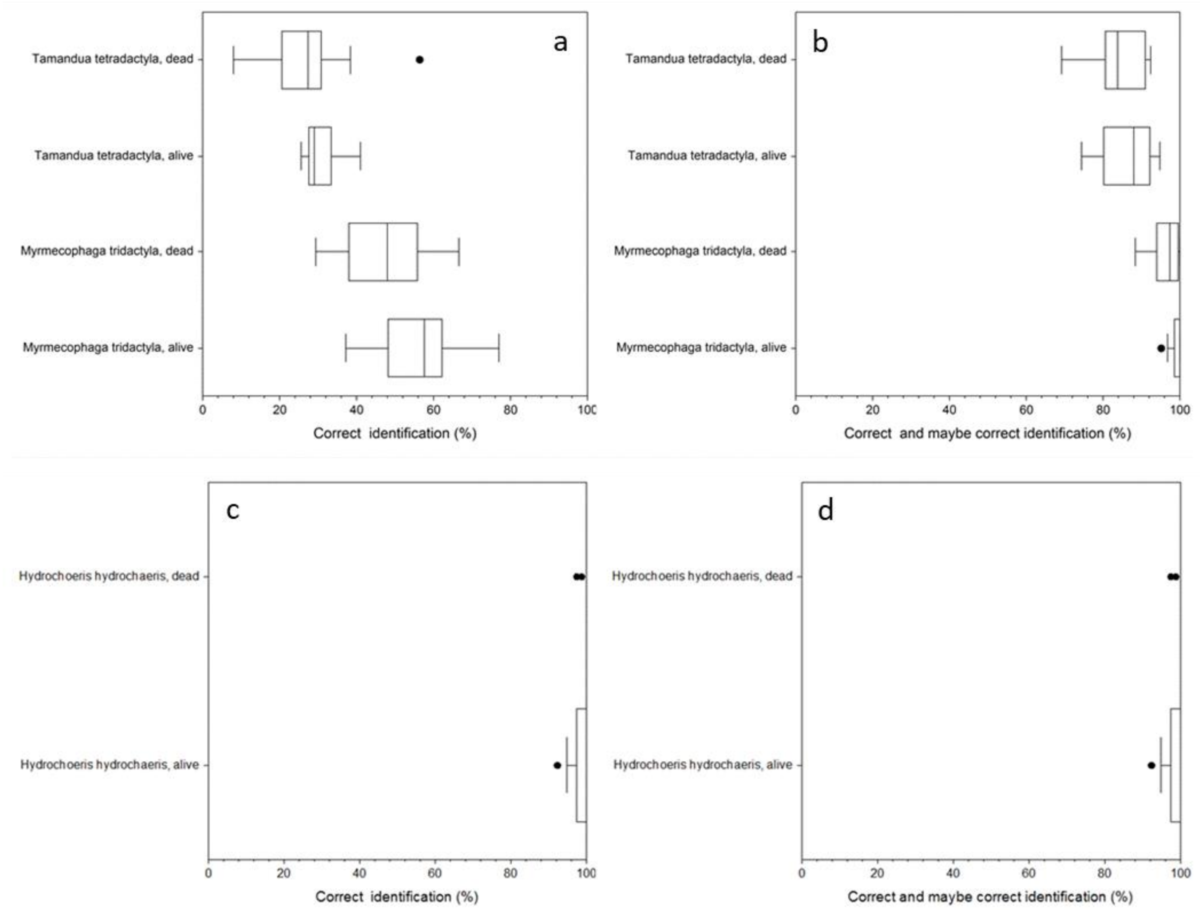

Figure 3. Box plots of the percentages of “correct” and “correct” and “maybe correct” identification for anteaters (a and b) and capybara (c and d). Box: middle 50% of the data (25–75 quartile); vertical line: median; whisker boundaries: 1.5 times inter-quartile range; dots: outliers.

Table 5. The differences in the ability of road maintenance personnel to identify species when they are "alive" vs. "dead". Two sided Mann-Whitney-U test.

	Correct identification			Correct and maybe correct identification		
Species	**Difference alive vs. dead?**	**Z-value**	**p-value**	**Difference alive vs. dead?**	**Z-value**	**p-value**
Maned wolf (*Chrysocyon brachyurus*)	no	-0.362	0.717	no	-1.849	0.064
Hoary fox (*Lycalopex vetulus*)	yes	2.407	0.016	yes	2.407	0.016
Crab-eating fox (*Cerdocyon thous*)	no	-0.083	0.934	no	-0.083	0.934
Puma (*Puma concolor*)	no	-1.475	0.140	no	-1.517	0.129
Ocelot (*Leopardus pardalis*)	no	-0.333	0.739	no	1.640	0.101
Southern tamandua (*Tamandua tetradactyla*)	no	1.419	0.156	no	0.831	0.406
Giant anteater (*Myrmecophaga tridactyla*)	yes	-2.014	0.044	yes	-2.494	0.013
Capybara (*Hydrochoerus hydrochaeris*)	no	-1.043	0.297	no	-0.961	0.337

2.4. DISCUSSION

In our study, the two methods used were complementary and strengthened our conclusions regarding the reliability of species identification of road-killed animals by non-experts. The data showed that non-experts usually correctly identified certain common, large, or highly recognizable species, similar to the findings of Waetjen & Shilling (2017) and Périquet et al. (2018). Rare or rarely seen species (e.g., striped hog-nosed skunk (*Conepatus semistriatus*), lesser grison (*Galictis cuja*), tayra (*Eira barbara*)), species that resemble other species based on body size, shape, and colors (e.g. small wild canid and felid species), or species that are not highly recognizable were often misidentified, ambiguously described, or not identified at all (similar to SWANSON et al., 2016). The records of poorly identified species may need to be combined with other species in a wider taxonomic group for further analyses, investigated further based on interviews or images, or excluded altogether.

The classroom test (data set 2) showed that road maintenance personnel could not reliably distinguish between crab-eating-fox (*Cerdocyon thous*) and hoary-fox (*Lycalopex *vetulus*). While the crab-eating-fox is generally larger than the hoary-fox, there is considerable overlap in the morphological characteristics of the two species which can make species identification difficult for both experts and non-experts. However, the results of our study also showed that road maintenance personnel typically correctly identified road-killed crab-eating-fox (*Cerdocyon thous*) along the highways, but not hoary-fox (*Lycalopex vetulus*) (data set 1). We think this is related to the fact that crab-eating-fox was very numerous in data set 1 (405 observations) compared to hoary-fox (33 observations), and that, therefore, Portuguese common names for crab-eating-fox were often correct, whereas Portuguese common names for hoary fox were rarely correct. Regardless, in the context of the study area, crab-eating-fox was typically correctly identified.

Our study also showed that small wild felid species were not reliably identified. Even though data set 1 showed that ocelot (*Leopardus pardalis*) was usually reliably identified when encountered as roadkill, the classroom test (data set 2) showed that road maintenance personnel could not reliably distinguish between ocelot and southern tiger cat (*Leopardus guttulus*). In addition, jaguarundi (*Puma yagouaroundi*) was not reliably identified in either dataset. We think that ocelot was usually reliably identified in dataset 1 because ocelot was numerous in data set 1 (41 observations) compared to southern tiger cat (zero confirmed observations), and that, therefore, Portuguese common names for ocelot were often correct whereas Portuguese common names for southern tiger cat were never correct. Note that while there were zero confirmed observations of southern tiger cat in data set 1, there may have been southern tiger cats included in the category *Leopardus* sp. (6 observations at a maximum). Regardless, in the context of the study area, ocelot was typically correctly identified.

Except for hoary fox (*Lycalopex vetulus*), giant anteater (*Myrmecophaga tridactyla*), and potentially also maned wolf (*Chrysocyon brachyurus*), the ability of road maintenance personnel to correctly identify the species was not significantly different between images of animals that were "dead" versus "alive". This was somewhat surprising as we expected road-killed animals to be more difficult to identify than animals shown alive. This may be related to the type of images we selected for road-killed animals; all images clearly showed the most important species characteristics and we did not use images of heavily mutilated road-killed animals. Therefore, the results of the "dead" versus "alive" comparison may be an overestimate of the ability of road maintenance personnel to identify road-killed animals in the field. On the other hand, the species identification of road-killed species encountered by road maintenance personal was similar or better than the species identification based on images presented to them in a classroom setting. This is perhaps because road maintenance personnel could investigate a road-killed animal in the field from all sides and at very close distance. This allowed for close examination of the characteristics of the different species such as color, markings, and general body size from different angles. Although the images we presented in the classroom setting showed all the relevant characteristics of the species (including a scale for size reference), images have limitations compared to examining a road-killed animal in a real-world setting. In addition, our classroom test only allowed the participants 20 seconds to identify the species shown on an image whereas no such time limits were imposed when they encountered a road-killed animal along a highway.

To improve the reliability of species identification of road-killed animals by non-experts, we recommend species identification training by experts (similar to STARR et al., 2014; PÉRIQUET et al., 2018), and specialized identification guides to assist non-experts in species identification (e.g. RIJKSWATERSTAAT, 1995; SIELECKI, 2009; BEISIEGEL et al., 2016). We also recommend that non-experts include images of the road-killed animals with the roadkill records and include a scale in the images. We suggest making multiple images of each road-killed animal, including close-ups of the head, legs and feet, and other body parts that may have species-specific markings or other characteristics. The latter is especially relevant if the observer is uncertain of the species name, or if it is suspected to be a species or species group that is known to be often misidentified by non-experts (e.g. small wild canids or felids). Specialized software on smartphones can reduce the effort and errors associated with the data collection process, can improve the spatial accuracy using the integrated Global Positioning System, and can link the images to the individual records for the road-killed species (OLSON et al., 2014; VERCAYIE & HERREMANS, 2015). We also suggest that experts verify the roadkill records and associated images for species that may be a concern for biological conservation and that are known to be poorly identified by road maintenance personnel.

2.5. CONCLUSIONS

We conclude that road maintenance personnel typically correctly identified certain common, large, or highly recognizable species. However, rare or rarely seen species, species that resemble other species (e.g. small wild canids and felids), or species that are not highly recognizable are often misidentified, ambiguously described, or not identified at all. Interestingly, the ability of road maintenance personnel to correctly identify the most common road-killed small wild canids and felids is dependent on the context. When similar less abundant species are rarely encountered, road maintenance personnel typically correctly identifies the most common road-killed small wild canids and felids. But our classroom tests showed that when similar species are presented in equal numbers, road maintenance personnel cannot reliably identify these most common mall wild canids and felids. Therefore, species that may be correctly identified in one region where similar species are rare, may not be correctly identified in another region where similar species are more abundant. To improve the reliability of species identification of road-killed animals, we recommend training for road maintenance personnel and other non-experts in species identification and for them to include images with a scale to accompany all roadkill records. We also suggest that experts verify the roadkill records and associated images for species that may be a concern for biological conservation and that are known to be poorly identified by non-experts. We believe these recommendations do not only apply to our study area, but that they are also useful elsewhere throughout the world where roadkill data are collected by people who are not experts in species identification.

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APPENDIX

The supplementary data include a table with information on the toll road companies that supplied the roadkill data and accompanying images (Appendix A), the Portuguese species descriptions for all species presented during the classroom species identification test (Data set 2) (Appendix B and C) and a table with descriptive statistics for the classroom species identification test (Data set 2) for the categories C = correct and C+M = correct + maybe correct (Appendix D).

Appendix A. Number of images provided and nomenclatures and road characteristics of each toll road.

Toll road company	Total of road length (km)	Images validated (n)	Period (year)	Roads sections
Autovias	316.50	828	2009-2014	SP-330; SP-255; SP-334, SP-345, SP-318
Cart	388.22	610	2009-2014	SP-270; SP-225; SP-327
Centrovias	218.16	977	2005-2012	SP-225; SP-310
Intervias	375.7	794	2005-2013	SP-147, SP-157, SP-191, SP-215, SP-330, SP-352, SPI 157/340
SPVias	505.73	13	2011-2014	SP-255; SP-127
Total	1804.31	3222		

Appendix B. Species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2).

	Results for dead images			Results for alive images		
Species tested	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
Chrysocyon brachyurus	guará (12), lobo guará (542)	lobo-do-mato (6), lobo (250)	cervo (1), guaxinim (1), quati (1), tamanduá-mirim (1), veado (1), Cachorro (3), cachorro-do-mato (13), left blank (22), raposa (42)	lobo do mato guará (2), guará (11), lobo-guará (635)	lobo do mato (8), lobo (343)	veado (2), cachorro (3), left blank (12), cachorro do mato (19), raposa (39)
Cerdocyon thous	cachorro do mato (330)		cachorro vinagre (1), onça (1) guará (1), guaxinim (1), raposa do mato (1), lobinho (2), lobo do mato (2), quati (2), cachorro filhote (3), gato do mato (3), gato (5), lobo guará (24), cachorro (41), left blank (50), lobo (86), raposa (342)	cachorro do mato (337)		cachorro doméstico (1), cachorro (1), coite (1), furão (1), gato (1), jaguatirica (1), puma (1), suçuarana (1), quati (5), lobo do mato (15), lobo guará (36), left blank (86), lobo (136), raposa (258).
Lycalopex vetulus	raposa (386)	raposa do mato (1)	gato do mato (1), javali (1), lobinho	raposinha (3), raposa (494)		cachorro doméstico (1), gambá (1),

Appendix B. Species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2).

	Results for dead images			Results for alive images		
Species tested	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
			(1), onça (1), onça parda (1), suçuarana (1), veado (2), cachorro (42), lobo guará (42), left blank (70), lobo (126), cachorro do mato (220)			jaguatirica (1) guaxinim (2), quati (3), lobo do mato (7), cachorro (11), lobo guará (50), left blank (52), lobo (96), cachorro do mato (174),
Puma concolor	onça suçuarana (3), puma (21), suçuarana (90), Onça parda (531),	onça (230)	gato do mato (1), guepardo (1), jaguar (1), onça pintada (1), preguiça (1), jaguatirica (2), leopardo (2), onça do mato (2), leoa (3), left blank (6)	onça suçuarana (8), puma (21), suçuarana (74), onça parda (501)	Onça marrom (1), onça do mato (3), onça (251)	gato do mato (1), onça preta (1), leoa (5), leopardo (5), jaguatirica (7), onça pintada (7), left blank (10)
Leopardus pardalis	jaguatirica (464)	gato do mato (102)	cachorro do mato (1), gato doméstico (1), onça malhada (1), filhote de onça (2), filhote de onça	jaguatirica (458)	gato do mato (178)	cachorro do mato (1), gato doméstico (1), gato selvagem (1), filhote de onça pintada (1), jaguar

Appendix B. Species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2).

	Results for dead images			Results for alive images		
Species tested	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
			pintada (2), onça do mato (3), gato (21), leopardo (1), onça parda (4), left blank (23), onça (93), onça pintada (177)			(1), lobo (1), onça parda (6), guepardo (2), onça do mato (2), suçuarana (3), gato (22), left blank (30), onça (86), onça pintada (102)
Tamandua tetradactyla	tamanduá mirim (232)	tamanduá (518)	cachorro (1), raposa (1), tigre (1), quati (2), preguiça (5), bicho preguiça (8), gambá (14), left blank (40, tamanduá bandeira (73)	tamanduá mirim (213)	tamanduá (413)	Lobo (1), raposa (1), suricata (1), quati (4), preguiça (6), bicho preguiça (12), left blank (19), tamanduá bandeira (46)
Myrmecophaga tridactyla	tamanduá bandeira (324)	tamanduá (362)	lobo guará (1), preguiça (1), bicho preguiça (2), gambá (2), left blank (12), tamanduá mirim (12)	tamanduá bandeira (587)	tamanduá (478)	anta (1), left blank (8)
Hydrochoerus hydrochaeris	capivara (891)		anta (1), tamanduá (1), left blank (2)	capivara (882)		lobo (1), rato (1), anta (2), Left blank

Appendix B. Species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2).

	Results for dead images			Results for alive images		
Species tested	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
						(9)

Appendix C. Identification of the species for live animal images given by the participants.

	Results for alive images		
Species tested (n)	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
Brown-throated sloth (*Bradypus variegatus)*	preguiça (67), bicho preguiça (107)		lontra (1), tamandua (1), tamandua bandeira (1), left blank (2)
Collared peccary (*Pecari tajacu*)	cateto (2)	porco (2), porco do mato (46)	porco javali (1), left blank (2), porco espinho (3), javaporco (8), javali (115)
Azara´s agouti (*Dazyprocta azarae*)	cutia (67)	roedor (1)	castor (1), guaxinim (1), jabuti (1), lontra (1), rato do brejo (1), porco da índia (2), quati (3), rato (4), rato do mato (4), esquilo (7), preá (7), ratão do banhado (7), rato do banhado (8), capivara (13), paca (15), left blank (36)
Domestic cat (*Felis catus*)	gato doméstico (22), gato (156)		Gato do mato (1)
Domestic dog (*Canis lupus familiaris*)	cão (2), cão doméstico (2), cachorro doméstico (30), cachorro (143)	canino (2)	
Lesser grisson (*Galictis cuja*)	furão (60)		ariranha (1), cachorro (1), cervo (1), doninha (1), foinha (1), guaxinim (1), jaritataca (1), jaritataca gambá (1), tamanduá mirim (1), texugo (1), veado (1) porco espinho (2), quati (3), lontra (4), tamanduá (4), ouriço (7), gambá (34), left blank (54)
Tapir (*Tapirus terestris*)	anta (168)		javaporco (1), lontra (2), tamanduá (2), left blank (6)

Appendix C. Identification of the species for live animal images given by the participants.

	Results for alive images		
Species tested (n)	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
White eared opossum (*Didelphis albiventris*)	saruê (13), gambá (120)		guaxinim (1), sagui (2), rato do mato (3), quati (4), rato (6), furão (9), raposa (9), left blank (12)
Jaguar (*Panthera onca*)	Onça pintada (126)	Onça (48)	Jaguatirica (1), left blank (1), onça parda (3)
Coati (*Nasua nasua*)	Quati do mato (1), quati (109)		Furão (1), raposa (2), tamanduá (3), gambá (4), guaxinim (28), left blank (31)
Raccoon (*Procyon cancrivorus*)	Mão pelada (1), guaxinim (123)		Esquilo (1), furão (1), raposa (2), gambá (3), left blank (15), quati (33)
Spotted paca (Cuniculus *paca*)	paca (111)		esquilo (1), anta (2), capivara (6), preá (11), cutia (23), left blank (25)
Brazilian porcupine (*Coendou prehensilis*)	ouriço cacheiro (2), porco espinho (47), ouriço (124)	bicho espinho (1)	cachorro do mato (1), esquilo (1), left blank (3)
Coypu (*Myocastor coypus*)	ratão do banhado (64)	rato do brejo (1), rato da água (1), ratão (3), castor (22)	ariranha (1), cotia (1), esquilo (1), furão (1), lebre (1), mão pelada (1), quati (1), preá (1), ratazana (1), ouriço (2), capivara (4), rato do mato (5), lontra (11), rato (19), left blank (38)
Brazilian cottontail (*Sylvilagus brasiliensis*)		coelho do mato (3), Coelho (93)	chinchila (1), lebre (82)
European hare (*Lepus europaeus*)	lebre do mato (1), lebre (130)	coelho do mato (2), coelho (29)	coelho tapiti (1), preá (1), left blank (15)

Appendix C. Identification of the species for live animal images given by the participants.

	Results for alive images		
Species tested (n)	**Correct common names (n)**	**Maybe correct common names (n)**	**Incorrect common names (n)**
Neotropical otter (*Lontra longicaudis*)	lontra (142)		foca (1), onça (1), ratão do banhado (3), furão (8), ariranha (11), left blank (13)
Gray brocket (*Mazama gouazoubira*)	veado catingueiro (2)	cervo (14), veado do mato (1), veado (156)	gazela (1), raposa (1), veado campeiro (1), veado mateiro (1), left blank (2)
Feral pig (*Sus scrofa*)	porco javali (1), javaporco (15), javali (94)	porco (17), porco do mato (41)	anta (1), tamanduá (1), porco doméstico (1), cateto (2), left blank (6)
White-lipped peccary (*Tayassu pecari*)	queixada (3)	porco (11), porco do mato (59)	left blank (1), porco espinho (1), cateto (9), javaporco (9), javali (86)
Nine-banded armadillo (*Dasypus novemcintus*)	tatu galinha (26)	tatu (136)	tatu peba (7), tatu bola (10)
Brazilian squirrel (*Guerlinguetus ingrami*)	esquilo (168)		quati (1), rato (1), saruê (1), tamanduá (1), castor (7)
Tyra (*Eira barbara*)*			ariranha (1), guaxinim (2), lontra (13), left blank (19), furão (25)
Striped hog-nosed skunk (*Conepatus semistriatus*)*	jaritataca (1)		tamandua (1), furão (2), left blank (11), gambá (45)
Southern tiger cat (*Leopardus guttulus*)*	gato do mato (27)		onça pintada (1), onça (3), left blank (5), gato (6), jaguatirica (18)
Jaguarundi (*Puma yagouaroundi*)*		gato selvagem (1), onça cinza (2), gato do mato (10)	furão (1), gato da neve (1), Jaguatirica (1), ariranha (2), onça preta (3), puma (4), onça (8), left blank (27)

Appendix D. Descriptive statistics for the species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2). C = correct and C+M = correct + maybe correct. Cond. = condition; N = number of images per species; Mean = % of Portuguese species descriptions that was correct; SD = Standard Deviation; SE = Standard Error.

Species	Cond.	C	C+M	N	Mean (%)	SD	SE	Min.	Max.	Range
Cerdocyon thous	alive	x		15	36.37	13.03	3.36	16.67	57.69	41.02
Cerdocyon thous	dead	x		15	36.55	12.61	3.25	12.82	58.97	46.15
Cerdocyon thous	alive		x	15	36.37	13.03	3.36	16.67	57.69	41.02
Cerdocyon thous	dead		x	15	36.81	13.08	3.37	12.82	61.54	48.72
Lycalopex vetulus	alive	x		15	54.85	13.22	3.41	27.42	70.97	43.55
Lycalopex vetulus	dead	x		15	42.51	14.61	3.77	20.51	75.81	55.30
Lycalopex vetulus	alive		x	15	54.85	13.22	3.41	27.42	70.97	43.55
Lycalopex vetulus	dead		x	15	42.61	14.88	3.84	20.51	77.42	56.91
Chrysocyon brachyurus	alive	x		18	60.78	6.544	1.54	51.61	77.42	25.81
Chrysocyon brachyurus	dead	x		15	60.06	11.59	2.99	41.03	80.65	39.62
Chrysocyon brachyurus	alive		x	18	93.13	3.36	0.79	87.18	98.39	11.21
Chrysocyon brachyurus	dead		x	15	89.66	5.54	1.43	82.05	98.39	16.34
Puma concolor	alive	x		15	68.32	10.51	2.71	50.00	89.74	39.74
Puma concolor	dead	x		15	73.37	11.08	2.86	50.00	87.18	37.18
Puma concolor	alive		x	15	96.35	2.32	0.59	91.94	100	8.06
Puma concolor	dead		x	15	97.64	1.82	0.47	94.87	100	5.13
Leopardus pardalis	alive	x		15	50.73	9.92	2.56	38.46	69.23	30.76
Leopardus pardalis	dead	x		15	50.49	11.71	3.02	25.64	74.35	48.71
Leopardus pardalis	alive		x	15	71.11	9.47	2.44	51.28	92.30	41.02
Leopardus pardalis	dead		x	15	62.42	15.34	3.96	28.20	84.61	56.41
Tamandua tetradactyla	alive	x		12	30.56	4.25	1.22	25.64	41.03	15.39
Tamandua tetradactyla	dead	x		15	27.61	11.06	2.85	8.06	56.41	48.35

Appendix D. Descriptive statistics for the species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2). C = correct and C+M = correct + maybe correct. Cond. = condition; N = number of images per species; Mean = % of Portuguese species descriptions that was correct; SD = Standard Deviation; SE = Standard Error.

Species	Cond.	C	C+M	N	Mean (%)	SD	SE	Min.	Max.	Range
Tamandua tetradactyla	alive		x	12	86.33	6.61	1.91	74.36	94.87	20.51
Tamandua tetradactyla	dead		x	15	83.66	7.83	2.02	69.23	92.31	23.08
Myrrmecophaga tridactyla	alive	x		18	56.08	10.93	2.57	37.10	76.92	39.82
Myrrmecophaga tridactyla	dead	x		12	46.90	11.29	3.26	29.49	66.67	37.18
Myrrmecophaga tridactyla	alive		x	18	99.17	1.41	0.33	95.16	100	4.84
Myrrmecophaga tridactyla	dead		x	12	96.33	3.91	1.13	88.46	100	11.54
Hydrochoerus hydrochaeris	alive	x		15	98.63	2.34	0.60	92.31	100	7.69
Hydrochoerus hydrochaeris	dead	x		15	99.57	0.92	0.23	97.44	100	2.56
Hydrochoerus hydrochaeris	alive		x	15	98.71	2.32	0.59	92.31	100	7.69
Hydrochoerus hydrochaeris	dead		x	15	99.57	0.92	0.23	97.44	100	2.56
Tapirus terrestris	alive	x		3	94.63	4.28	2.47	89.7	97.4	7.70
Tapirus terrestris	alive		x	3	94.63	4.28	2.47	89.7	97.4	7.70
Bradypus variegatus	alive	x		3	97.20	0.34	0.20	96.8	97.4	0.60
Bradypus variegatus	alive		x	3	97.20	0.34	0.20	96.8	97.4	0.60
Pecari tajacu	alive	x		3	0.86	1.50	0.86	0	2.60	2.60
Pecari tajacu	alive		x	3	24.20	17.20	9.93	5.10	38.5	33.4
Dazyprocta azarae	alive	x		3	39.83	12.45	7.18	25.6	48.7	23.1
Dazyprocta azarae	alive		x	3	40.36	12.82	7.40	25.6	48.7	23.1

Appendix D. Descriptive statistics for the species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2). C = correct and C+M = correct + maybe correct. Cond. = condition; N = number of images per species; Mean = % of Portuguese species descriptions that was correct; SD = Standard Deviation; SE = Standard Error.

Species	Cond.	C	C+M	N	Mean (%)	SD	SE	Min.	Max.	Range
Felis catus	alive	x		3	99.56	0.75	0.43	98.7	100	1.30
Felis catus	alive		x	3	99.56	0.75	0.43	98.70	100	1.30
Canis lupus familiaris	alive	x		3	99.13	1.50	0.86	97.40	100	2.60
Canis lupus familiaris	alive		x	3	100	0	0	100	100	0
Galictis cuja	alive	x		3	36.96	22.33	12.89	11.50	53.20	41.70
Galictis cuja	alive		x	3	36.96	22.33	12.89	11.50	53.20	41.70
Didelphis albiventris	alive	x		3	72.63	14.06	8.12	59	87.10	28.10
Didelphis albiventris	alive		x	3	72.63	14.06	8.12	59	87.10	28.10
Panthera onca	alive	x		3	71.40	4.82	2.78	67.90	76.90	9
Panthera onca	alive		x	3	97.53	2.40	1.38	95.20	100	4.80
Nasua nasua	alive	x		3	63.60	9.85	5.68	55.10	74.40	19.30
Nasua nasua	alive		x	3	63.60	9.85	5.68	55.10	74.40	19.30
Procyon cancrivorus	alive	x		3	70.70	13.78	7.95	56.40	83.90	27.50
Procyon cancrivorus	alive		x	3	70.70	13.78	7.95	56.40	83.90	27.50
Cuniculus paca	alive	x		3	61	7.40	4.27	54.80	69.20	14.40
Cuniculus paca	alive		x	3	61	7.40	4.27	54.80	69.20	14.40
Coendou prehensilis	alive	x		3	96.16	3.85	2.22	92.30	100	7.70
Coendou prehensilis	alive		x	3	97.03	2.65	1.53	94.90	100	5.10
Myocastor coypus	alive	x		3	33.30	11.38	6.57	20.50	42.30	21.80
Myocastor coypus	alive		x	3	49.40	8.94	5.16	43.60	59.70	16.10
Sylvilagus brasiliensis	alive	x		3	0	0	0	0	0	0
Sylvilagus brasiliensis	alive		x	3	47.63	27.55	15.91	20.50	75.60	55.10

Appendix D. Descriptive statistics for the species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2). C = correct and C+M = correct + maybe correct. Cond. = condition; N = number of images per species; Mean = % of Portuguese species descriptions that was correct; SD = Standard Deviation; SE = Standard Error.

Species	Cond.	C	C+M	N	Mean (%)	SD	SE	Min.	Max.	Range
Lepus europaeus	alive	x		3	75.13	10.54	6.08	67.70	87.20	19.50
Lepus europaeus	alive		x	3	92.53	10.28	5.93	80.80	100	19.20
Lontra longicaudis	alive	x		3	79.23	1.71	0.99	77.40	80.80	3.40
Lontra longicaudis	alive		x	3	79.23	1.71	0.99	77.40	80.80	3.40
Mazama gouazoubira	alive	x		3	1.70	2.94	1.70	0	5.10	5.10
Mazama gouazoubira	alive		x	3	96.90	1.80	1.04	94.90	98.40	3.50
Sus scrofa	alive	x		3	58.60	22.68	13.09	38.70	83.30	44.60
Sus scrofa	alive		x	3	93.46	2.37	1.37	91.90	96.20	4.30
Tayassu pecari	alive	x		3	1.50	1.60	0.92	0	3.20	3.20
Tayassu pecari	alive		x	3	41.83	10.46	6.04	30.60	51.30	20.70
Dasypus novemcintus	alive	x		3	14.96	2.61	1.50	12.90	17.9	5
Dasypus novemcintus	alive		x	3	91.73	7.46	4.30	85.50	100	14.50
Guerlinguetus ingrami	alive	x		3	93.96	5.94	3.43	87.10	97.40	10.30
Guerlinguetus ingrami	alive		x	3	93.96	5.94	3.43	87.10	97.40	10.30
Eira barbara	alive	x		3	0	0	0	0	0	0
Eira barbara	alive		x	3	0	0	0	0	0	0
Conepatus semistriatus	alive	x		3	1.96	3.40	1.96	0	5.90	5.90
Conepatus semistriatus	alive		x	3	1.96	3.40	1.96	0	5.90	5.90
Leopardus guttulus	alive	x		3	49.40	16.92	9.77	31	64.30	33.30
Leopardus guttulus	alive		x	3	49.40	16.92	9.77	31	64.30	33.30

Appendix D. Descriptive statistics for the species identification by the participants of the live and dead animals shown in images in a classroom setting (Data set 2). C = correct and C+M = correct + maybe correct. Cond. = condition; N = number of images per species; Mean = % of Portuguese species descriptions that was correct; SD = Standard Deviation; SE = Standard Error.

Species	Cond.	C	C+M	N	Mean (%)	SD	SE	Min.	Max.	Range
Puma yagouaroundi	alive	x		3	0	0	0	0	0	0
Puma yagouaroundi	alive		x	3	47.63	27.55	15.91	20.50	75.60	55.10

3. CHAPTER 2: HOW MANY MAMMALS ARE ROADKILLED PER YEAR IN SÃO PAULO STATE, BRAZIL? AN ESTIMATE BASED ON ROADKILL DATA COLLECTED BY TOLL ROAD COMPANIES

Fernanda Delborgo Abra, Marcel Pieter Huijser, Marcelo Magioli, Alex Augusto Abreu Bovo, Katia Maria Paschoaletto Micchi de Barros Ferraz

Capítulo 2: Quantos mamíferos silvestres são atropelados por ano no Estado de São Paulo, Brasil? Uma estimativa baseada em dados de atropelamentos coletados por concessionárias de rodovias

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RESUMO

Para as espécies de animais silvestres, as rodovias apresentam dois impactos principais: o efeito barreira e a morte direta de animais por atropelamento. Muitos estudos estimaram números de atropelamentos para diferentes grupos de animais ao longo de rodovias com características diferentes e em diferentes períodos de tempo. Neste estudo, analisamos dados de atropelamentos de mamíferos de médio e grande porte de 18 concessionárias de rodovias no Estado de São Paulo, e então extrapolamos os padrões de atropelamentos para todo o sistema de rodovias pavimentadas no Estado. Para estimar a mortalidade de mamíferos em rodovias públicas de duas pistas, usamos dados de animais atropelados (n = 993) coletados por rodovias concedidas antes de duplicar as vias de 2 para 4 pistas. Ao longo de 10 anos de monitoramento de atropelamentos em rodovias concedidas (2005-2014), 37.744 mamíferos foram atropelados, com um total de 32 espécies de médio a grande porte (número médio de mamíferos atropelados por ano = 3.774 ± 1.159; min = 1.932; máx. = 5,369; 0,6 mamíferos atropelados/ km /ano). As espécies mais atropeladas foram mamíferos comuns e generalistas adaptados a paisagens modificadas (80% dos dados), mas também é necessário ressaltar altos números de espécies ameaçadas (4,3% dos dados), que apresentam uma séria preocupação para a conservação. A maioria dos atropelamentos reportados ocorreu durante o período noturno (66,03%, n = 14.189) e nos meses chuvosos (55,55%, n = 15.318). Os acidentes com mamíferos tenderam a aumentar entre 2009 e 2014 (R2 = 0,614; p = 0,065), com um aumento médio de 313,5 indivíduos por ano. Extrapolando os resultados para todo o estado de São Paulo, a estimativa média é de 39.605 mamíferos de médio e grande porte atropelados por ano. Nossos resultados permitem direcionar estudos com espécies específicas, a fim de compreender o risco de extinção de populações de mamíferos e subsidiar o desenvolvimento de planos de ação mais precisos.

Palavras-chave: Atropelamento; Estimativa; Rodovia; Mamífero; Espécies ameaçadas

Chaper 2: How many wild mammals are roadkilled per year in São Paulo State, Brazil? An estimate based on roadkill data collected by toll road companies

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ABSTRACT

For wildlife species, roads have two main impacts: the barrier effect and direct death of animals through wildlife-vehicle collisions. Many studies have estimated roadkill numbers for different animal groups along roads with different characteristics and over different time periods. In this study, we analyzed medium- and large-sized mammal roadkill data from 18 toll road companies in São Paulo State, Brazil, and then extrapolated the roadkill patterns for the entire system of paved roads in the State. To estimate mammal mortality along two-lane public roads, we used roadkill data (n = 993) collected by toll road companies before they duplicated the roads from 2 to 4-lanes to estimate the number of mammal roadkills for all paved roads in São Paulo State. Over 10 years of roadkill monitoring on toll roads (2005-2014), 37,744 mammals were roadkilled, with a total of 32 medium- to large-sized species (average number of roadkilled individuals per year = 3,774 ± 1,159; min = 1,932; max = 5,369; 0.6 individuals roadkilled/km/year). The most roadkilled species were common and generalist mammals adapted to human-modified landscapes (HMLs) (80% of the data), but also high roadkill numbers of threatened and endangered species (4.3% of the data), which present a serious concern for conservation. Most of the reported roadkills occurred during the nocturnal period (66.03%, n = 14,189) and in rainy months (55.55%, n = 15,318). Mammal roadkills tended to increase between 2009 and 2014 (R^2 = 0.614; p = 0.065), with an average increase of 313.5 individuals per year. Extrapolating the results for the entire São Paulo State, resulted in an average estimate of 39,605 medium- and large-sized mammals roadkilled per year. It is recommendable to make a caveat for specific species that were under or overestimated in this study. Our findings permit to direct studies with specific species in order to understand the extinction risk of mammal populations and to subsidize the development of more precise action plans.

Keywords: Roadkill; Estimates; Roads; Mammals; Threatened species

3.1. INTRODUCTION

Although roads are key drivers of social-economic development, they have a wide variety of environmental impacts, both during their construction (DAIGLE, 2010; CALISKAN, 2013) and their operational phase (FORMAN & ALEXANDER, 1998; TROMBULAK & FRISSEL, 2000; COFFIN, 2007; LAURANCE, 2014). Roads have two main impacts for wildlife: the direct death of individual animals through animal-vehicle collisions, and the barrier effect of the transportation corridor (NELLEMANN et al., 2001; FORMAN et al., 2003; FAHRIG & RYTWINSKI, 2009; LESBARRÈRES & FAHRIG 2012).

Direct road mortality has the potential to alter the demographic structure of populations (MUMME et al., 2001; STEEN & GIBBS, 2004) and can result in local population sinks (NIELSEN et al., 2006). The extent of these impacts depends on the characteristics of the roads, such as road density, traffic volume, landscape features, proximity to protected areas, and the roadkilled species, including their regional population size and life history (FAHRIG et al., 1995; AMENT et al., 2008; FRAIR et al., 2008; RYTWINSKI & FAHRIG, 2013; FREITAS et al., 2015).

Many studies have estimated roadkill numbers for different animal groups along roads with different characteristics and over different time periods. Annual roadkill estimates include 159,000 mammals and 653,000 birds in the Netherlands (FORMAN & ALEXANDER, 1998), seven million birds in Bulgaria (van der ZANDE et al., 1980), and five million amphibians and reptiles in Australia, (BENNETT, 1991; FORMAN 1995). In the United States, it has been estimated that 80 million birds are killed on roads each year (ERICKSON et al., 2005), while another study estimated that one million vertebrates per day die along the same roads (FORMAN & ALEXANDER, 1998).

In Brazil, there are two estimates available for vertebrate roadkill: 14.7 (± 44.8) million and 475 million roadkilled vertebrates per year (DORNAS et al., 2012; CBEE, 2019). The CBEE (Centro Brasileiro de Ecologia de Estradas) estimated that approximately 430 million small animals (< 1 kg) die on Brazilian roads. The remaining 45 million are divided into medium (40 million; e.g. *Didelphis* spp., *Lepus europaeus*, *Alouatta* spp.) and large vertebrates (five million; e.g. *Puma concolor, Chrysocyon brachyurus, Panthera onca, Tapirus terrestris, Hydrochoerus hydrochaeris*).

Quantifying roadkill numbers and patterns in space and time is important to justify, plan, design, and fund effective mitigation measures. However, it is hard to reliably quantify the number of roadkilled animals due to the length of the road network, and high temporal and spatial variability in roadkill hotspots, besides the low detectability of small and rare species (SMITH & DODD, 2003; DODD et al., 2004; SANTOS et al., 2016).

In this study, we estimate the total number of medium- and large-sized mammals roadkilled per year along all paved roads of São Paulo State (6,580 km) based on roadkill data collected by toll road companies. Our study is the first well documented approach that estimates the minimum, maximum, average and median roadkill numbers for medium- and large-sized mammals in São Paulo State; the state with the highest population density and road network, dominated by human-modified landscape (HMLs). We also discuss the implications for species conservation, especially threatened and endangered species.

3.2. MATERIALS AND METHODS

3.2.1. Study area

The state of São Paulo is located in the southeast of Brazil (248,209 km^2) (Fig. 1) and is the most developed and prosperous state of the country, generating 33.9% of the Brazilian Gross Domestic Product. Also, São Paulo State is home to about 44 million people, about 21,6% of the total population in Brazil (IBGE, 2018).

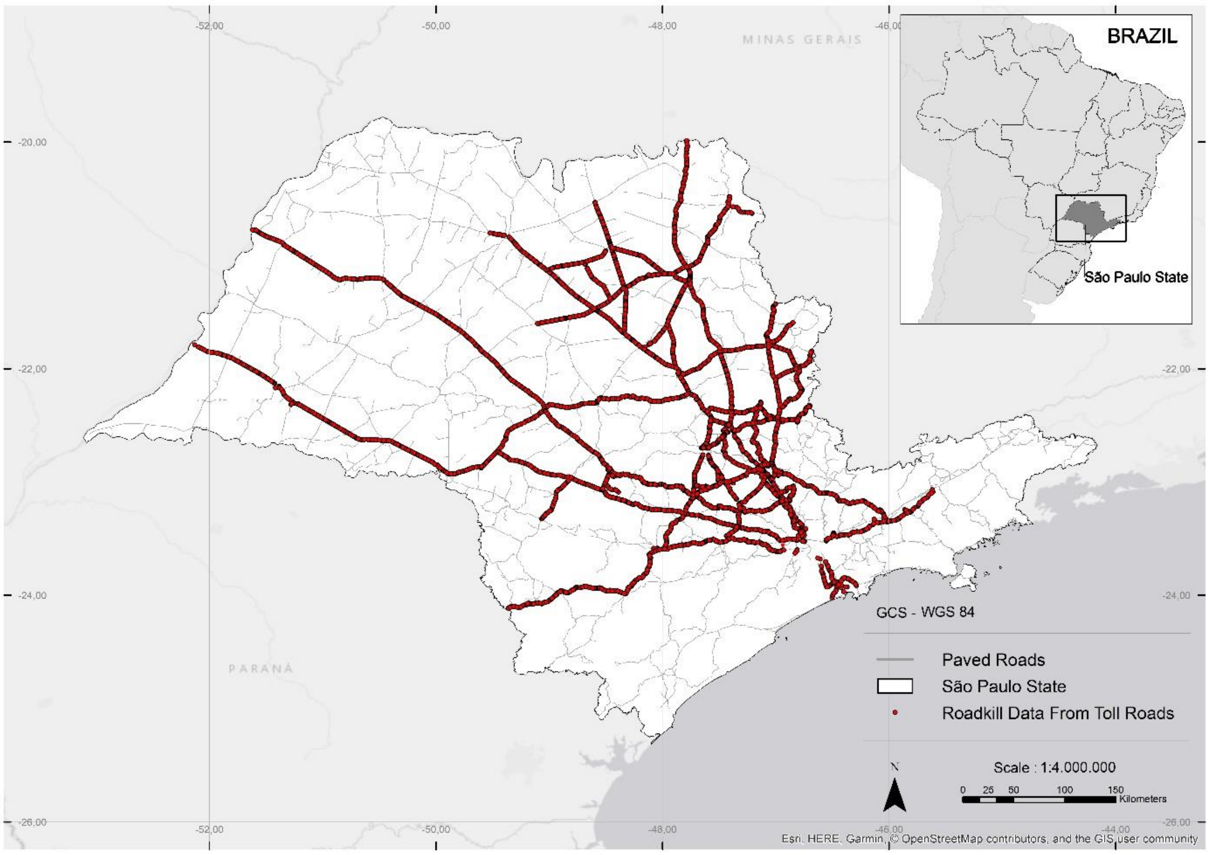

Figure 1. Location of the São Paulo State, Brazil, highlighting the paved road network (gray lines) and the roadkill data from toll roads (red dots).

Over the last decades, the state of São Paulo experienced rapid land use changes. This included conversion of Atlantic Forest and Cerrado biomes, both considered world biodiversity hotspots (MITTERMEIER et al., 2011), into pasture and croplands, urban areas (DEAN, 1995; RIBEIRO et al., 2009; INSTITUTO FLORESTAL, 2010; PROJETO MAPBIOMAS, 2018), an expansion of the road network (33% increase in length between 1988 to 2013) (DER, 2019), and an increase in the number of registered vehicles (329% increase between 1998 and 2018) (DETRAN, 2019).

São Paulo State has 199,371 km of unpaved and paved roads (0.8 km roads/km^2), one of the highest road densities in Brazil (DER, 2018). Since 1990, some Brazilian states initiated a road concessions program to improve the road network and have it meet safety and other engineering standards. The program aims to change public highways into highways managed by private toll road companies, under the condition that the toll road companies will improve the roads; including an upgrade from 2-lane highways to 4-lane highways. This modernization is paid for by the users through tolls (ARTESP, 2019; DNIT, 2019). Road concessions in São Paulo State started in 1998 and not only aimed to improve the safety and other engineering standards of roads, but also aimed to improve their environmental and social sustainability (ARTESP, 2019). This strategy to improve the road network seems to have been a success. In 2018, the CNT (Confederação Nacional do Transporte) evaluated all paved roads in Brazil, and 18 of the 20 best paved roads were located in São Paulo State, all managed by toll road companies (CNT, 2018).

The total length of paved roads in São Paulo State is 36,503 km. These roads are managed by four types of administrators: (i) public state roads are managed by Departamento de Estradas de Rodagem (DER) (2 or 4-lanes); (ii) state toll roads managed by different private toll road companies (2 or 4-lanes); (iii) Federal roads managed by Federal transportation agency (2-lanes) and different private toll road companies (4-lanes); and (iv) roads managed by different municipalities with only 2-lanes (Table 1) (ARTESP, 2018; DER, 2018).

Table 1. Total length of paved roads in São Paulo State, Brazil, per type of road administrator and the number of lanes.

Road description	Nº lanes	Length (km)	Proportion (%)	Source
Municipality paved roads (MPR_2L)	2	13,376	36.64	DER (2013)
State paved roads (SPR_2L)	2	14,500	39.72	DER (2013)
State paved roads (SPR_4L)	4	979	2.68	DER (2013)
State paved toll roads (SPTR_4L)	2 and 4	6,580	18.02	DER (2013)
Federal paved roads (FPR_2L)	2	447.160	1.22	DER (2018)
Federal paved roads (FPR_4L)	4	621.250	1.7	DER (2018)
Total		**36,503.410**	**100**	

The roads managed by DER or municipalities usually have two lanes, narrow or non-existent clear zones, frequent absence of streetlights, and relatively slow and poor medical assistance. In comparison, toll roads tend to be major four lane highways that have been reconstructed over the last few decades. These highways tend to have wide clear zones, guard rails, median barriers (e.g. concrete Jersey median barriers) in specific locations, streetlights in selected areas, and relatively fast and modern medical and mechanical assistance provided through the respective toll road companies. The traffic volume and posted legal speed limit (varying between 80-120 km/h) is typically higher on toll roads than roads managed by DER or municipalities (ARTESP, 2019).

3.2.2. Roadkill data

The toll road companies are responsible for the operation and maintenance of the roads they manage. This includes checking the entire length of their highways at least every three hours for stranded vehicles, debris and animal carcasses on the pavement or adjacent to it. This effort includes providing assistance to drivers when they need help, contributing to meet higher standards of traffic safety and free flowing traffic. The toll road companies are required to remove and report animal carcasses of both wild and domestic species since 2005 (required by Agência de Transportes do Estado de São Paulo – ARTESP). For each animal carcass, maintenance personnel are required to collect the date, time, road number or name, kilometer reference post (accurate to 100 m) or geographic coordinates, the Portuguese-common name of the species, and the status and fate of the animal, for example, if the carcass of the animal was sent to a specific institution or buried.

3.2.2.1. Species identification and corrections to the toll road roadkill data

We analyzed mammal roadkill data from 18 different toll road companies managing 6,580 km of roads. The data were collected from 2005 through 2014 (10 years) (Appendix A). Because the roadkill data were collected by non-experts, there are errors and inconsistencies in species identification (ABRA et al., 2018). Thus, we applied correction factors to the species identification by the non-experts based on Abra et al. (2018). These correction factors were based on a subset of the same roadkill database data and were calculated based on a comparison of the Portuguese species description provided by road maintenance personnel (non-experts) to the identification provided by experts after evaluating the images provided by the toll road companies. For the corrected database, we used the scientific name of species. However, for Portuguese species descriptions that were not encountered in the subset of the data used by Abra et al. (2018), we kept the Portuguese common name and added "unconfirmed" to the species name.

Not all toll road companies collected roadkill data in all years between 2005 through 2014, mainly because the private companies entered in new toll road contracts in different years. Rather than reducing years or the road length for our roadkill estimates, we calculated average values for the missing data based on the average number of roadkilled individuals (species/kilometer/year) for the years when data were available (Appendix B). The missing data calculated by number of years related to 13.33% of the total data. After providing estimates for the missing data for these specific toll road companies, we estimated the total number of roadkilled individuals of each species per year using the corrected identification reports of roadkill individuals.

3.2.2.2. Roadkill temporal patterns on toll road companies

We conducted exploratory analyses of the temporal patterns of the mammal roadkill data for the years we had data available from all 18 toll road companies (2009-2014). All roadkill records had the date when the carcass was found, but not all records contained the hours. For the records we had the hours, we stablished diurnal period time from 6:00 h to 18:00 h and nocturnal period from 18:01 h to 5:59 h. We distinguished between the dry season (April-September) and the rainy season (October-March) (ALVARENGA, 2012).

Considering species that comprised more than 20% of the roadkill data, we conduct analyzes including all roadkilled species and removing the species with high roadkill numbers. For the records validated by the correction factors (ABRA et al., 2018), we did an exploratory temporal analysis, including season, month, and hours or period of the day when the animals were found roadkilled; we considered only species with more than 45 records (Appendix E). Finally, we investigated potential changes in the total number of reported roadkills per year (2009-2014) through linear regression analyzes.

3.2.2.3. Roadkill estimates

We used the roadkill database from toll road companies to estimate roadkills for entire São Paulo State road network, with corrections for the number of lanes (Table 1). To estimate mammal mortality along two-lane public roads (DER, municipality and Federal roads), we used roadkill data collected by toll road companies before they duplicated the roads from 2 to 4-lanes. Because we extrapolated roadkill data along 2- lane toll roads for the remaining 2-lane roads in São Paulo State, we not only wanted to have an estimate for the average number of roadkilled mammals per road length unit, but also to provide a measure of uncertainty around these averages. Therefore, we divided the 2-lane toll roads into 10-km long sections, reflecting a balance between sample size and reducing the likelihood of extreme values (see section below). Using relatively long sections (10 km) was also appropriate as the total road length that we were calculating an estimate for was very long (28,323 km of 2-lane roads, not managed by toll road companies) (see Table 1, Appendix C).

We investigated the effect of road length on the average number and variation of roadkilled mammals using data from one toll road in São Paulo State: Rodovia dos Bandeirantes (SP-348). We divided this toll road into sections of 1, 5 and 10 km, and calculated the number and variation of roadkilled mammals for the different road length units and summarized it in boxplots (Fig. 2).

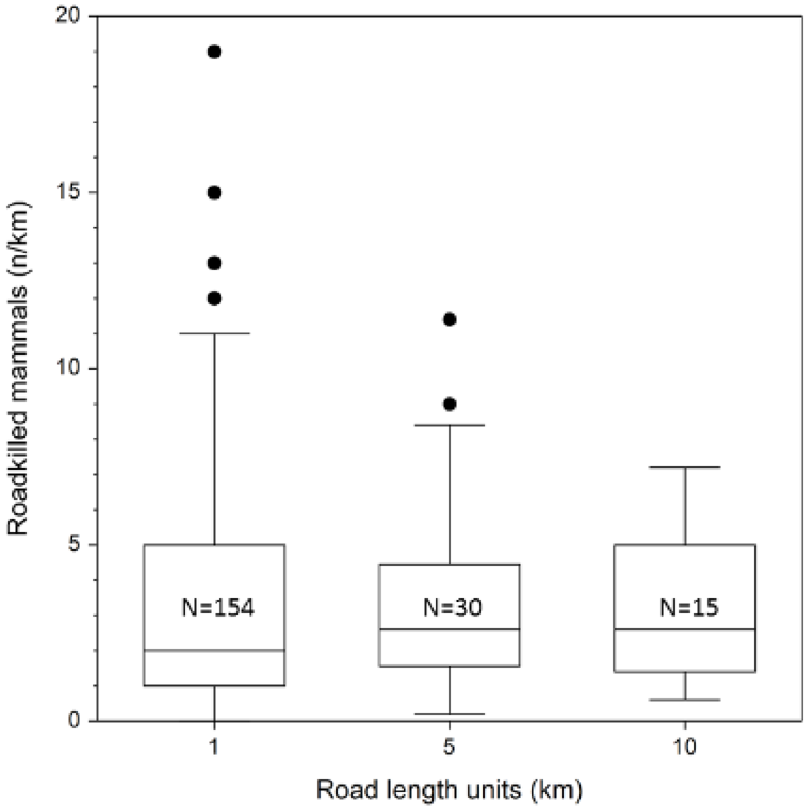

Figure 2. Number of roadkilled mammals in each road section of Rodovia dos Bandeirantes (SP-348). Box: middle 50% of the data (25–75 quartile); horizontal line: median; whisker boundaries: 1.5 times inter-quartile range; outliers greater than 1.5 times the inter-quartile range. The N correspond to the number of road sections.

The variation in the number of roadkilled animals per km decreased with longer road sections. There is a greater likelihood of extreme values, including zero observations, when comparing short road sections to long ones.

For 2-lane toll roads roadkill data, we applied the same correction factors previously described. We calculated the number of individual roadkills per species for each of the 27 road sections, and then calculate descriptive statistics for each species including average, standard deviation, median, minimum, and maximum. Finally, we used these values to estimate the total number of roadkilled individuals per species per year (and associated variation) along 2-lane roads not managed by toll roads.

For 4-lane roads not managed by toll road companies, we used the same values we obtained for 4-lane toll roads per km and multiplied them by the total length of each type of 4-lane road. The total length of 4-lane roads managed by DER and Federal Highways was 1,595 kilometers.

We then proceeded to calculate the estimated number of mammal roadkill per species for all paved roads in São Paulo State using the following formulas:

Minimum Nº of Roadkill per species/year = (SPR_4L + SPTR_4L + FPV_4L) + (MPR_2L + SPR_2L + FPR_2L)

Maximum Nº of Roadkill per species/year = (SPR_4L + SPTR_4L + FPV_4L) + (MPR_2L + SPR_2L + FPR_2L)

Average Nº of Roadkill per species/year = (SPR_4L + SPTR_4L + FPV_4L) + (MPR_2L + SPR_2L + FPR_2L)

Median Nº of Roadkill per species/year = (SPR_4L + SPTR_4L + FPV_4L) + (MPR_2L + SPR_2L + FPR_2L)

Given that:

MPR_2L = Municipality paved road with 2-lanes

SPR_2L = State paved road with 2-lanes

SPR_4L = State paved road with 4-lanes

SPTR_4L = State paved toll road with 4-lanes

FPR_2L = Federal paved road with 2-lanes

FPV_4L = Federal paved road with 4-lanes

None of the 27 road sections had data for Lowland tapir (*Tapirus terrestris*), Southern tiger cat (*Leopardus gutullus*), Brazilian guinea pig (*Cavia* sp.*)* and Collared peccary (*Pecari tajacu*), which is partially explained by their limited distribution in São Paulo State. For example, Lowland tapir and Collared peccary are restricted to high quality forest remnants (e.g. protected areas such as Morro do Diabo, Carlos Botelho and Serra do Mar State Parks). Other explanations for the absence of observations for some species are small body size (e.g. Brazilian guinea pig), sampling methods employed (TEIXEIRA et al., 2013), or because species are rare (e.g. Jaguar, *Panthera onca*; Margay cat, *Leopardus wiedii*; Pampas cat, *Leopardus colocola*). For species with limited distribution, small body size or low density, we highlight that roadkill numbers are possibly underestimated. Other species such as Hoary fox (*Lycalopex vetulus*) occur only in habitat patches of Brazilian savannah (Cerrado), rendering the extrapolation for the entire state not applicable.

3.3. RESULTS

3.3.1. Species identification and correction factors for toll roads

Toll road companies recorded 37,744 medium and large-sized roadkilled mammals (average = 3,774 ±1,159 individuals, min = 1,932, max = 5,369 per year, and 0.6 animals roadkilled/km/year), totaling 32 wild species (Table 2). Capybara (*Hydrochoerus hydrochaeris*, 33.42%), European hare (*Lepus europaeus*, 14.32%), Crab-eating fox (*Cerdocyon thous*, 13.13%), Nine banded armadillo (*Dasypus novemcinctus*, 6.29%), Porcupine (*Coendou* sp., 6.09%), Six banded armadillo (*Euphractus sexcinctus*, 4.07%), Southern tamandua (*Tamandua tetradactyla*, 3.16%) and Raccoon (*Procyon cancrivorus*, 2.40%) were the most frequently reported roadkilled species, accounting for more than 80% of all reported roadkills. Eight of these species are considered threatened with extinction on State, Federal and International levels: Maned wolf (*Chrysocyon brachyurus*), Hoary fox (*Lycalopex vetulus*), Giant anteater (*Myrmecophaga tridactyla*), Puma (*Puma concolor*), Black horned capuchin (*Sapajus nigritus*), Lowland tapir (*Tapirus terrestris*), Jaguarundi (*Herpailurus yagouaroundi*), Southern tiger cat (*Leopardus guttulus).* Only two species in the data are considered non-native in Brazil: European hare (*Lepus europaeus*) and Wild boar (S*us scrofa*); and the European hare was the second most frequently roadkilled species along toll roads in São Paulo State.

Table 2. Numbers (total and average) and frequency (FR) of roadkilled medium- and large-sized mammals along toll roads in São Paulo State, Brazil, from 2005 to 2014, including threaten categories at State (Decreto Nº 63853/2018), National (ICMBio/MMA 2018) and World (IUCN 2019) scales. * Unconfirmed animal species identification. Legend: NA = Not applicable, LC = Least concern, VU = Vulnerable, NT = Near threatened, EN = Endangered, IS = Invasive species.

English Common Name	**Scientific Name**	**São Paulo**	**Brazil**	**World**	**Total**	**Average**	**FR. (%)**
Capybara	*Hydrochoerus hydrochaeris*	LC	LC	LC	12,614	1261	33.42
European hare	*Lepus europaeus*	IS	IS	LC	5,406	541	14.32
Crab-eating fox	*Cerdocyon thous*	LC	LC	LC	4,957	496	13.13
Nine-banded armadillo	*Dasypus novemcinctus*	LC	LC	LC	2,375	238	6.29
Porcupine	*Coendou* sp.	NA	NA	NA	2,299	230	6.09
Six-banded armadillo	*Euphractus sexcinctus*	LC	LC	LC	1,537	154	4.07
Southern tamandua	*Tamandua tetradactyla*	LC	LC	LC	1,193	119	3.16
Raccoon	*Procyon cancrivorus*	LC	LC	LC	906	91	2.40
White-eared opossum	*Didelphis albiventris*	LC	LC	LC	773	77	2.05
Non identified opossum	*Didelphis* sp.	LC	LC	LC	615	62	1.63
Maned-wolf	*Chrysocyon brachyurus*	VU	VU	NT	570	57	1.51
Hoary fox	*Lycalopex vetulus*	VU	VU	VU	565	57	1.50
Non identified armadillo	Armadillo ni	NA	NA	NA	563	56	1.49
Dasypodidae	*Dasypus* sp.	NA	NA	NA	504	50	1.34
Gray brocket deer	*Mazama gouazoubira*	LC	LC	LC	437	44	1.16
Striped hog-nosed skunk	*Conepatus semistriatus*	LC	LC	LC	290	29	0.77
Giant anteater	*Myrmecophaga tridactyla*	VU	VU	VU	233	23	0.62
Lesser grison	*Galictis cuja*	LC	LC	LC	193	19	0.51
South American coati	*Nasua nasua*	LC	LC	LC	169	17	0.45
Brocket deer	*Mazama* sp.	NA	NA	NA	163	16	0.43
Puma	*Puma concolor*	VU	VU	LC	152	15	0.40
Coypu	*Myocastor coypus*	LC	LC	LC	139	14	0.37

English Common Name	Scientific Name	São Paulo	Brazil	World	Total	Average	FR. (%)
Ocelot	*Leopardus pardalis*	VU	LC	LC	137	14	0.36
*Unconfirmed Sagui	NA	NA	NA	NA	127	13	0.34
*Unconfirmed Porco-espinho	NA	NA	NA	NA	109	11	0.29
Black-and-gold howler monkey	*Alouatta caraya*	EN	LC	LC	103	10	0.27
Marmoset	*Callithrix* sp.	NA	NA	NA	82	8	0.22
Black-horned Capuchin	*Sapajus nigritus*	LC	LC	NT	62	6	0.16
Lowland paca	*Cuniculus paca*	LC	LC	LC	57	6	0.15
Non identified mammal	Mammal ni	NA	NA	NA	51	5	0.14
Neotropical otter	*Lontra longicaudis*	VU	LC	LC	41	4	0.11
Small spotted cat	*Leopardus* sp.	VU/EN	NA	NA	41	4	0.11
Jaguarundi	*Herpailurus yagouaroundi*	VU	VU	LC	38	4	0.10
*Unconfirmed Bicho-preguiça	NA	NA	NA	NA	36	4	0.10
*Unconfirmed Esquilo	NA	NA	NA	NA	32	3	0.08
Wild boar	*Sus scrofa*	IS	IS	LC	29	3	0.08
Naked-tail armadillo	*Cabassous* sp.	LC	LC	LC	25	3	0.07
*Unconfirmed Roedor	NA	NA	NA	NA	20	2	0.05
Non identified marsupial	Marsupial ni	NA	NA	NA	16	2	0.04
Brazilian guinea pig	*Cavia* sp.	NA	LC	LC	12	1	0.03
Lowland tapir	*Tapirus terrestris*	EN	VU	VU	10	1	0.03
*Unconfirmed Tatu galinha/peba	NA	NA	NA	NA	9	0.9	0.02
Tayra	*Eira barbara*	LC	LC	LC	9	0.9	0.02
*Unconfirmed Ariranha	NA	NA	NA	NA	7	0.7	0.02
*Unconfirmed Bugio	NA	NA	NA	NA	5	0.5	0.01
*Unconfirmed Mico-leão	NA	NA	NA	NA	5	0.5	0.01
*Unconfirmed Macaco-prego	NA	NA	NA	NA	4	0.4	0.01

English Common Name	Scientific Name	São Paulo	Brazil	World	Total	Average	FR. (%)
*Unconfirmed Sussuarana	NA	NA	NA	NA	4	0.4	0.01
*Unconfirmed Primata	NA	NA	NA	NA	3	0.3	0.01
Southern tiger cat	*Leopardus guttulus*	VU	VU	VU	3	0.3	0.01
*Unconfirmed Onça-pintada filhote	NA	NA	NA	NA	2	0.2	0.01
*Unconfirmed Porco	NA	NA	NA	NA	2	0.2	0.01
*Unconfirmed Sagui-de-tufo-preto	NA	NA	NA	NA	2	0.2	0.01
*Unconfirmed Cateto	NA	NA	NA	NA	1	0.1	0.00
*Unconfirmed Cervo-do-pantanal	NA	NA	NA	NA	1	0.1	0.00
*Unconfirmed Gambá-de-orelha-branca	NA	NA	NA	NA	1	0.1	0.00
*Unconfirmed Gato-maracajá	NA	NA	NA	NA	1	0.1	0.00
*Unconfirmed Javaporco	NA	NA	NA	NA	1	0.1	0.00
*Unconfirmed Onça filhote	NA	NA	NA	NA	1	0.1	0.00
*Unconfirmed Veado-mateiro	NA	NA	NA	NA	1	0.1	0.00
Collared peccary	*Pecari tajacu*	LC	LC	LC	1	0.1	0.00
TOTAL					**37,744**	**3,774**	**100**

3.3.2. Roadkill temporal patterns on toll road companies

For 26,542 out of 27,573 mammal carcasses reported along the toll roads (2009-2014) the hours of the record were reported; only 3.74% (n = 1,031) of the data did not have the time available for analysis. Most of reported roadkills (66.03%), occurred during the nocturnal period (n = 14,189) and 33.70 % (n = 12,353) during the diurnal period (Fig. 3). Excluding the capybara, which is the species with most records (33.42% of all roadkill data), the proportion of roadkills changed between diurnal (37.32%) and nocturnal (62.68%) periods. The peak of collisions for all mammal species was between 6:00 h and 8:00 h (Fig. 4).

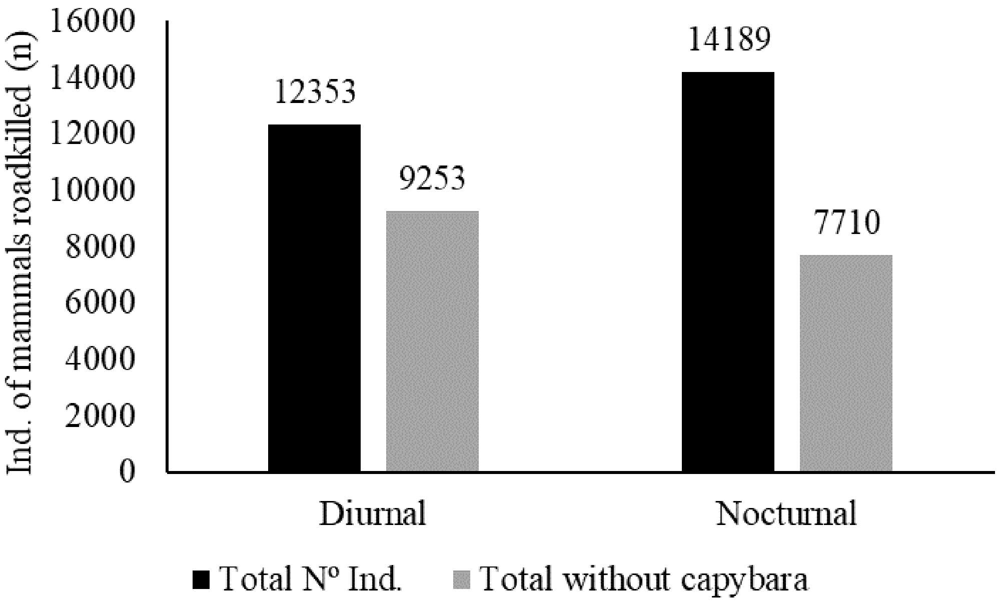

Figure 3. Number of roadkilled medium and large sized mammals during diurnal and nocturnal periods, with and without capybara (*Hydrochoerus hydrochaeris*), from 2009 to 2014 in toll roads of São Paulo State, Brazil.

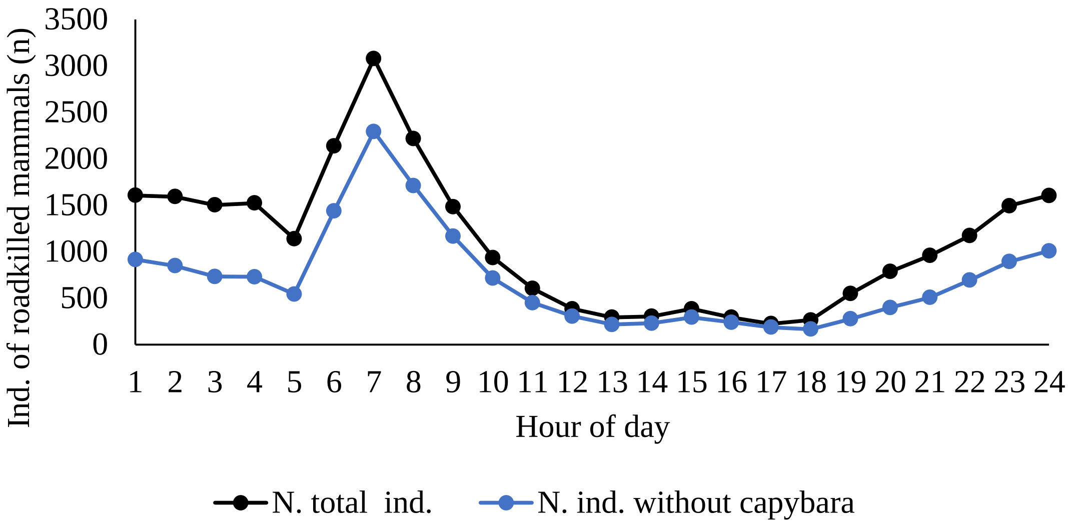

Figure 4. Number of roadkilled medium and large sized mammals per hour of day, with and without capybara (*Hydrochoerus hydrochaeris*), from 2009 to 2014, in toll roads of São Paulo State, Brazil.

The number of mammal carcass records showed a slightly seasonal variation, with more reports during the rainy season (55.55%, n = 15,318), than during the dry season (44.45%, n = 12,255) (Fig. 5). By excluding capybaras, the difference between seasons diminished (rainy = 52.95%; dry = 47.05%).

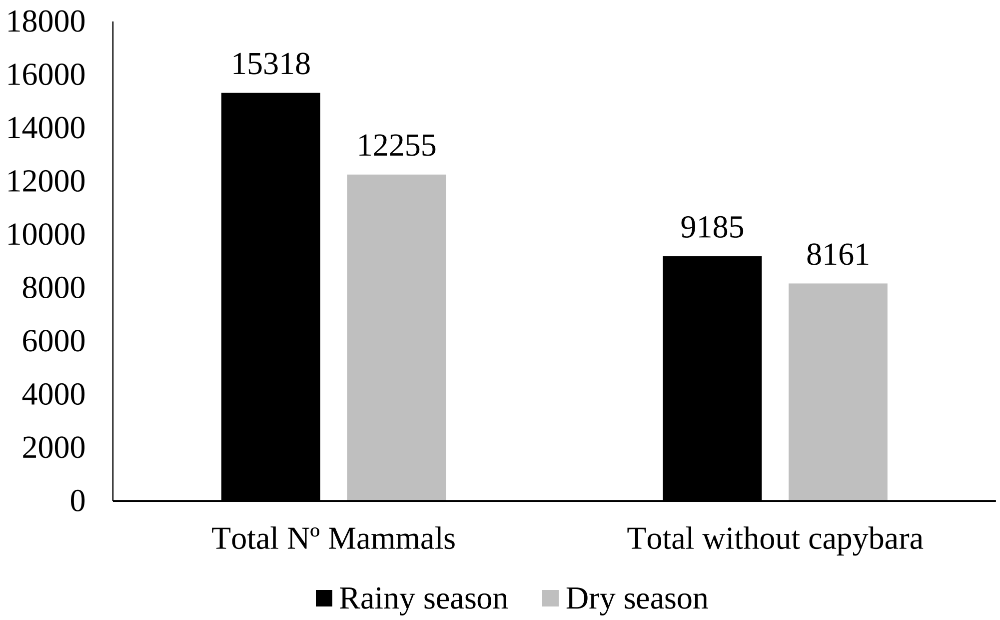

Figure 5. Number of roadkilled medium and large sized mammals per season (dry and rainy), with and without capybara (*Hydrochoerus hydrochaeris*), from 2009 to 2014, in toll roads of São Paulo State, Brazil.

The peak of the mammal collisions occurred on November (n = 3,042), followed by December (n = 2,827) and October (n= 2,821) (Fig. 6).

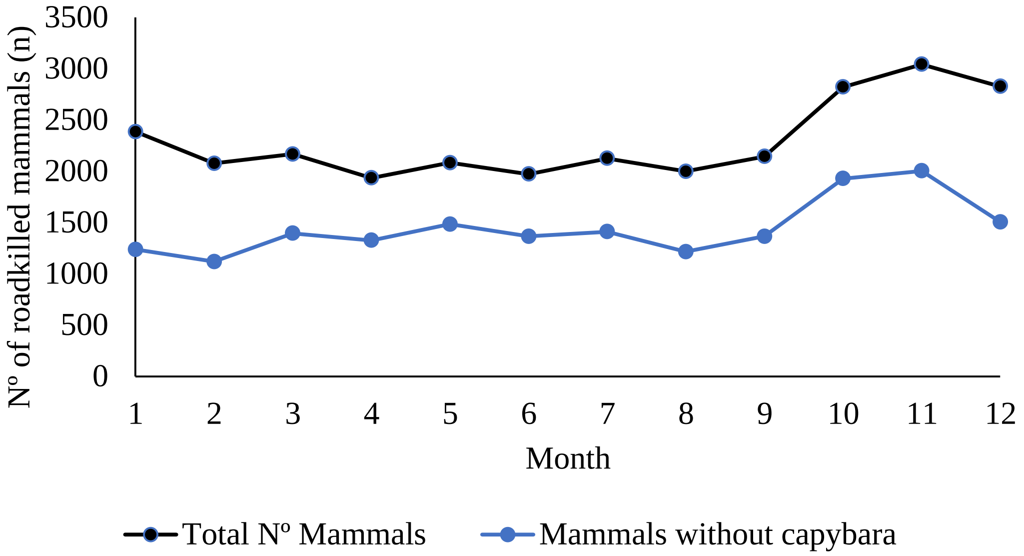

Figure 6. Number of roadkilled medium and large sized mammals, with and without capybara (*Hydrochoerus hydrochaeris*), throughout 2009 to 2014 on toll roads in São Paulo State, Brazil.

Mammal roadkills tended to increase between 2009 and 2014 (R^2 = 0.614; p = 0.065), with an average increase of 313.5 individuals per year (Fig. 7).

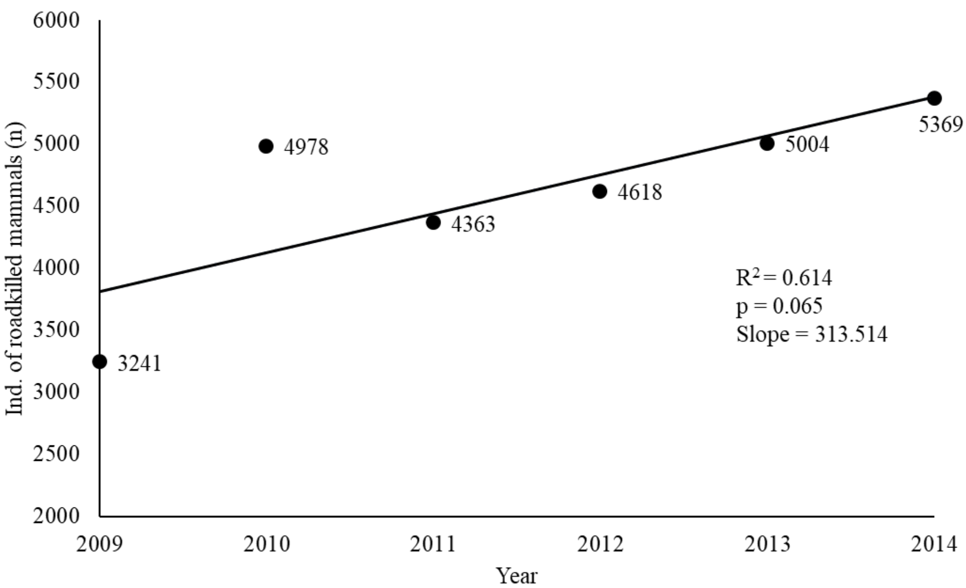

Figure 7. The number of roadkilled medium and large sized mammals per year (2009 through 2014) along the toll roads in São Paulo State, Brazil.

3.3.3. Roadkill estimates

The twenty-seven road sections of 10-km long had recorded 993 (min = 1, max = 116, average = 37) mammal individuals roadkilled (Fig. 8; Appendix D).

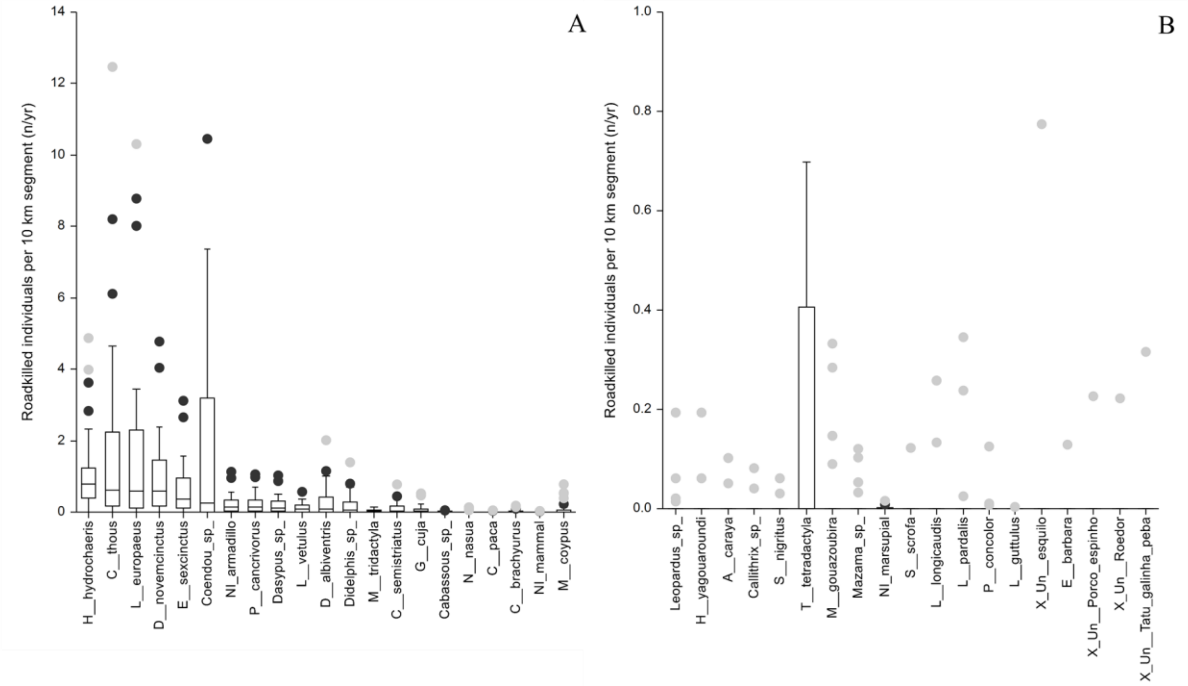

Figure 8. Number of roadkilled medium and large sized mammals in the 27 road sections of 10-km long. A) Roadkill numbers ranging from 0 to 13 individuals and B) individual roadkill numbers ranging from 0 to 1. Box: middle 50% of the data (25^{th}–75^{th} quartile); horizontal line: median; whisker boundaries: 1.5 times inter-quartile range; outliers greater than 1.5 times the inter-quartile range. The N correspond to the number of road sections. Gray dots correspond to outliers and black dots to extreme outliers.

The sum of roadkills per year for 2- lane and 4- lane paved roads in São Paulo State resulted in estimates of roadkilled individuals of medium- and large-sized mammals on paved roads of São Paulo State (min = 5,563; max = 175,963; average = 39,605; median = 16,662). (Table 3).

Table 3. Estimate of roadkill numbers per species or animal taxonomic group per year for all paved roads in São Paulo State, Brazil. Legend: Min = Minimum, Max = Maximum. Species with "*" refers to Unconfirmed animal species which did not have reference values from Abra et al. (2018) and the Portuguese common names could not be validated by pictures into scientific names. Species with ** are considered underestimated, and species with *** are considered overestimated.

Species	Average	Median	Min	Max
Hydrochoerus hydrochaeris	5,435	4,051	1,793	15,595
Cerdocyon thous	6,889	2,477	740	36,050
Lepus europaeus	7,018	2,464	788	29,976
Dasypus novemcinctus	3,572	2,007	361	13,887
Euphractus sexcinctus	2,332	1,296	233	9,062
Coendou sp.	5,945	1,055	362	29,964
NI armadillo	845	475	85	3,284
Procyon cancrivorus	857	499	139	3,136
Dasypus sp.	766	430	76	2,984
*Lycalopex vetulus****	457	338	84	1,692
Didelphis albiventris	1,113	340	121	5,823
Didelphis sp.	801	258	96	4,041
Myrmecophaga tridactyla	149	132	33	453
Conepatus semistriatus	425	126	45	2,237
Galictis cuja	289	79	30	1,513
Cabassous sp.	38	21	4	149
Nasua nasua	100	41	26	402
Cuniculus paca	39	18	8	144
Chrysocyon brachyurus	156	84	75	585
NI mammal	26	12	8	94
Myocastor coypus	368	34	30	2,231
Leopardus sp.	78	6	6	554
Herpailurus yagouaroundi	74	5	5	553
Alouatta caraya	50	15	15	304
Callithrix sp.	40	12	12	243
Sapajus nigritus	30	9	9	183
Tamandua tetradactyla	770	173	173	2,148
Mazama gouazoubira	189	59	59	1,000
Mazama sp.	76	29	29	370
NI marsupial	8	2	2	47
Sus scrofa	27	4	4	350
Lontra longicaudis	95	6	6	736
Leopardus pardalis	112	19	19	997
Puma concolor	47	21	21	376
*Leopardus guttulus***	0	0	0	10

Species	Average	Median	Min	Max
*Unconfirmed Esquilo	156	5	5	2198
*Eira barbara***	26	1	1	367
*Unconfirmed Porco espinho	61	16	16	658
*Unconfirmed roedor	47	3	3	633
*Unconfirmed tatu galinha/peba	64	2	2	896
*Pecari tajacu***	0.21	0.21	0.21	0.21
*Tapirus terrestris***	2	2	2	2
*Cavia aperea***	2	2	2	2
*Unconfirmed Ariranha	1	1	1	1
*Unconfirmed Bicho preguiça	6	6	6	6
*Unconfirmed Bugio	1	1	1	1
*Unconfirmed Cervo do pantanal	0	0	0	0
*Unconfirmed Macaco prego	1	1	1	1
*Unconfirmed Mico leão	1	1	1	1
*Unconfirmed Sagui	23	23	23	23
*Unconfirmed Sussuarana	1	1	1	1
*Unconfirmed Veado mateiro	0	0	0	0
*Unconfirmed Cateto	0	0	0	0
*Unconfirmed Gambá de orelha branca	0	0	0	0
*Unconfirmed Gato maracajá	0	0	0	0
*Unconfirmed Javaporco	0	0	0	0
*Unconfirmed Onça filhote	0	0	0	0
*Unconfirmed Onça pintada filhote	0	0	0	0
*Unconfirmed Porco	0	0	0	0
*Unconfirmed Sagui de tufo preto	0	0	0	0
*Unconfirmed Primata	0	0	0	0
Total	**39,605**	**16,662**	**5,563**	**175,963**

The mammal order that was most frequently reported as roadkill was Rodentia, followed by Carnivora and Cingulata, which together summed about 73% of all average estimate for São Paulo State (Fig. 9).

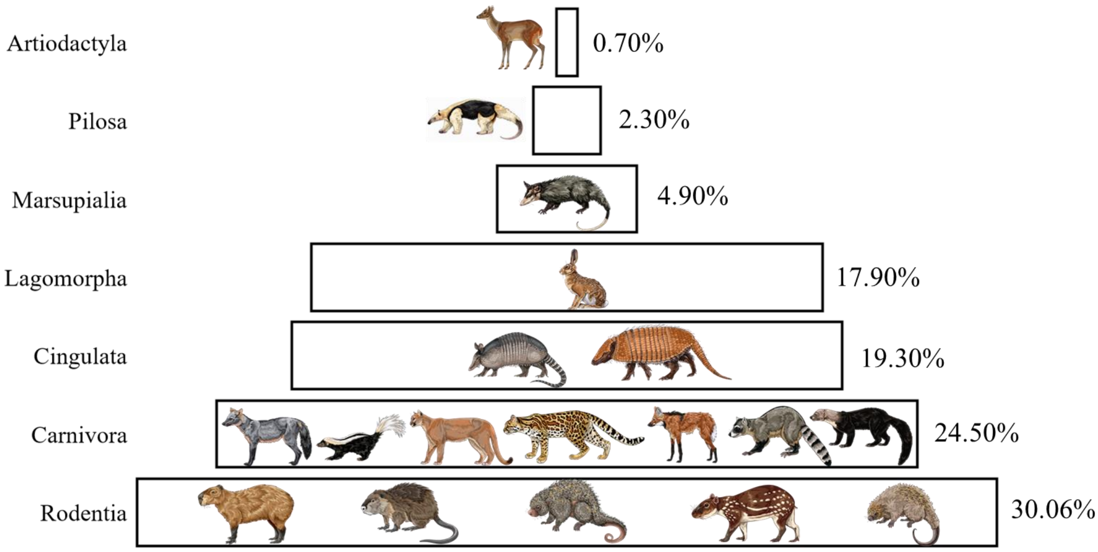

Figure 9. Representativeness of the orders of the most roadkilled mammals of the state of São Paulo, Brazil, following the average estimate. Orders were considered ≥ 0.7%.

3.4. DISCUSSION

3.4.1. Toll roads

The roadkill monitoring program is extensive and has a relatively consistent and frequent search and reporting effort; the entire length of the toll roads is checked at least once every three hours. Though the roadkill data is a strong evidence of individual loss for different species, is necessary to note that not all roadkills are recorded due to carcass removal by scavengers (RATTON ET AL., 2014; SANTOS et al., 2016) or people (MEDICI & ABRA, 2019), and the impossibility to detect and record carcasses out of the right of ways (e.g. they get hit on the road but die off the road).

Carcasses of cinegetic species, such as armadillos (especially *Dasypus* spp.), lowland tapir, lowland paca (*Cuniculus paca*) and brocket deer (*Mazama* spp.) can be removed by drivers to make use of the meat. Possibly, carcasses of puma (*Puma concolor*), and small spotted cats (*Leopardus* spp.) also has the potential to be removed (CORREIO DO ESTADO, 2011; G1, 2011) due to the commercial value attributed to their fur, skull, teeth or other body parts, which are used as trophy, amulet and medicine (MACDONALD et al., 2010).

The ten years of roadkill monitoring revealed a chronic loss of mammal species in São Paulo State, including threatened species, which represent 4.3% of all data. The roadkill is considered one of the most negative impacts for threatened species and it has been referred on Brazilian National Action Plans from Instituto Chico Mendes de Conservação da

Biodiversidade (ICMBio), Brazilian red list and on the Brazilian Assessment of Species Conservation Status (ICMBio, 2011a; 2011b, MEDICI et al., 2012; LEMOS et al., 2013; ICMBio, 2018).

Species as capybara, European hare, crab-eating fox, nine-banded armadillo and porcupines, were the most frequently reported roadkilled mammals on toll roads in São Paulo state. All these species are also normally recorded in mammal inventories and considered habitat generalists, thriving in most human-modified landscapes (HMLs) (LYRA-JORGE et al., 2008; BUENO, et al. 2013; FREITAS et al., 2015; GALETTI et al., 2016; MAGIOLI et al., 2016, 2018; ASCENSÃO et al., 2017; AZEVEDO et al., 2018; BOVO et al., 2018). European hare is an invasive species and has succeeded in colonizing and expanding its distribution in Brazil (De FARIA et al., 2016). The species is widespread in São Paulo State, and was one of the most roadkilled mammals in our study.

The changes in landscape composition and structure, mostly triggered by opening of transportation corridors, tend to eliminate wildlife species that are more sensitive to the loss of habitat and resources (GASCON et al., 1999; FAHRIG, 2003; LYRA-JORGE et al., 2008), favoring generalist species that are capable of exploiting new environments such as agriculture crops or disturbed habitats (DOWNES et al., 1997, MAGIOLI et al. under revision). The number of capybaras roadkilled accounts for more than one third of all roadkills, stressing the urgency of management actions that limit the access of this species to roads. Capybara is the largest living rodent, averaging about 50 - 90 kg in HMLs in São Paulo state (FERRAZ et al., 2005; Marcelo Labruna, Pers. Comm). This species is now the most common living mammal in HMLs at the São Paulo State, overabundant in landscapes dominated by sugarcane crops in Southeastern Brazil (VERDADE & FERRAZ ,2006; FERRAZ et al., 2007), explained by food availability and natural predators decline (e.g. *Puma concolor*) (FERRAZ et al., 2003; FERRAZ et al., 2007; VERDADE et al., 2012; BOVO et al., 2016; NIELSEN et al., 2016).

Accordingly, Abra et al. (2019) shows that the number of animal-vehicle collisions are increasing in São Paulo State, and despite the data from mammal carcass removal from our study was not statistically significant due to small sampling size, there was an increase of 313 mammal carcasses per year on toll roads. An increase in traffic volume, new roads in remote areas, and augmenting populations of species that thrives in HMLs, are factors that are potentially contributing to roadkill increase (ABRA et al., 2019).

3.4.2. Temporal patterns

Most mammal carcasses were recorded during the night, from dusk to midnight, but also from dawn to 9:00 h similar to temperate regions (GROOT BRUINDERINK & HAZEBROEK, 1996; HUIJSER et al., 2008) and following the same patterns of animal-vehicle crashes (wild and domesticated mammals) in São Paulo State (ABRA et al., 2019). We believe that the time of roadkills is mainly related to species activity patterns and traffic volume. Unfortunately, we could not obtain data on traffic volume for all roads in this study, but it is expected a high traffic volume on roads from 6:00 h to 8:00 h am, increasing the number of roadkills (Pedro Romanini, Pers. Comm).

The number of roadkills for all species combined in rainy season were slightly higher with 55.55% of all records for all mammal species combined. For herbivores (specific species, firstly as grazers and secondly as browsers), rainy season can increase the offer of leave sprouts in habitats close to roads, what exposes the animals much more to the road traffic. Moreover, the constant cut of vegetation on the right-of-ways, increases the availability of sprouts, which acts as an attractant for herbivores. On toll roads, all space on right-of-way is dominated by grass (*Poacea* species), an attractive food resource, available all year around, for species such as capybara, coypu (*Myocastor coypus*), European hare and brocket deer (RICHARD & JULIÁ, 2001; BORGES & COLARES, 2007; PUIG et al., 2007; COLARES et al., 2010).

In HMLs, the first peak of activity of capybaras, for example, started earlier at 5:00 h and the second, later at 18:00 h. The second peak of activity lasts until 21:00 h, with low activity between 7:00 h and 17:00 h (LOPEZ et al, 2019 in prep). This activity pattern matches our results, as the roadkill rate of capybaras were higher in the aforementioned periods.

During the dry season, some species tend to expand their habitat range in search of food, which implicates on higher movement rates and an increase of contact with roads (SILVEIRA et al., 2010). Roadkills were higher during dry months for specific species in our study, mainly carnivores, such as Crab-eating fox (*Cerdocyon thous*), Maned wolf (*Chrysocyon brachyurus*) and Ocelot (*Leopardus pardalis*). Lemos et al. (2011) found that the number of Crab-eating foxes and hoary foxes were higher during the dry season.

3.4.3. Roadkill estimates for São Paulo State

The wide variation in species roadkilled per road section was expected because roads cross different types of landscape, from natural to urban areas, which directly influences species richness and abundance (FREITAS et al., 2015; ASCENSÃO et al., 2017). Despite choosing a road section length (10-km long) with less variation in roadkill numbers, we still had considerable variation between species roadkilled, but more importantly in the 27 sections there was a lack of species such as Lowland tapir, Southern tiger cat, Brazilian guinea pig and Collared peccary, which drastically reduced the chances of the species be more represented on the estimates.

Despite 27 sections of 10 km each is a descent sample size, if we had more reference data from 2-lane roads we could strength the roadkill estimates with less uncertainties or variation.

For this study, we believe that our but the lack of quantity of real and long-term data from 2-lane roads from DER and the roads managed by municipalities. Considering our limitations, we believe that the roadkill estimates for São Paulo State can be useful as a subside to environmental and transportation agencies to promote better planning, and to direct investments in effective mitigation measures to counteract the negative effects of roads (RYTWINSKI et al., 2016).

It is necessary to make a caveat for the roadkill estimates of Hoary foxes. This species is the only truly endemic carnivore of the Cerrado biome of Brazil (JÁCOMO et al. 2004). All validated records of Hoary fox made by Abra et al. (2018) were inside the limits of Cerrado in the state of São Paulo, but the extrapolation for toll roads or public roads encompasses stretches of road outside the biome, thus not reflecting the real values for the roadkills. That's the reason this specific species was overestimated in this study.

Finally, we recommend the use of the averages estimates for Action National Plans or Population Viability Analyzes (PVA), aiming to test probability of population extinction using roadkill numbers (DINIZ & BRITO, 2013).

3.5. FINAL CONSIDERATIONS

Our study is a first attempt to generate roadkill estimates in a large scale in Brazil. Based on our results, estimates generated in reginal scales are more accurate than extrapolations in large scales (biomes or nationwide). Despite basically recording generalist species, is necessary to highlight the high number of individual losses for threatened species on toll roads, the increased number in the extrapolation all paved roads in São Paulo State.

From the outcomes of this study will be possible to conduct others analyses with specific species as population viability analysis to calculated and understand the impact of the individual losses from different species cause in populations as the extinction risk and to develop a plan of action, when needed. The roadkills seems to be a chronic and growing impact for wildlife populations what can act as an important driver of defaunation.

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APPENDIX

Appendix A. Toll road companies and the year they started to collect roadkill data from 2005 to 2014 in roads of São Paulo State, Brazil. For the toll road companies that did not collect roadkill data in certain years, we calculated the average number of roadkilled mammals based on the present data for the same companies. *SPI/SPA are intersection roads or roads of access also under concession from different toll roads companies.

		Year of data collection										
		2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Road length (km)**
Toll road companies	**Autoban**	X	X	X	X	X	X	X	X	X	X	316.752
	Autovias	X	X	X	X	X	X	X	X	X	X	316.500
	Cart	Average	Average	Average	Average	X	X	X	X	X	X	
	Centrovias	X	X	X	X	X	X	X	X	X	X	218.160
	Colinas	X	X	X	X	X	X	X	X	X	X	306.896
	Ecopistas	Average	Average	Average	Average	X	X	X	X	X	X	148.790
	Ecovias	X	X	X	X	X	X	X	X	X	X	176.790
	Intervias	X	X	X	X	X	X	X	X	X	X	375.696
	Renovias	X	X	X	X	X	X	X	X	X	X	345.660
	Rodoanel	Average	Average	Average	X	X	X	X	X	X	X	30.000
	Rondon	Average	Average	Average	Average	X	X	X	X	X	X	413.370
	Rota das Bandeiras	Average	Average	Average	Average	X	X	X	X	X	X	297.000
	SpVias	X	X	X	X	X	X	X	X	X	X	505.734
	Tebe	X	X	X	X	X	X	X	X	X	X	155.982
	Tietê	Average	Average	Average	Average	X	X	X	X	X	X	415.125

		Year of data collection									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Road length (km)
	Triângulo do Sol	Average	X	X	X	X	X	X	X	X	X	442.196
	ViaNorte	X	X	X	X	X	X	X	X	X	X	236.600
	ViaOeste	X	X	X	X	X	X	X	X	X	X	168.620
	***SPI/SPA**											1,186.129

Appendix B. Calculations of roadkills average per species per year for data collected by toll road companies and roadkills average per species for the years of missing data. CT = Cart, ECO = Ecopista, RD = Rodoanel, RN = Rondon, RB = Rota das Bandeiras, TT = Tietê, TS = Triângulo do sol. ADCY = Average of data collected per year, AMD = Average of Missing data, NA = Not available. Species with "*" refers to Unconfirmed animal species which did not have reference values from Abra et al. (2018) and the Portuguese common names could not be validated by pictures into scientific names.

Species	CT ADCY	CT AMD	ECO ADCY	ECO AMD	RD ADCY	RD AMD	RN ADCY	RN AMD	RB ADCY	RB AMD	TT ADCY	TT AMD	TS ADCY	TS AMD
*Unconfirmed Ariranha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.50	2.00	0.11	0.11
*Unconfirmed Bicho-preguiça	0.17	0.67	0.83	3.33	0.57	1.71	0.17	0.68	1.50	6.00	NA	NA	NA	NA
*Unconfirmed Bugio	0.33	1.33	NA	NA	NA	NA	0.17	0.67	0.17	0.67	NA	NA	NA	NA
*Unconfirmed Cervo do pantanal	0.17	0.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
*Unconfirmed Esquilo	NA	NA	NA	NA	NA	NA	NA	NA	1.67	6.67	0.17	0.67	NA	NA
*Unconfirmed Macaco-prego	NA	NA	NA	NA	NA	NA	0.17	0.67	NA	NA	NA	NA	NA	NA
*Unconfirmed Mico-leão	NA	NA	0.17	0.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
*Unconfirmed Porco Espinho	1.33	5.33	2.67	10.67	0.14	0.43	NA	NA	0.33	1.33	1.00	4.00	0.44	0.44
*Unconfirmed Rato	NA	NA	0.17	0.67	NA	NA	1.00	4.00	NA	NA	NA	NA	0.56	0.56
*Unconfirmed Rato do mato	0.17	0.67	NA	NA	NA	NA	NA	NA	NA	NA	0.17	0.67	NA	NA
*Unconfirmed Sagui	NA	NA	NA	NA	NA	NA	NA	NA	13.67	54.67	0.17	0.67	NA	NA
*Unconfirmed Sussuarana	NA	NA	NA	NA	NA	NA	NA	NA	0.17	0.67	NA	NA	NA	NA
*Unconfirmed Tatu galinha	0.67	2.67	NA	NA	NA	NA	0.17	0.67	NA	NA	NA	NA	NA	NA
*Unconfirmed Tatu peba	0.67	2.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
*Unconfirmed Veado mateiro	0.17	0.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Alouatta caraya	0.70	2.78	NA	NA	NA	NA	0.83	3.33	2.85	11.39	0.21	0.83	1.99	1.99
Cabassous sp.	0.30	1.18	0.02	0.07	NA	NA	0.50	2.00	0.13	0.52	0.38	1.53	0.39	0.39
Callithrix sp.	0.56	2.22	NA	NA	NA	NA	0.67	2.67	2.28	9.11	0.17	0.67	1.59	1.59
Cavia aperea	0.50	2.00	NA	NA	NA	NA	0.17	0.67	NA	NA	0.67	2.67	NA	NA
Cerdocyon thous	41.53	166.13	4.05	16.20	0.12	0.35	51.20	204.81	58.07	232.28	77.03	308.13	66.23	66.23

Species	CT ADCY	CT AMD	ECO ADCY	ECO AMD	RD ADCY	RD AMD	RN ADCY	RN AMD	RB ADCY	RB AMD	TT ADCY	TT AMD	TS ADCY	TS AMD
Chrysocyon brachyurus	2.89	11.57	0.93	3.71	NA	NA	0.98	3.91	1.20	4.79	1.83	7.30	3.41	3.41
Coendou sp.	16.17	64.67	NA	NA	NA	NA	3.17	12.67	43.83	175.33	56.17	224.67	7.22	7.22
Conepatus semistriatus	1.31	5.23	1.33	5.33	0.04	0.12	1.50	6.00	11.90	47.60	2.24	8.95	0.65	0.65
Cuniculus paca	0.73	2.92	0.40	1.59	0.00	0.01	0.20	0.79	0.70	2.80	0.39	1.55	0.25	0.25
Dasypus novemcinctus	35.05	140.18	1.66	6.64	NA	NA	38.83	155.33	12.47	49.89	35.61	142.45	35.90	35.90
Dasypus sp.	5.97	23.87	0.36	1.43	NA	NA	8.33	33.33	2.58	10.33	7.65	30.60	7.72	7.72
Didelphis albiventris	4.85	19.39	3.68	14.73	0.11	0.32	3.88	15.53	31.12	124.46	6.13	24.52	1.87	1.87
Didelphis sp.	4.42	17.66	2.59	10.35	0.08	0.23	3.76	15.05	22.22	88.88	6.28	25.10	2.09	2.09
Eira barbara	0.06	0.22	0.17	0.67	NA	NA	0.06	0.22	NA	NA	NA	NA	0.07	0.07
Euphractus sexcinctus	21.89	87.55	1.07	4.29	0.001	0.00	25.21	100.82	8.05	32.21	23.13	92.53	23.32	23.32
Galictis cuja	1.73	6.92	1.17	4.67	0.02	0.07	0.95	3.78	7.14	28.57	1.34	5.37	0.54	0.54
Herpailurus yagouaroundi	0.40	1.59	0.08	0.33	NA	NA	0.40	1.59	NA	NA	0.50	2.00	0.15	0.15
Hydrochoerus hydrochaeris	156.15	624.58	78.85	315.41	2.56	7.69	45.36	181.42	91.83	367.31	49.70	198.79	110.64	110.64
Leopardus guttulus	0.01	0.03	NA	NA	NA	NA	0.01	0.03	0.02	0.06	0.02	0.06	0.04	0.04
Leopardus pardalis	1.34	5.34	NA	NA	NA	NA	0.80	3.19	0.70	2.81	0.11	0.43	0.35	0.35
Leopardus sp.	0.53	2.11	0.08	0.33	NA	NA	0.38	1.51	0.04	0.15	0.63	2.51	0.12	0.12
Lepus europaeus	52.45	209.79	0.84	3.34	0.28	0.85	39.52	158.06	66.96	267.84	58.24	232.97	59.97	59.97
Lontra longicaudis	0.56	2.22	0.11	0.45	NA	NA	0.45	1.78	0.56	2.22	0.22	0.89	0.15	0.15
Lycalopex vetulus	6.48	25.93	0.57	2.28	0.02	0.05	1.03	4.13	6.21	24.85	11.09	44.36	7.24	7.24
Mamifero ni	0.69	2.77	0.14	0.55	0.002	0.01	0.73	2.93	0.30	1.19	0.82	3.27	0.30	0.30
Marsupial ni	0.11	0.43	0.02	0.07	0.001	0.00	0.22	0.86	0.16	0.63	0.31	1.24	0.18	0.18
Mazama gouazoubira	2.17	8.67	0.25	1.01	0.31	0.94	0.98	3.91	1.84	7.34	3.61	14.45	0.78	0.78
Mazama sp.	1.67	6.67	0.09	0.35	0.11	0.34	0.36	1.42	0.67	2.66	1388.00	5552.0	0.33	0.33
Myocastor coypus	5.49	21.96	1.02	4.06	0.004	0.01	0.30	1.18	0.88	3.51	1715.00	6860.0	0.25	0.25

Species	CT ADCY	CT AMD	ECO ADCY	ECO AMD	RD ADCY	RD AMD	RN ADCY	RN AMD	RB ADCY	RB AMD	TT ADCY	TT AMD	TS ADCY	TS AMD
												0		
Myrmecophaga tridactyla	3.13	12.51	0.02	0.07	NA	NA	2.03	8.13	0.15	0.61	1.42	5.67	2.66	2.66
Nasua nasua	3.37	13.49	0.37	1.48	0.001	0.00	1.90	7.60	0.56	2.24	3.24	12.97	0.75	0.75
ouriço ni	0.11	0.43	0.02	0.07	0.001	0.00	0.22	0.86	0.16	0.63	0.31	1.24	0.18	0.18
Pecari tajacu	0.17	0.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Procyon cancrivorus	12.88	51.51	2.18	8.73	0.04	0.11	10.25	40.99	12.34	49.36	14.47	57.89	5.95	5.95
Puma concolor	1.89	7.56	NA	NA	NA	NA	0.73	2.93	0.56	2.25	0.61	2.43	1.56	1.56
Sapajus apela	0.42	1.67	NA	NA	NA	NA	NA	NA	1.71	6.83	0.13	0.50	1.19	1.19
Sapajus nigritus	NA	NA	NA	NA	NA	NA	0.50	2.00	NA	NA	NA	NA	NA	NA
Tamandua tetradactyla	19.94	79.74	0.15	0.58	NA	NA	16.54	66.15	0.48	1.91	7.86	31.45	19.57	19.57
Tapirus terrestris	0.83	3.33	NA	NA	NA	NA	0.17	0.67	NA	NA	NA	NA	NA	NA
Tatu ni	8.01	32.05	0.39	1.57	NA	NA	9.17	36.67	2.85	11.38	8.42	33.69	8.50	8.50

Appendix C. Characteristics of the 27 road sections of 10-km long before upgrade, and the number of wild medi um- and large-sized mammal roadkills in São Paulo State, Brazil.

Toll road_company	Road Code	Cities	Initial_km Marker	Final_km Marker	Difference (Initial km - Final km)	Section ID	10 km_Section	Roadkill per_section (N)	First record Roadkill Monitoring (Month/year)	Initial_Month of_Upgrade (Month/year)
Tebe	SP-351	Bebedouro/Catanduva	153.172	218.020	64.848	1	153-162	7	January-05	March-12
Tebe	SP-351	Bebedouro/Catanduva	153.172	218.020	64.848	2	163-172	34	January-05	March-12
Tebe	SP-351	Bebedouro/Catanduva	153.172	218.020	64.848	3	173-182	33	January-05	March-12
Tebe	SP-351	Bebedouro/Catanduva	153.172	218.020	64.848	4	183-192	18	January-05	March-12
Tebe	SP-351	Bebedouro/Catanduva	153.172	218.020	64.848	5	193-202	17	January-05	March-12
Tebe	SP-351	Bebedouro/Catanduva	153.172	218.020	64.848	6	203-212	12	January-05	March-12
SPVias	SP-255	Avaré	237.771	278.000	40.229	7	237-246	29	February-05	February-10
SPVias	SP-255	Avaré	237.771	278.000	40.229	8	247-256	31	February-05	February-10
SPVias	SP-255	Avaré	237.771	278.000	40.229	9	257-266	19	February-05	February-10
SPVias	SP-255	Avaré	237.771	278.000	40.229	10	267-276	22	February-05	February-10
Colinas	SP-127	Saltinho/ Tietê	51.000	83.000	32.000	11	51-60	75	January-05	July-07
Colinas	SP-127	Saltinho/ Tietê	51.000	83.000	32.000	12	61-70	88	January-05	July-07
Colinas	SP-127	Saltinho/ Tietê	51.000	83.000	32.000	13	71-80	46	January-05	July-07
SPVias	SP-270	Capela do Alto/ Itapetininga	132.620	148.400	15.780	14	132-141	52	February-05	August-12
Colinas	SP-300	Porto Feliz/ Tietê	135.000	158.650	23.650	15	135 - 144	116	January-05	July-07
Colinas	SP-300	Porto Feliz/ Tietê	135.000	158.650	23.650	16	145-154	103	January-05	July-07
Triângulo do Sol	SP-333	Jaboticabal/ Taquaritinga	123.500	142.600	19.100	17	123 - 132	5	January-06	September-07
Triângulo do	SP-333	Jaboticabal/	123.500	142.600	19.100	18	133-142	9	January-06	September-07

Toll road_company	Road Code	Cities	Initial_km Marker	Final_km Marker	Difference (Initial km - Final km)	Section ID	10 km_Section	Roadkill per_section (N)	First record Roadkill Monitoring (Month/year)	Initial_Month of_Upgrade (Month/year)
Sol		Taquaritinga								
SPVias	SP-270	Araçoiaba da Serra/ Capela do Alto	115.500	132.620	17.120	19	115-124	59	February-05	July-11
Ecovias	SP-160	São Bernardo do Campo	25.854	40.739	14.885	20	25-34	18	March-05	December-12
Colinas	SP-127	Cerquilho/ Tatuí	91.500	105.900	14.400	21	91-100	51	January-05	July-07
Rodovias do Tietê	SP-308	Capivari	127.730	141.410	13.680	22	127-136	54	October-09	June-12
Rodovias do Tietê	SP-308	Rio das Pedras	141.410	153.500	12.090	23	141-150	25	October-09	November-11
Cart	SP-270	Maracaí	481.500	493.340	11.840	24	481-490	38	March-09	August-12
Rodovias do Tietê	SP-101	Monte Mor	14.640	25.700	11.060	25	14-23	1	October-09	April-12
Triângulo do Sol	SP-326	Taquaral/ Pitangueiras	358.000	368.500	10.500	26	358-367	3	January-06	February-07
Cart	SP-270	Maracaí	471.332	481.500	10.168	27	471-180	28	March-09	April-12

Appendix D. Descriptive statistics for each species from the 27 road sections of 10-km long in São Paulo State, Brazil. Legend: Min. = Minimum, Max = Maximum, SD = Standard Deviation.

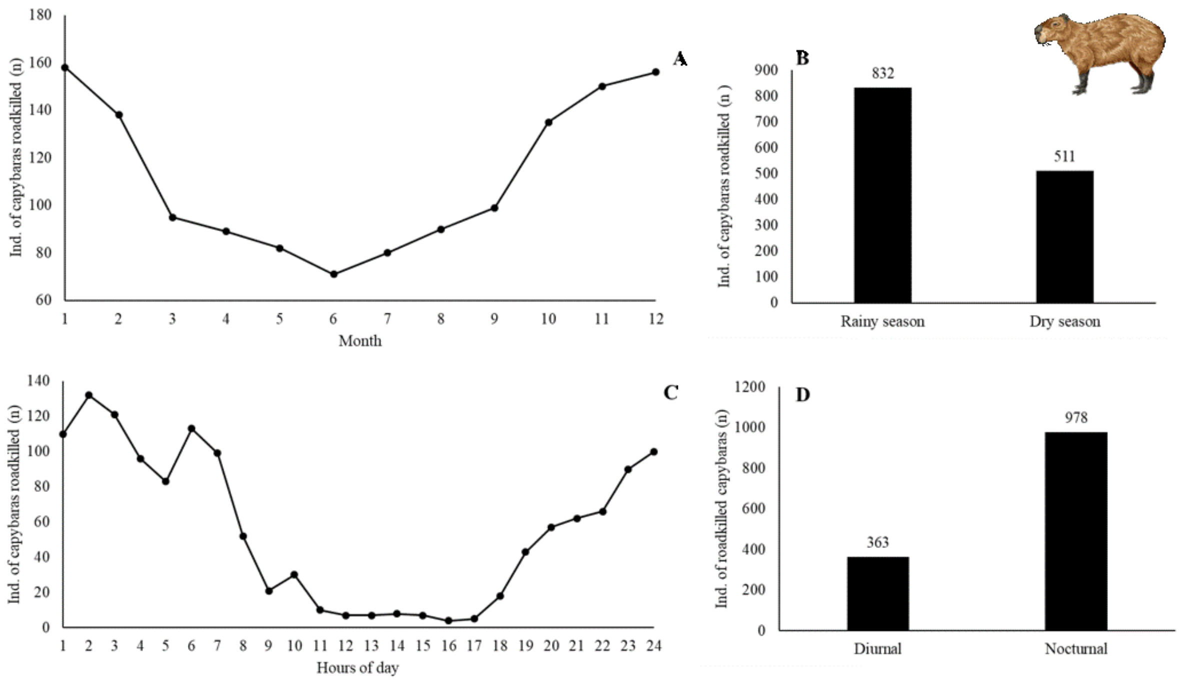
Species	Min.	Max	Average	SD	Median
Hydrochoerus hydrochaeris	0.00	4.87	1.29	1.27	0.80
Cerdocyon thous	0.00	12.47	2.17	2.94	0.61
Lepus europaeus	0.00	10.31	2.20	3.04	0.59
Dasypus novemcinctus	0.00	4.78	1.13	1.20	0.58
Euphractus sexcinctus	0.00	3.12	0.74	0.78	0.38
Coendou sp.	0.00	10.45	1.97	2.76	0.24
NI armadillo	0.00	1.13	0.27	0.28	0.14
Procyon cancrivorus	0.00	1.06	0.25	0.29	0.13
Dasypus sp.	0.00	1.03	0.24	0.26	0.12
Lycalopex vetulus	0.00	0.57	0.13	0.14	0.09
Didelphis albiventris	0.00	2.01	0.35	0.50	0.08
Didelphis sp.	0.00	1.39	0.25	0.34	0.06
Myrmecophaga tridactyla	0.00	0.15	0.04	0.03	0.04
Conepatus semistriatus	0.00	0.77	0.13	0.19	0.03
Galictis cuja	0.00	0.52	0.09	0.14	0.02
Cabassous sp.	0.00	0.05	0.01	0.01	0.01
Nasua nasua	0.00	0.13	0.03	0.04	0.01
Cuniculus paca	0.00	0.05	0.01	0.01	0.00
Chrysocyon brachyurus	0.00	0.18	0.03	0.05	0.00
NI mammal	0.00	0.03	0.01	0.01	0.00
Myocastor coypus	0.00	0.78	0.12	0.21	0.00
Leopardus sp.	0.00	0.19	0.03	0.05	0.00
Herpailurus yagouaroundi	0.00	0.19	0.02	0.05	0.00
Alouatta caraya	0.00	0.10	0.01	0.03	0.00
Callithrix sp.	0.00	0.08	0.01	0.02	0.00
Sapajus apella	0.00	0.06	0.01	0.02	0.00
Tamandua tetradactyla	0.00	0.70	0.21	0.23	0.00
Mazama gouazoubira	0.00	0.33	0.05	0.09	0.00
Mazama sp.	0.00	0.12	0.02	0.03	0.00
NI marsupial	0.00	0.02	0.00	0.00	0.00
Sus scrofa	0.00	0.12	0.01	0.02	0.00
Lontra longicaudis	0.00	0.26	0.03	0.07	0.00
Leopardus pardalis	0.00	0.35	0.03	0.08	0.00
Puma concolor	0.00	0.13	0.01	0.02	0.00

Species	Min.	Max	Average	SD	Median
Leopardus guttulus	0.00	0.00	0.00	0.00	0.00
*Un. Esquilo	0.00	0.77	0.05	0.15	0.00
Eira barbara	0.00	0.13	0.01	0.02	0.00
*Un. Porco espinho	0.00	0.23	0.02	0.04	0.00
*Un. Roedor	0.00	0.22	0.02	0.04	0.00
*Un. Tatu galinha/peba	0.00	0.32	0.02	0.06	0.00

Appendix E. Temporal patterns for roadkill mammal species with identification validated by picture with sample size ≥ 45.

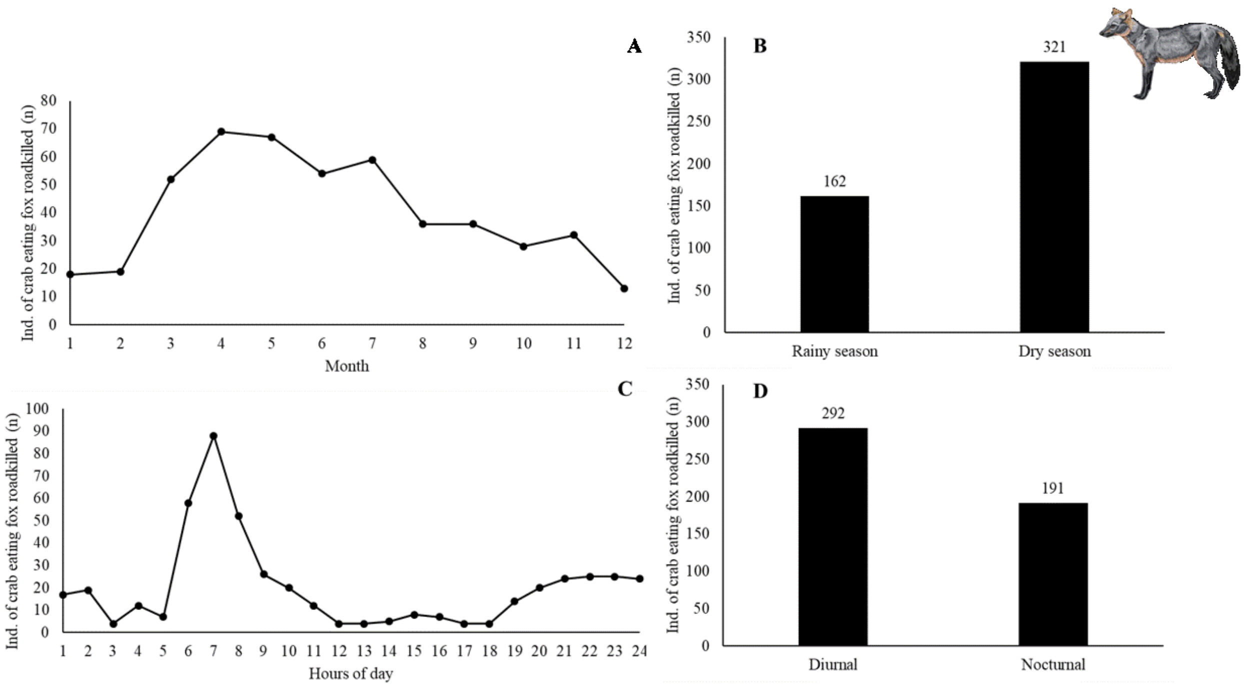
Capybara (*Hydrochoerus hydrochaeris*)
N = 1343

A) Total number of roadkilled capybaras (*Hydrochoerus hydrochaeris*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled capybaras from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled capybaras from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled capybaras from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.

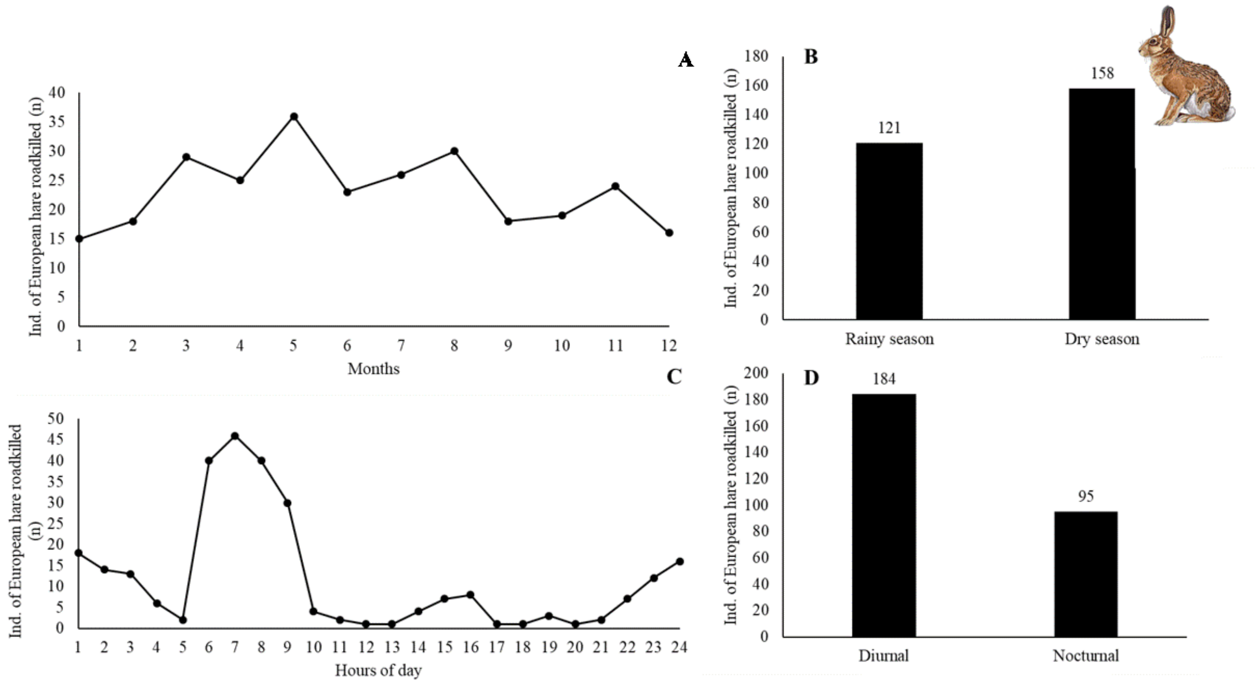


Crab eating fox (*Cerdocyon thous*)
N = 483

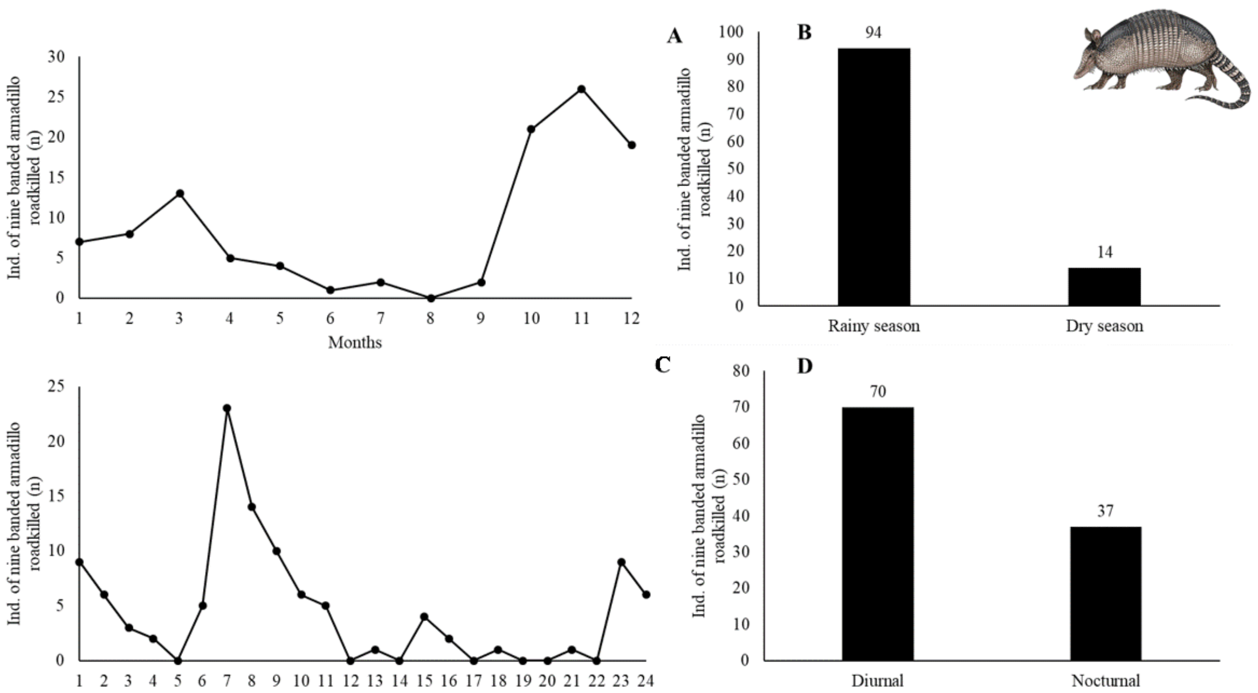
A) Total number of roadkilled crab eating fox (*Cerdocyon thous*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled crab eating fox from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled crab eating fox from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled crab eating fox from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.



European hare (*Lepus europaeus*)
N = 279
A) Total number of roadkilled European hare (*Lepus europaeus*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled European hare from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled European hare from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled European hare from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.

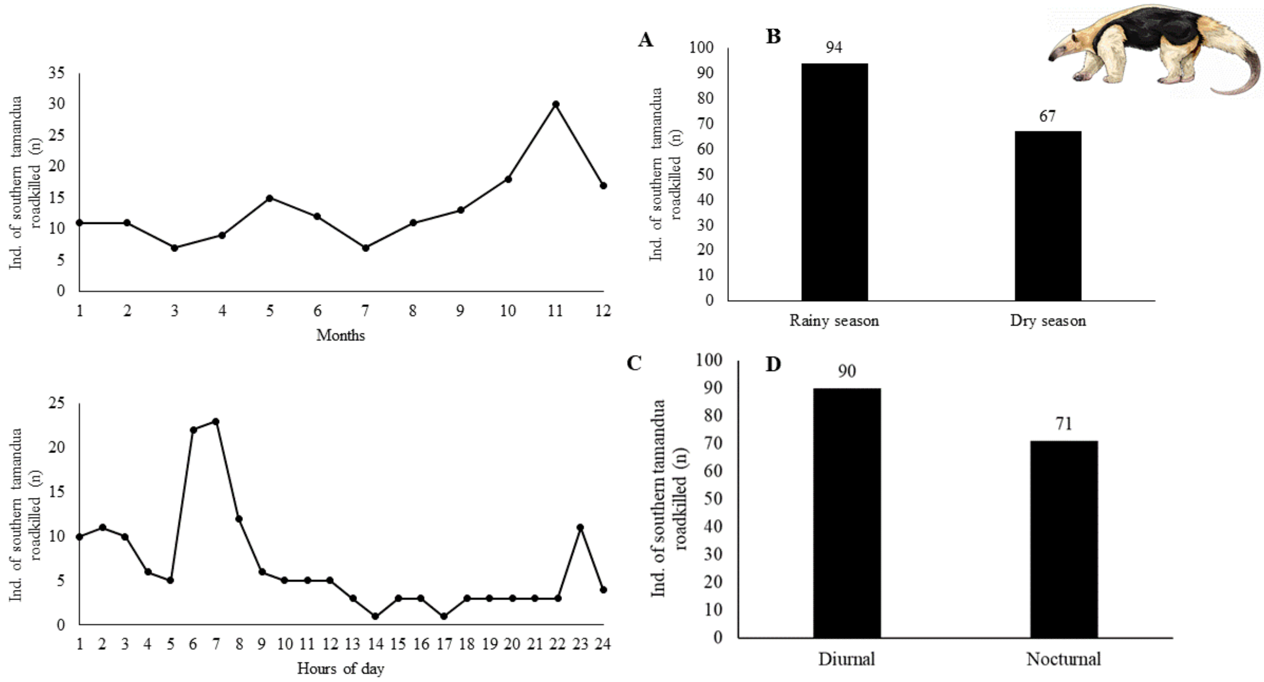


Nine banded armadillo (*Dasypus novemcinctus*)
N = 108
A) Total number of roadkilled nine banded armadillo (*Dasypus novemcinctus*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled nine banded armadillo from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled nine banded armadillo from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled nine banded armadillo from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.



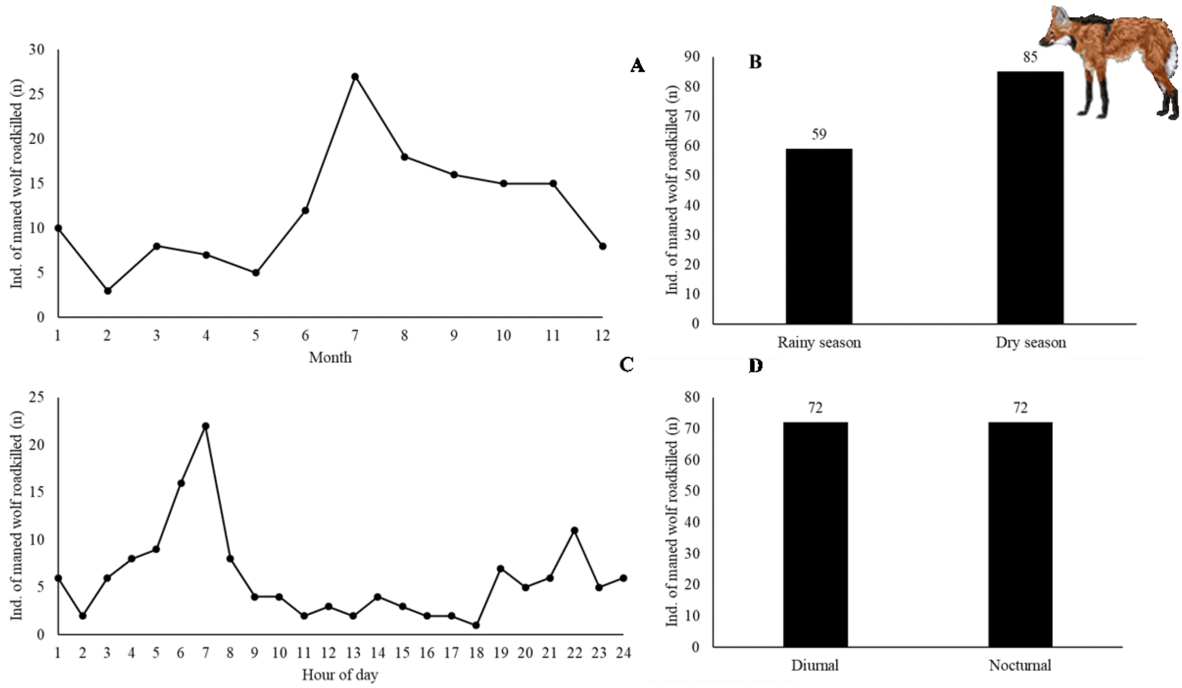
Southern anteater (*Tamandua tetradactyla*)
N = 161

A) Total number of roadkilled Southern anteater (*Tamandua tetradactyla*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled Southern anteater from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled Southern anteater from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled Southern anteater from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.

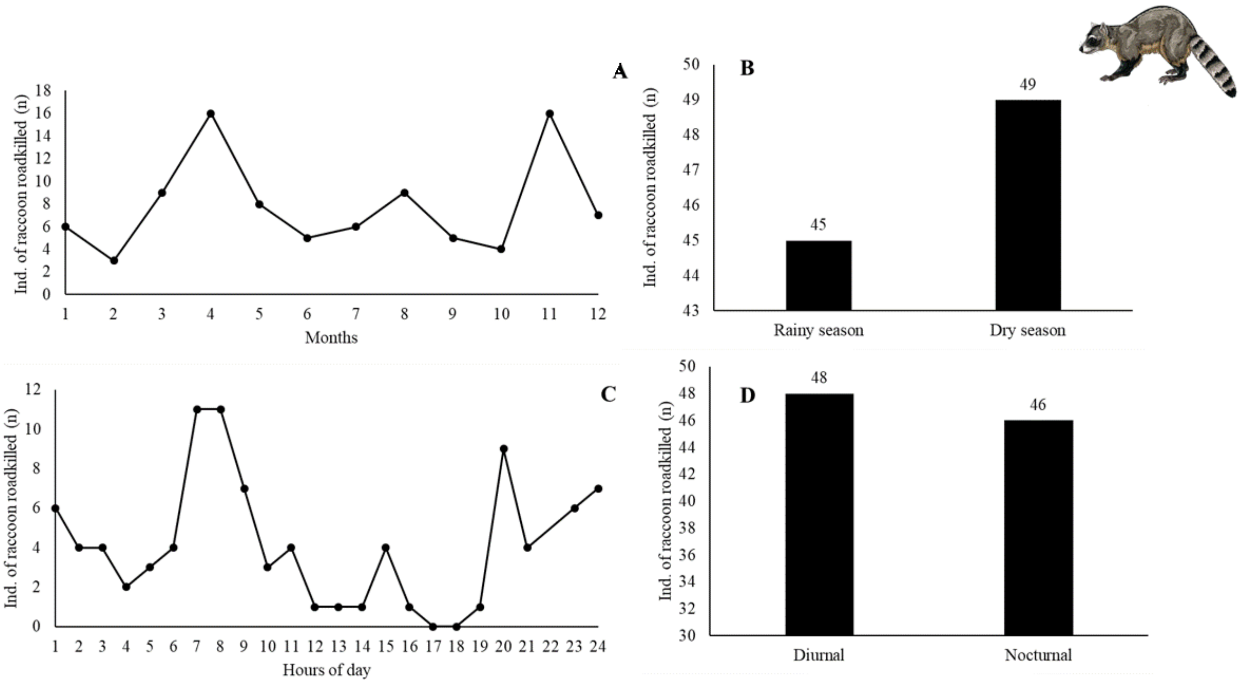


Maned wolf (*Chrysocyon brachyurus*)
N= 144

A) Total number of roadkilled maned wolf (*Chrysocyon brachyurus*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled maned wolf from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled maned wolf from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled maned wolf from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.

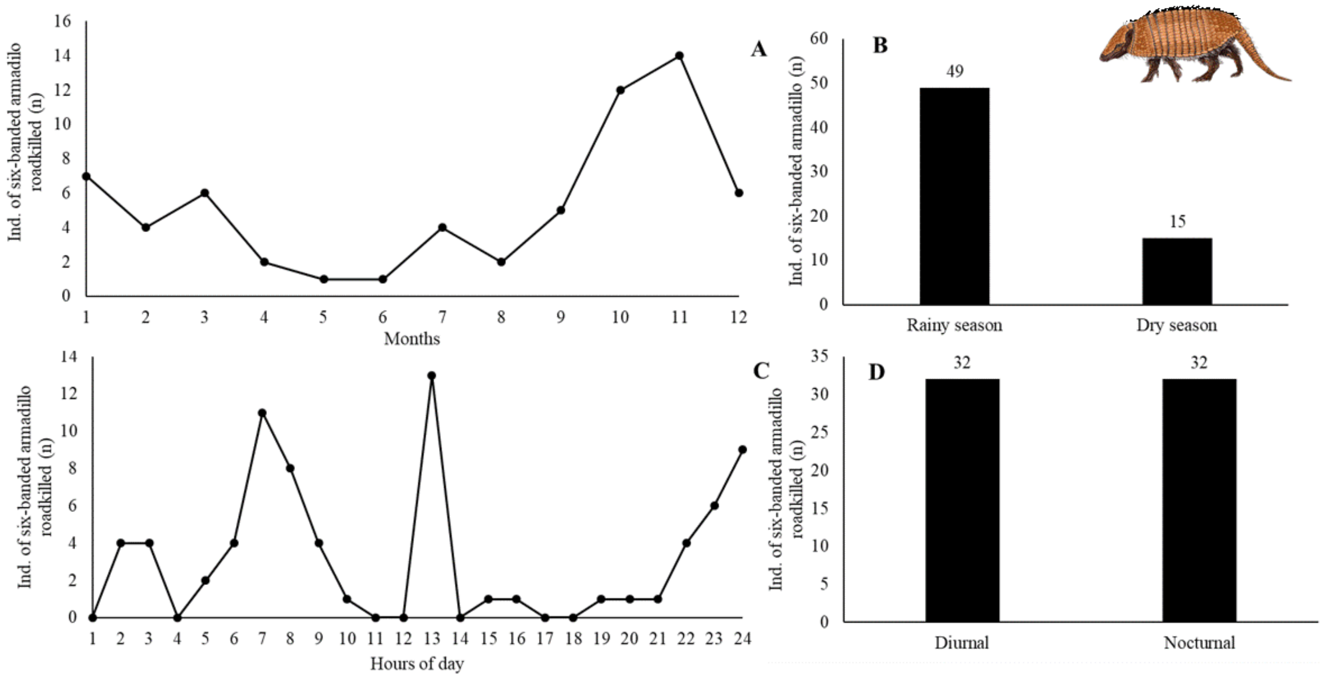


Raccoon (*Procyon cancrivorus*)
N = 94
A) Total number of roadkilled raccoon (*Procyon cancrivorus*) from 2005 to 2014 in toll roads of São Paulo State, Brazil, per month. B) Total number of roadkilled raccoon from 2005 to 2014 in toll roads of São Paulo State during rainy or dry season. C) Total number of roadkilled raccoon from 2005 to 2014 in toll roads of São Paulo State, Brazil, along day hours. D) Total number of roadkilled raccoon from 2005 to 2014 in toll roads of São Paulo State during diurnal and nocturnal periods.



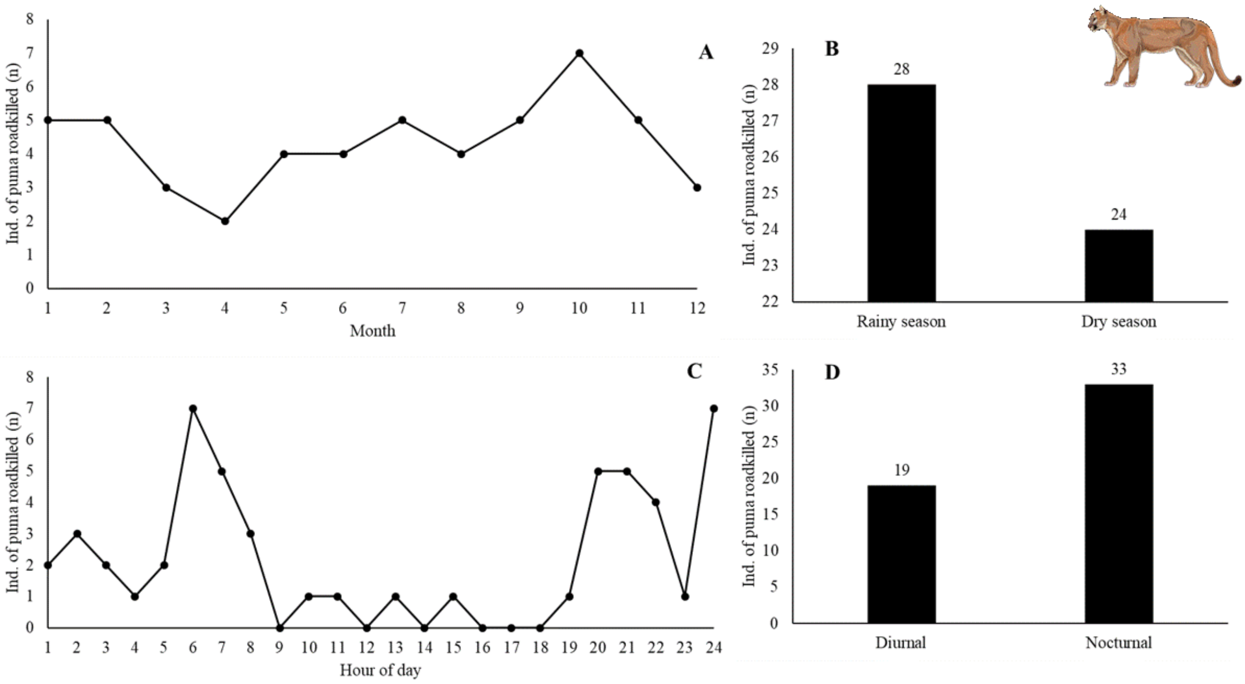
Six-banded armadillo (*Euphractus sexcinctus*)
N = 64

A) Total number of six-banded armadillo roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State per month, B) Total number of six-banded armadillo roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State during rainy or dry season, C) Total number of six-banded armadillo roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State along day hours, D) Total number of six-banded armadillo roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State during diurnal and nocturnal periods.



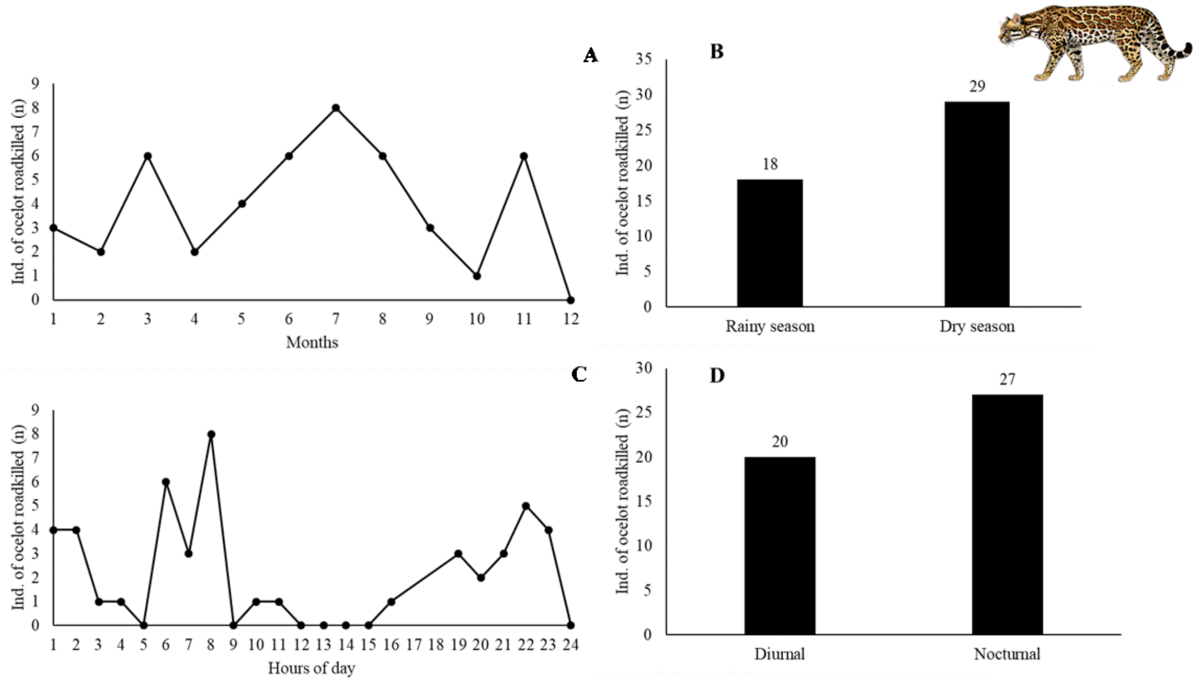
Puma (*Puma concolor*)
N = 52

A) Total number of pumas roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State per month, B) Total number of pumas roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State during rainy or dry season, C) Total number of pumas roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State along day hours, D) Total number of pumas roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State during diurnal and nocturnal periods.

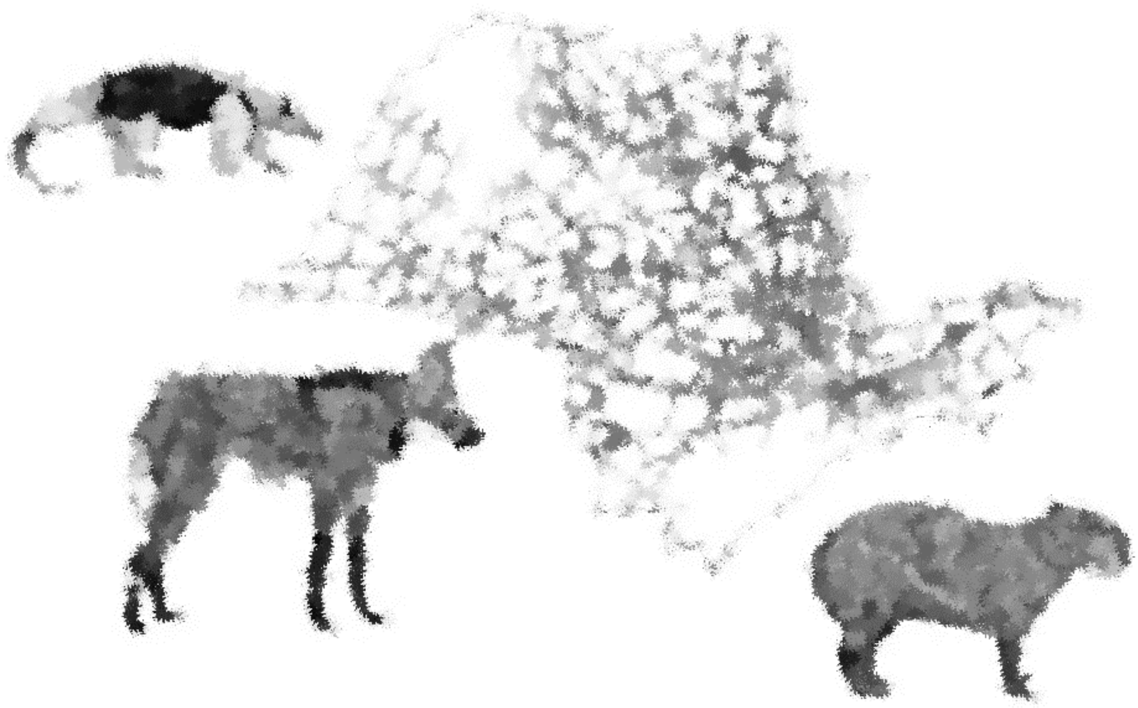


Ocelot (*Leopardus pardalis*)
N = 47

A) Total number of ocelots roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State per month, B) Total number of ocelots roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State during rainy or dry season, C) Total number of ocelots roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State along day hours, D) Total number of ocelots roadkilled carcasses throughout 2005 to 2014 from toll roads in São Paulo State during diurnal and nocturnal periods.



4. CHAPTER 3: WHERE ARE WILD MAMMALS ROADKILLED? PREDICTIVE ROADKILL MODELS USING LANDSCAPE VARIABLES IN SÃO PAULO STATE



Abra, Fernanda Delborgo, Ferraz, Katia Maria Paschoaletto Micchi de Barros, Carolina Ortiz R. da Silva, Huijser, Marcel Pieter, Jefferson Lordello Polizel

Capítulo 3: Onde os mamíferos silvestres são atropelados? Modelos de predição de atropelamento usando variáveis da paisagem no estado de São Paulo.

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RESUMO

Pesquisadores ao redor do mundo estão utilizando novas ferramentas de modelagem, bem como a Modelagem de Distribuição de Espécies (MDE), para orientar processos decisórias na biologia da conservação. Neste capítulo, nós utilizamos a abordagem MDE para prever o atropelamento de oito espécies alvo em rodovias pavimentadas do Estado de São Paulo: capivara (*Hydrochoerus hydrochaeris*), cachorro do mato (*Cerdocyon thous*), lobo guará (*Chrysocyon brachyurus*) raposinha do campo (*Lycalopex vetulus*), onça parda (*Puma concolor*), jaguatirica (*Leopardus pardalis*), tamanduá mirim (*Tamandua tetradactyla*) e tamanduá bandeira (*Myrmecophaga tridactyla*). Essa modelagem foi baseada em dados de atropelamentos de rodovias concedidas entre 2005 e 2014. Nós também identificamos agregações de atropelamentos, no mesmo período, utilizando o software KDE+. Nós geramos 28 MPA, dos quais nós selecionamos oito com AUC igual ou superior a 0,7, bem como se apresentaram adequados para distribuição dos atropelamentos. Além de MPA específicos para cada espécie alvo, nós também geramos modelos de consenso de MPA para todas as espécies alvo combinadas, com exceção de raposinha do campo que foi modelada em um espaço geográfico diferente, todas as sete espécies combinadas com exceção de capivara e raposinha e as espécies ameaçadas com exceção da raposinha. Para ambas os MPAs para cada espécie alvo e MPAs de consenso, quantificamos a extensão de quilômetros onde a probabilidade de atropelamento era superior a 70%. Tanto a análise do MPA e dos pontos críticos de atropelamentos mostrou que o nordeste do Estado de São Paulo é mais crítico para a mortalidade em rodovias em geral, mas também para espécies ameaçadas. As variáveis preditoras que se mostratam mais relevantes para explicar os modelos de predição dos atropelamentos foram altitude, porcentagem de cobertura florestal e uso do solo. Os modelos de consenso para as sete espécies-alvo identificaram 3,62% da rede rodoviária que é altamente crítica para os atropelamentos. A MPA pode ser útil para agências ambientais e de transporte no estado de São Paulo, com o objetivo de aconselhar medidas de mitigação para seções de estradas específicas e para espécies específicas. Os modelos apresentados neste capítulo podem atender à segurança humana, conservação biológica ou ambas as preocupações combinadas. Encorajamos o uso de modelagem preditiva de atropelamentos durante o licenciamento ambiental para construção ou duplicação de rodovias em escalas locais ou regionais durante o processo de planejamento de rodovias e planejamento de medidas de mitigação.

Palavras-chave: Rodovia; Atropelamento; Mamífero; Paisagem; Modelo de predição de atropelamento; Maxent

Chapter 3: Where are wild mammals roadkilled? Predictive roadkill models using landscape variables in São Paulo State

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ABSTRACT

Researchers worldwide are using new modelling tools, such as the Species Distribution Modelling (SDM), to orient decision processes on biological conservation. In this chapter, we used the SDM approach to generate roadkill predictive models (RPM) for eight target mammal species on paved roads in São Paulo state: Capybara (*Hydrochoerus hydrochaeris*), Crab eating fox (*Cerdocyon thous*), Maned wolf (*Chrysocyon brachyurus*) Hoary fox (*Lycalopex vetulus*), Puma (*Puma concolor*), Ocelot (*Leopardus pardalis*), Southern tamandua (*Tamandua tetradactyla*) and Giant anteater (*Myrmecophaga tridactyla*). We used roadkill data (n = 2,306) from toll road companies (~ 6.500 km) from 2005 to 2014 and non-correlated predictors such as land use, percentage of tree cover, altitude, slope, distance to protected areas, distance to water, to run models in Maxent. We also identified roadkill hotspots on the same toll roads in São Paulo State for the same period using the software KDE+. We generated 28 RPM from which we selected eight with AUC equal or up to 0,7. Beyond the specific models for each target species we also had consensus of RPM for all target species combined with exception of Hoary fox that had the RPM on a different geographic space, all target species combined expecting Hoary fox and Capybara and all threatened species excepting Hoary fox. For both RPMs for each target species and consensus RPM we quantified the length where the probability of roadkills were equal and higher than 70%. The RPM and the roadkill hotspots analyses showed that the northeast of São Paulo State is more critical for road mortality in general, but also for threatened and endangered species. The main predictor for the RPM were altitude, tree cover and land use. The consensus models for the seven target species identified 3.62% of the road network that is highly critical for roadkill. The RPMs can be useful to environmental and transportation agencies in São Paulo state aiming to advice mitigation measures for specific road sections and for specific species. The models presented on this chapter can attend to human safety, biological conservation, or both combined concerns. We encourage the use of roadkill predictive modelling during environmental licensing for road construction or duplication in local or regional scales during the process of road design and planning of mitigation measures.

Keywords: Road; Roadkill; Mammal; Landscape; Roadkill predict models; Maxent

4.1. INTRODUCTION

Animals move through the landscape for a variety of reasons and often interact with matrix, roads, traffic and other linear infrastructure (GUNSON & TEIXEIRA, 2015). The roads can affect movement, dispersal capacity of individuals (NELLEMANN et al., 2001; VISTNES et al., 2004; LESBARRÈS & FAHRIG, 2012) and the traffic also causes animal-vehicle collisions (FORMAN & ALEXANDER, 1998; FAHRIG & RYTWINSKI, 2009; van der REE et al., 2015).

The unnatural mortality of animals due to vehicle collisions is a primary, measurable and obvious effect that reduces animal populations (FORMAN & ALEXANDER, 1998). It has the potential to alter the demographic structure of populations (MUMME et al., 2001; STEEN & GIBBS, 2004), reduce abundance (ARÉVALO & NEWHARD, 2011) and to create local population sinks (NIELSEN et al., 2006). The roads are an important and silent driver to defaunation, the process of loss of species and wildlife populations (DIRZO et al., 2014).

Most of road ecology studies all around the world focus on medium and large sized mammals (HUIJSER et al., 2013; ELOFF & van NIEKERK, 2005; VIDYA & THUPPIL, 2010; KLÖCKER et al., 2006). This group is part of fundamental ecological processes, such as herbivory, predation (CUARÓN, 2000) and seed dispersal (FRAGOSO & HUFFMANN, 2000; GALETTI et al., 2001). They comprise the most endangered species in the world; 27% of mammals are at risk of extinction (CARDILLO et al., 2005; SCHIPPER et al., 2008), are very charismatic (COURCHAMP et al., 2018) used as “umbrella” in strategic planning for conservation (JENKINS et al., 2013) which directly implies on biodiversity conservation. They also promote more serious vehicle collisions to drivers because they present considerable body masses, which implies in driver´s safety and economic losses (CONOVER et al., 1995; GROOT BRUINDERINK & HAZEBROEK, 1996; HUIJSER et al., 2008; ABRA et al., 2019). The mammal-vehicle collision have increased substantially over the last few decades (GROOT BRUINDERINK & HAZEBROEK, 1996; HUIJSER et al., 2008) and many sorts of efforts are being conducted to justify, plan, design, and funding effective mitigation measures (RYTWINSKI et al., 2016).

Road ecologists worldwide, have used available georeferenced locations of wildlife-vehicle collisions to determine spatial distribution patterns along roads (RAMP et al., 2005, 2006; MOUNTRAKIS & GUNSON, 2009) and the outcomes demonstrates that wildlife-vehicle collisions are not at random, but they are spatially clustered for vertebrate species

(JOYCE & MAHONEY, 2001; CLEVENGER et al., 2003; RAMP et al., 2006). Researcher also have used new modelling tools, such as the Species Distribution Modelling (SDM), to orient decision processes on biological conservation (ELITH & LEATHWICK, 2009; FRANKLIN, 2010) as predictive roadkill modeling (PRM) (MALO et al., 2004) to determine variables (e.g. landscape, road design, road traffic), that could explain the collisions of specific species (FINDER et al., 1999; JOYCE & MAHONEY, 2001; NIELSEN et al., 2003; SEILER, 2004; DUSSAULT et al., 2006; GARROTE et al., 2018; WILLIAMS et al., 2019).

The use of the MaxEnt algorithm, for example, has been extensively used in species distribution models in many conservation plans as the design of reserve networks (MELLER et al., 2014), to predict the invasion ability of exotic species (PETERSON & VIEGLAIS, 2001), species distribution (FERRAZ et al., 2012; ANGELIERI et al., 2016) and, lately, to predict Iberian-linx (*Lynx pardinus*) road mortality in Europe (GARROTE et al., 2018).

Predictive models can be useful for environmental and transportation agencies because they can be functional and practical to identify priority areas for mitigation (e.g. underpasses, overpasses, fences, animal detection systems), provide information on new road design and predict what impacts roads might be having on wildlife populations. More importantly, they can also be used to identify those factors contributing to the likelihood of fatalities (RAMP et al., 2005).

Here, we used the SDM approach to predict roadkills, in general and for eight target mammal species, in São Paulo state based on roadkill data from toll road companies from 2005 to 2014. We also identified roadkill hotspots on the same toll roads in São Paulo State for the same period. Finally, we discussed predictive roadkill modeling and roadkill hotspot results for São Paulo state, aiming to prioritize implementation of mitigation measures for existing roads or roads under planning.

4.2. MATERIALS AND METHODS

4.2.1. Study area

The state of São Paulo is located in southeast region of Brazil (248,209 km^2) (Fig. 1) and is the most developed and prosperous state of the country, generating 33.9% of the Brazilian Gross Domestic Product. Also, São Paulo State is home to about 44 million people, about 21,6% of the total population in Brazil (IBGE, 2018).

In general, the region has a tropical climate with seasonal differences in temperature and precipitation (22 - 28 ºC on average; 1450 - 2050 mm precipitation annually). In addition, there are regional differences in weather patterns because of elevation, slope and distance to the Atlantic Ocean (INMET, 2019).

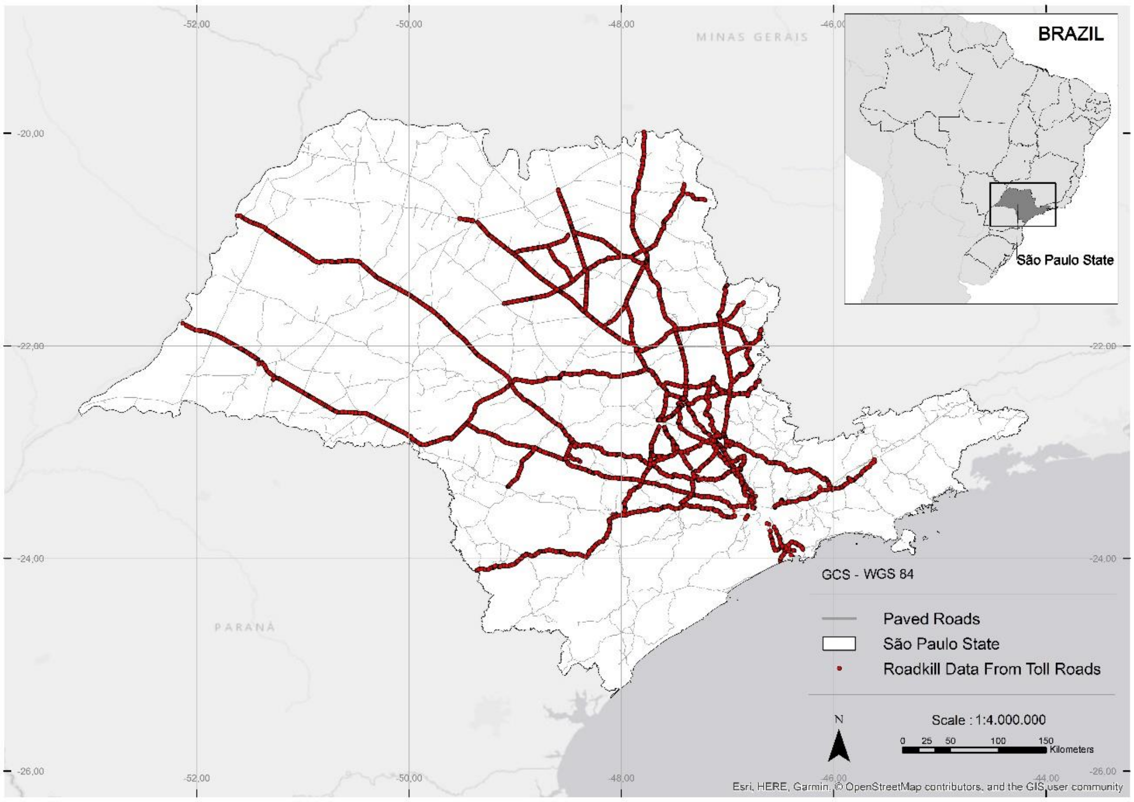

Figure 1. São Paulo State, Brazil, highlighting in red lines, the paved toll roads network.

Over the last decades, São Paulo State experienced rapid land use changes. This included conversion of Atlantic Forest and Cerrado biomes, both considered as world biodiversity hotspots (MITTERMEIER et al., 2011), into pasture and croplands, urban areas (Dean, 1995; Ribeiro et al., 2009; Instituto Florestal, 2010), an expansion of the road network (33% increase in length between 1988 to 2013) (DER, 2019), and an increase in the number of registered vehicles (329% augment between 1998 and 2018) (DETRAN, 2019).

Therefore, we determine the limits of São Paulo State as the geographic space for modeling, excepting for specific species with limited occurrence area as Hoary fox (*Lycalopex vetulus*) (JÁCOMO et al., 2004), endemic of Cerrado biome witch we determined the 20km buffer zone on Cerrado biome limits on São Paulo State.

4.2.1.1. Roadkill data collection

We received mammal roadkill data from 18 toll road companies in São Paulo State (~ 6.500 km) from 2005 to 2014. All carcasses were registered by maintenance personal using information's as date, time of carcass register, road code, kilometer marker (km + meters) or geographic coordinates, the species common name, number of individuals, the status of fate of the animal roadkilled, for example if the animal was sent to a specific institution for research purposes or buried.

We selected eight target species for modeling: Capybara (*Hydrochoerus hydrochaeris,* n = 1,343), Crab eating fox (*Cerdocyon thous,* n = 483), Maned wolf (*Chrysocyon brachyurus,* n = 144) Puma (*Puma concolor,* n = 52), Giant anteater (*Myrmecophaga tridactyla,* n = 37), Southern tamandua (*Tamandua tetradactyla,* n = 161), Ocelot (*Leopardus pardalis,* n = 47) and Hoary fox (*Lycalopex vetulus,* n = 39).

The Capybara, Crab eating fox and Southern tamandua were selected because they are common roadkilled mammals and, mostly Capybara, is highly related with human safety for São Paulo State roads (HUIJSER et al., 2013; ABRA et al., 2019). Species as Puma, Maned wolf, Giant anteater, Ocelot and Hoary fox were selected because they are threatened and endangered species in Brazil (ICMBio, 2018) as well as to attend specific actions from the National Action Plans elaborated by Brazilian Federal government (ICMBio, 2017).

Because the roadkill data were collected by non-experts, there are errors and inconsistencies in species identification. To avoid errors in modeling process we decided by using the roadkill dataset validated by specialists from Abra et al. (2018) (see Chapter 1).

The roadkill records were more clustered in some areas, indicating a possible sample bias (spatial dependence), which could be either caused by a more extensively sampling in some areas than in others or by a higher risk of being roadkilled. As Maxent requires unbiased sample, we used the *Gaussian kernel density of sampling localities* tool of the SDM tollbox – version 2.4 (BROWN, 2014), generating around four different sampling bias distances for all target species. This method generated a density surface of the occurrence records, also known as Bias Grid, which upweighted presence-only data points with fewer neighbors in the geographic landscape (PHILLIPS et al., 2008). So, all bias grid was incorporated into the modeling process in the Maxent (version 3.4.1; PHILLIPS et al., 2006; PHILLIPS et al., 2008) (Appendix A).

4.2.1.2. Environmental variables

We selected six predictors for modeling (Table 1). The predictors were sampled to 250 meters of spatial resolution, extracted by the mask of São Paulo State. For the endemic Hoary fox we used as a mask of 20 km buffer zone from the limits of the Cerrado biome. All predictors were converted to ASCII grid format for the Maxent modeling.

To test the spatial correlation of the predictor variables and to avoid the unnecessary complexity of the models, we performed the Pearson correlation analysis eliminating correlated predictors (≥ 0.7), using the SDM toolbox (version 2.4; BROWN 2014) (Appendix B).

All procedures were made at ArcGIS 10.2.2 (ESRI, 2014).

Table 1. Non-correlated predictors for roadkill modeling.

Variable	Resolution (m)	Description;	Source
Distance to water (Dist_water)	30	Distance (m) from the nearest waterbody.	ANA
Altitude	30	Elevation (m) from the sea level. It represents the most important physical attribute of surface.	SRTM/NASA
Terrain slope	30	Terrain slope (%). It represents local gradient of elevation.	Derived from SRTM
Land use	30	Rough land-use classification, mainly distinguishing crops, pasture, forestry and urban areas.	FBDS
Tree cover	30	It presents the distribution of remnants of natural vegetation existing in the state of São Paulo, classified by phytophysiognomy. Mapping made with satellite images 2008 and 2009.	SRTM/NASA
Protected areas (integral protection) Dist_PA	30	For São Paulo state, the protected areas are the major forest patch in the landscape. We excluded marine protected areas and protected areas of sustainable use.	MMA

4.2.1.3. Roadkill predictive models (RPM)

We used the Maximun Entropy algorithm (MaxEnt) software to model the distribution of target mammal species roadkills on road network in São Paulo state (PHILLIPS et al., 2006; PHILLIPS & DUDIK, 2008; GARROTE et al., 2018). We chose this algorithm because it presented good performance in comparison with the other algorithms used for predicting distributions (ELITH et al., 2011; ANGELIERI et al., 2016). The prediction of MaxEnt is subject to constraints derived from environmental conditions at recorded occurrence locations.

The models were generated using bootstrapping methods with 10 random partitions with replacements of 70% of the dataset for training models and 30% por testing and selected 10,000 background points with 500 interactions (PEARSON, 2007).

The models were evaluated according to the Area Under Curve (AUC) values. The AUC considers the proportion of correct and incorrect predictions over the possible thresholds. Values above 0.7 are good model indicators and above 0.9 represent excellent models (PETERSON et al., 2011).

The probability values in the final RPM varies from 0 to 1. Here, we assumed that the probability of each pixel value is associated to the probability of roadkill or, as named here, risk to roadkill. The RPM were cut by two different thresholds, resulting in binary maps: 0 (no roadkill risk) and 1 (maximum roadkill risk). The thresholds used were: 1) the low presence threshold (LPT), and 2) a threshold that indicated the higher probabilities values for roadkill, in this case, values equal or up to 0.70 (Fig. 2). We considered the omission error and the binomial probability for the LPT as provided by the maxent output.

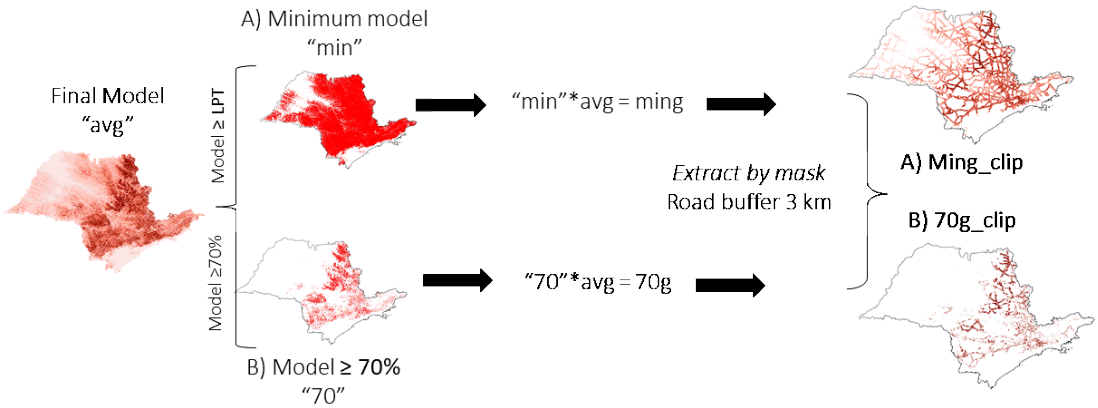

Figure 2. Modelling process schema to obtain maps of predictive roadkills: a) all possible areas with roadkill risk, and b) probability of roadkills equal or up to 70%.

For each average model, we showed the most significative predictors variables by responses curves related to the roadkill probabilities. Finally, all final models were cut by a buffer zone ok 3 km of all paved roads in São Paulo state or for the Cerrado biome in São Paulo state, specifically for Hoary fox.

Finally, we calculated the length in km of road sections equal or up to 70% of risk to roadkill for the target mammals species and we listed the Municipalities where these road sections were present.

All procedures were made at ArcGIS 10.2.2 (ESRI, 2014).

4.2.1.4. Model selection

We selected one best model for each target species from the 28 different models generated (Appendix A). We discarded all models which AUC inferior to 0.7. Then, if more than one model appeared to be suitable to roadkill, the criteria of tiebreaker was to select the model with higher AUC.

4.2.1.5. Model validation

We validated our models with an independent roadkill dataset for the same eight mammal species from 2015 to 2018. In total we had new 1,005 roadkill records: Capybara (*Hydrochoerus hydrochaeris,* n = 611), Crab eating fox (*Cerdocyon thous*, n = 224), Maned wolf (*Chrysocyon brachyurus,* n = 14) Puma (*Puma concolor*, n = 19), Giant anteater (*Myrmecophaga tridactyla,* n =20), Southern tamandua (*Tamandua tetradactyla*, n = 89) Ocelot (*Leopardus pardalis,* n = 16) and Hoary fox (*Lycalopex vetulus,* n = 12). This roadkill database also followed the methods of validation of species identification accordingly to Abra et al. (2018) (see Chapter 1).

We plotted the new roadkill records on the binary final model for each species to evaluate if the RPM had correctly predicted them, using the *Extract values by point* from *Spatial Analyst* tool in ArcGiS 10.2.2 (ESRI, 2014). Then, we calculated the proportion of roadkill correctly predicted by each RPM.

4.2.1.6. Consensus models for roadkill

We performed a consensus model for predicting roadkill using the seven selected models performed on the limit of São Paulo State. Because Hoary fox was modelled in a different geographic space, the species was not included in the consensus models.

The consensus model is produced from the arithmetic mean of the set of algorithms and the predictions of each algorithm are combined to produce a single model (ARAÚJO et al., 2005). In this case, we have three different combined the models to identify road critical sections with probability higher than 70% of roadkill: i) all seven species together, ii) all seven species together excepting capybara and iii) only threatened species. The combination was performed with the arithmetic mean of the predictions of roadkill for the species. The final consensus models were cut by a buffer zone of 3 km of all paved roads in São Paulo state. We calculated the length in kilometers for the critical road sections and listed what municipalities these sections were present.

4.2.1.7. Roadkill hotspot analysis

The spatial distribution of roadkills was evaluated by statistical analysis using KDE + software (BÍL et al., 2013; 2016). We ran two analyses, one for all mammals combined, entering as input the shapefile with all roadkill records (n = 37,736) and a second one with Capybara (n = 12,521). Because we have different results about the reliability of species identification accordingly with Abra et al. 2018, we chose to run the analysis using all Capybara records available because the correction of identification for this specific species was superior than 90%.

To identify roadkill hotspots or critical zones, the program uses a Kernel density estimate to find significant clusters of occurrences of deaths in addition to a method of hierarchizing aggregations of fatalities. We categorized the value of the cluster strength (Str_Dens2 attribute) obtained for each hotspot. The critical zones were graded into five categories of importance accordingly with the natural breaks of the values: Very high, High, Medium, Low and Very low (DORNAS et al., 2019). We considered the categories medium to very high applicable to be used by transportation or environmental agencies as priorities to reduce the collisions.

The analyzes were performed with GPS data accuracy, bandwidth equal to 150 and 800 Monte Carlo simulations (platform standard). For each cluster section, we extracted the coordinates of the both ending points and used the *Reverse Geocode* from *Geocoding tool* of ArcGis 10.2.2 to get the address of each section, including the road code and km + m (ESRI, 2014).

4.3. RESULTS

4.3.1. Roadkill predictive models (RPM)

We selected eight predictive roadkill models (Table 2; Fig. 3 to 10) considered plausible for explaining roadkill in paved roads in São Paulo state (Appendix A, C and D).

As expected, the whole length of paved roads in São Paulo showed risk for roadkill for different species in a varied intensity.

Table 2. Results of RPM for the target mammal species (AUC for testing = area under curve, LPT = low presence threshold). All selected models showed $p \leq 0.05$ associated to the LPT, except for Hoary fox ($p = 0.08$).

Species_BiasGrid	Training samples	Testing samples	AUC ± SD	LPT	Omission
*Cerdocyon thous*_bias03	276	118	0.789 ± 0.017	0.203	0.010
*Chrysocyon brachyurus*_bias06	90	38	0.874 ± 0.022	0.169	0.008
*Leopardus pardalis*_bias05	29	12	0.802 ± 0.051	0.258	0.050
*Lycalopex vetulus*_bias04	26	10	0.730 ± 0.075	0.304	0.060
*Myrmecophaga tridactyla*_bias06	24	9	0.864 ± 0.058	0.230	0.078
*Puma concolor*_bias04	36	15	0.727 ± 0.051	0.328	0.047
*Tamandua tetradactyla*_bias02	102	43	0.729 ± 0.030	0.225	0.005
*Hydrochoerus hydrochaeris*_bias01	541	231	0.761 ± 0.013	0.162	0.0004

Capybara was the target species with higher risk of roadkill and Hoary fox showed lower risk, also because was modelled in a limited geographic area, smaller than São Paulo state.

Among the threatened species, Maned wolf has a higher risk of roadkill, followed by Ocelot and Puma. Roadkill of common species as Crab eating fox and Southern tamandua were predicted with a higher intensity in most of the paved roads in the State, but still demonstrated that the critical areas are concentrated on the Northeast region.

The RPM correctly predicted of the independent dataset for mammal species (Appendix E), except for the Hoary fox (Table 3).

Table 3. Roadkill predictive model validation using independent roadkill data. Legend: RPM = roadkill predictive model.

Common name	Species	Validation of RPM (%)
Crab eating fox	*Cerdocyon thous*	99.55
Maned wolf	*Crysocyon brachyurus*	100
Capybara	*Hydrochoerus hydrochaeris*	99.84
Hoary fox	*Lycalopex vetulus*	58.33
Ocelot	*Leopardus pardalis*	100
Giant anteater	*Myrmecophaga tridactyla*	100
Puma	*Puma concolor*	100
Southern tamandua	*Tamandua tetradactyla*	100
All species combined	-	

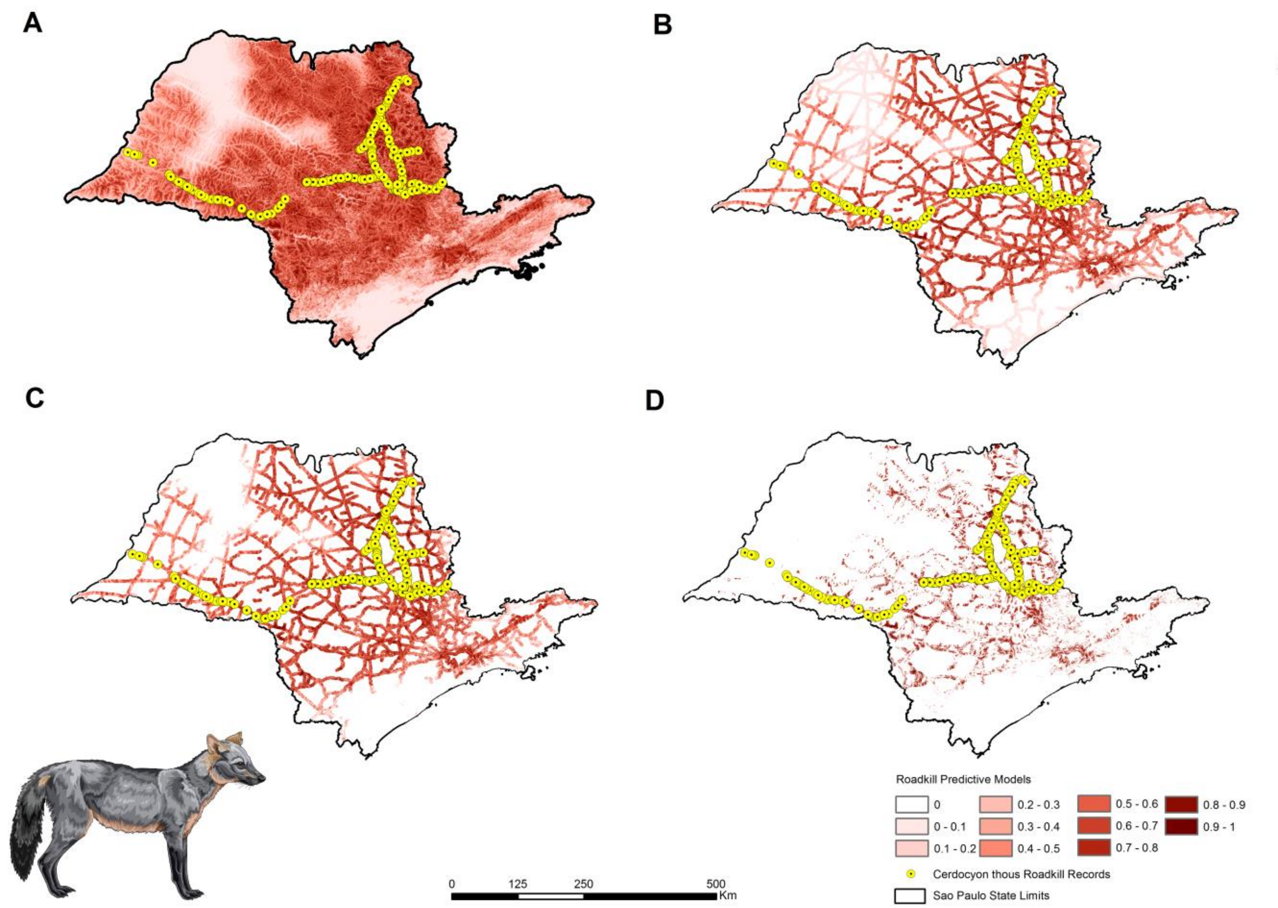

Figure 3. Roadkill predictive model (RPM) for Crab eating fox (*Cerdocyon thous*): A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkills (≥70%) in the buffer zone of paved roads.

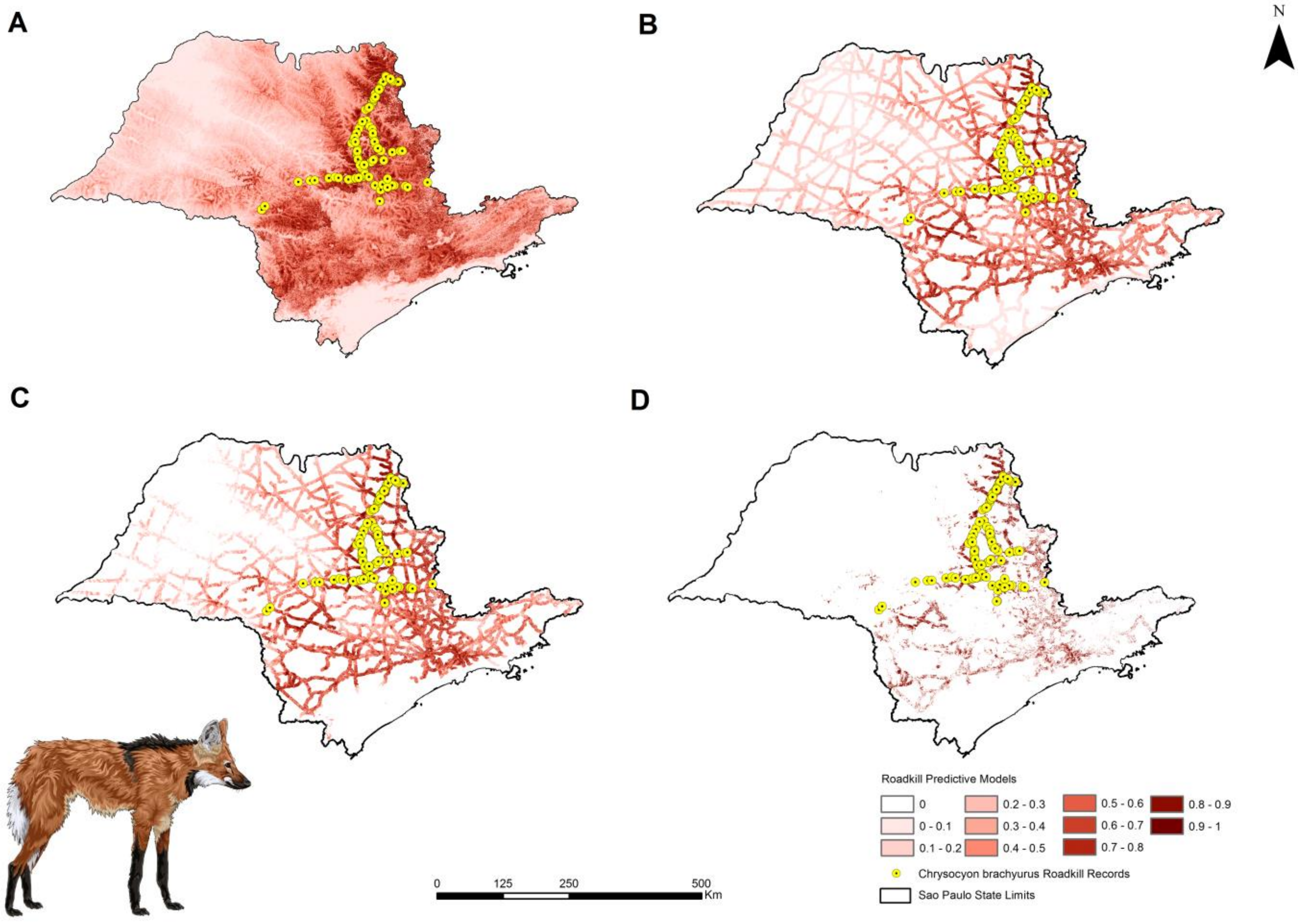

Figure 4. Roadkill predictive model (RPM) for Maned wolf (*Chrysocyon brachyurus)*: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

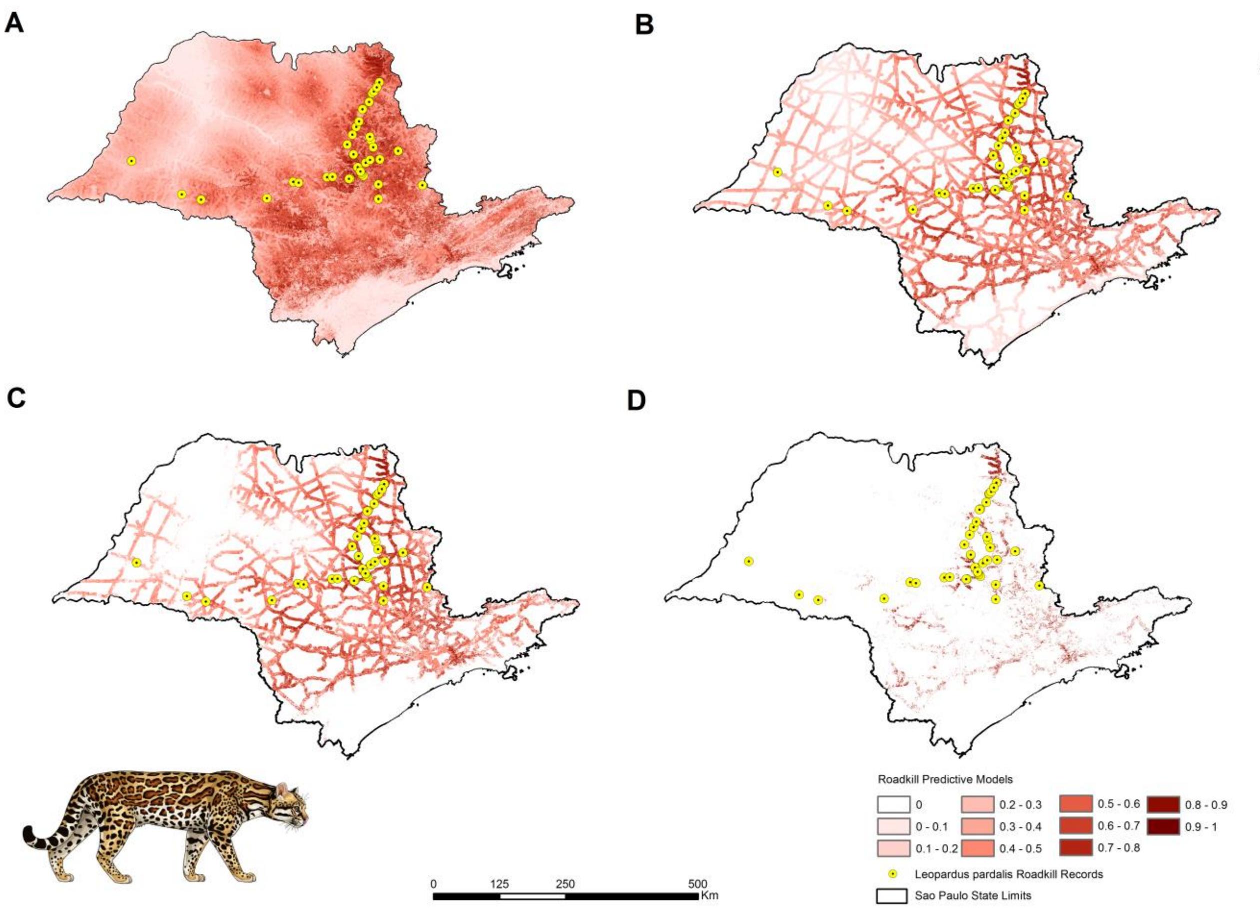

Figure 5. Roadkill predictive model (RPM) for Ocelot (*Leopardus pardalis)*: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

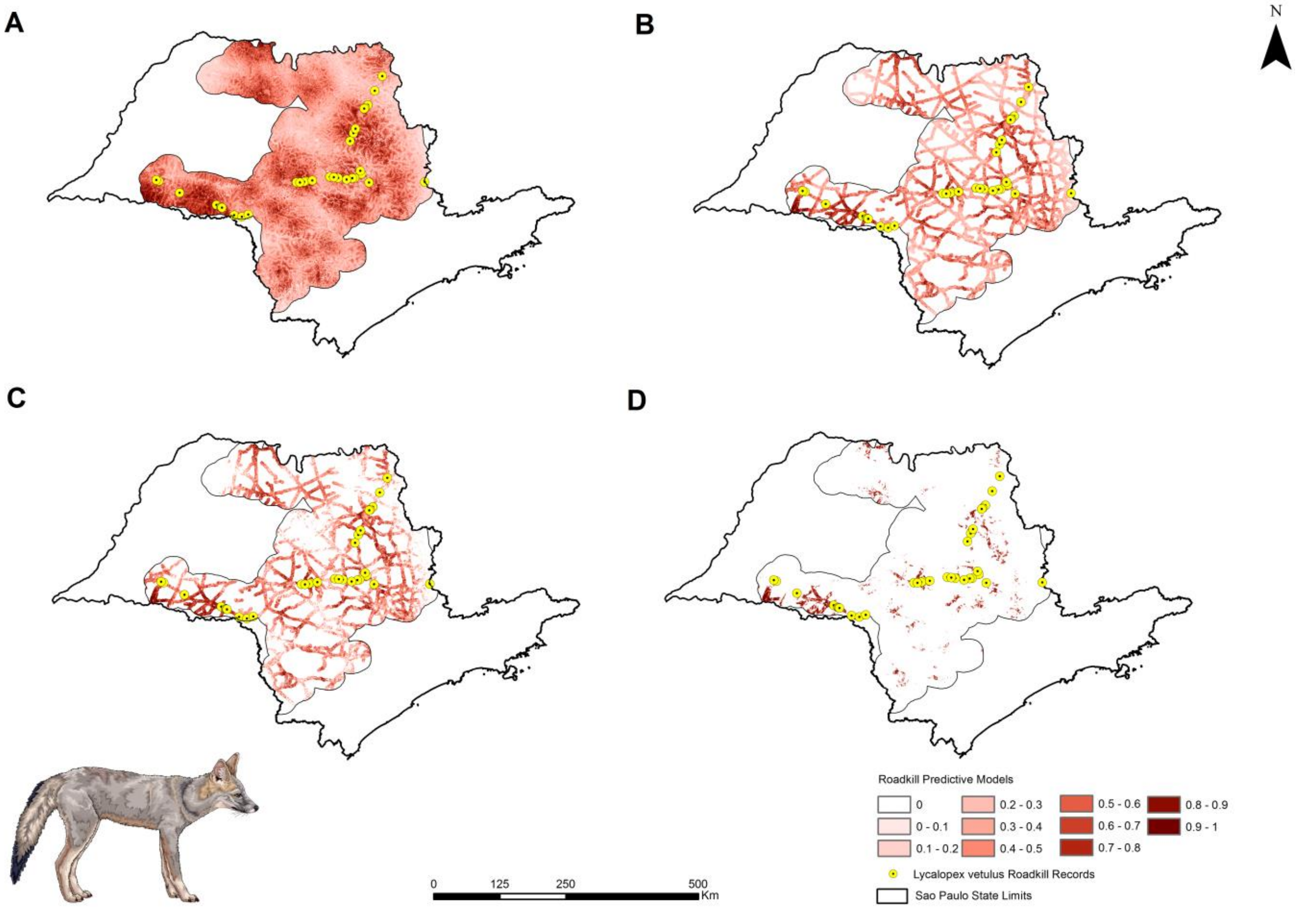

Figure 6. Roadkill predictive model (RPM) for Hoary fox (*Lycalopex vetulus)* which was modelled in a specific geographic area, a buffer zone of 20 km from the Cerrado limits in São Paulo state: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

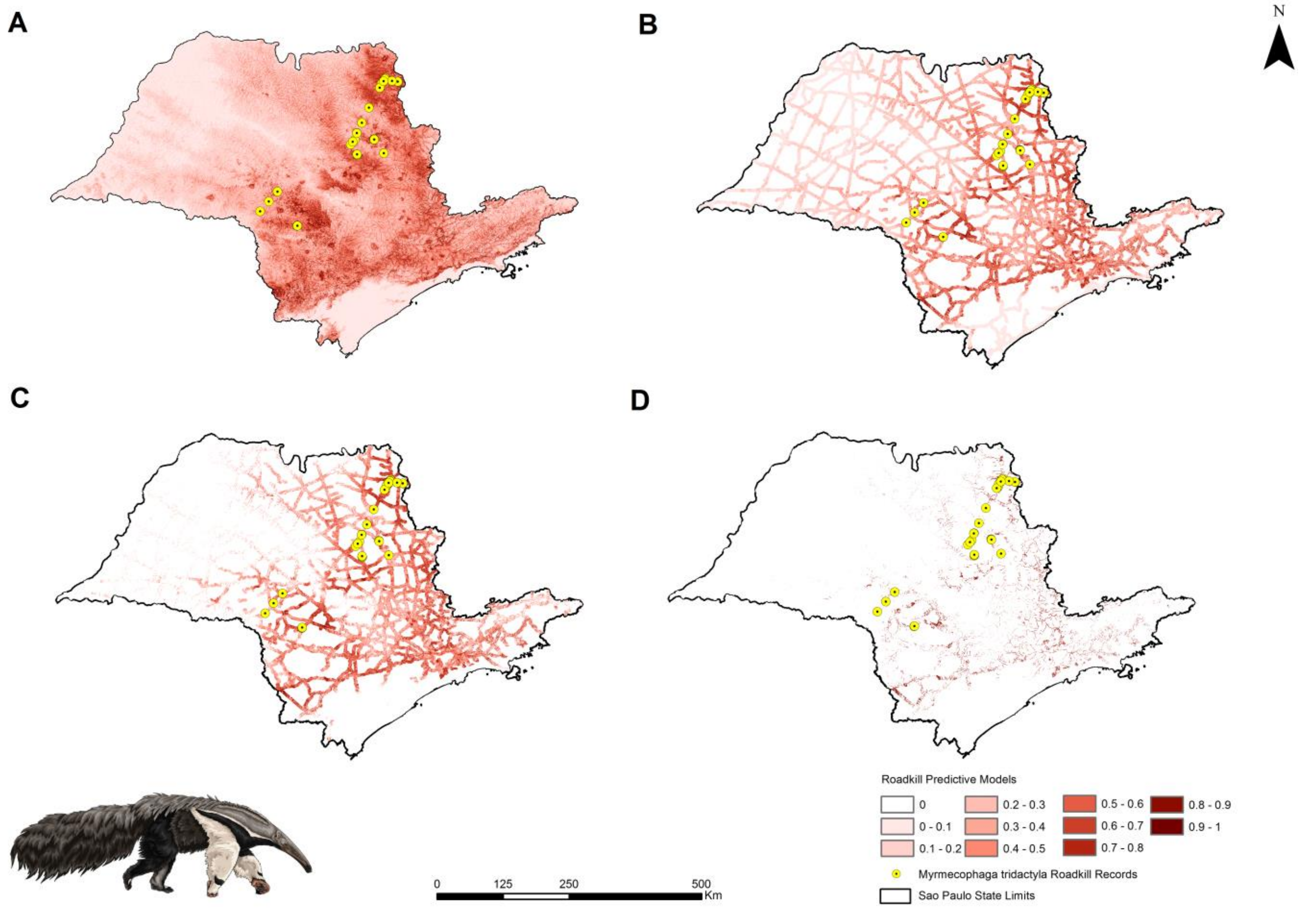

Figure 7. Roadkill predictive model (RPM) for Giant anteater (*Myrmecophaga tridactyla)*: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

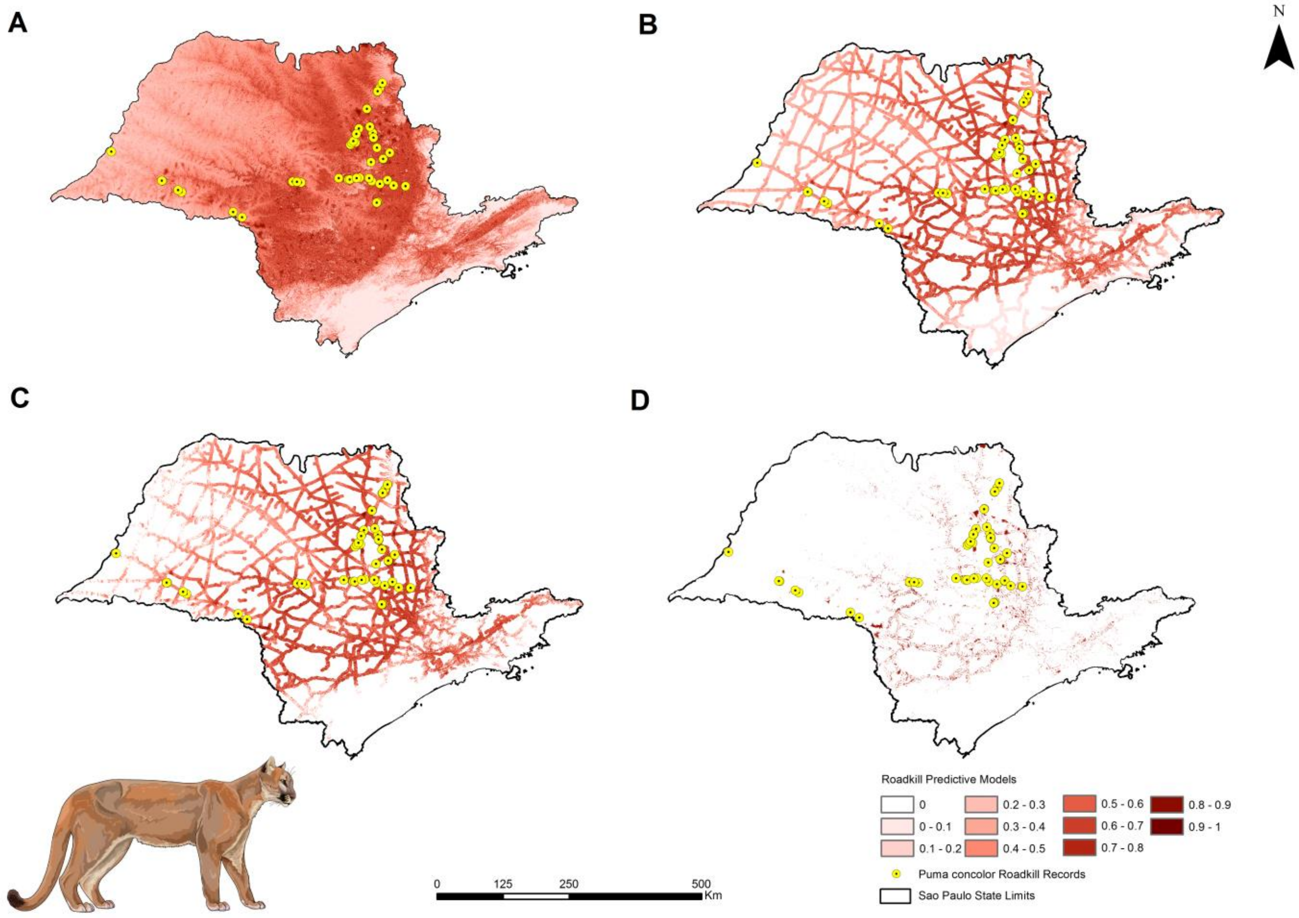

Figure 8. Roadkill predictive model (RPM) for Puma (*Puma concolor)*: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

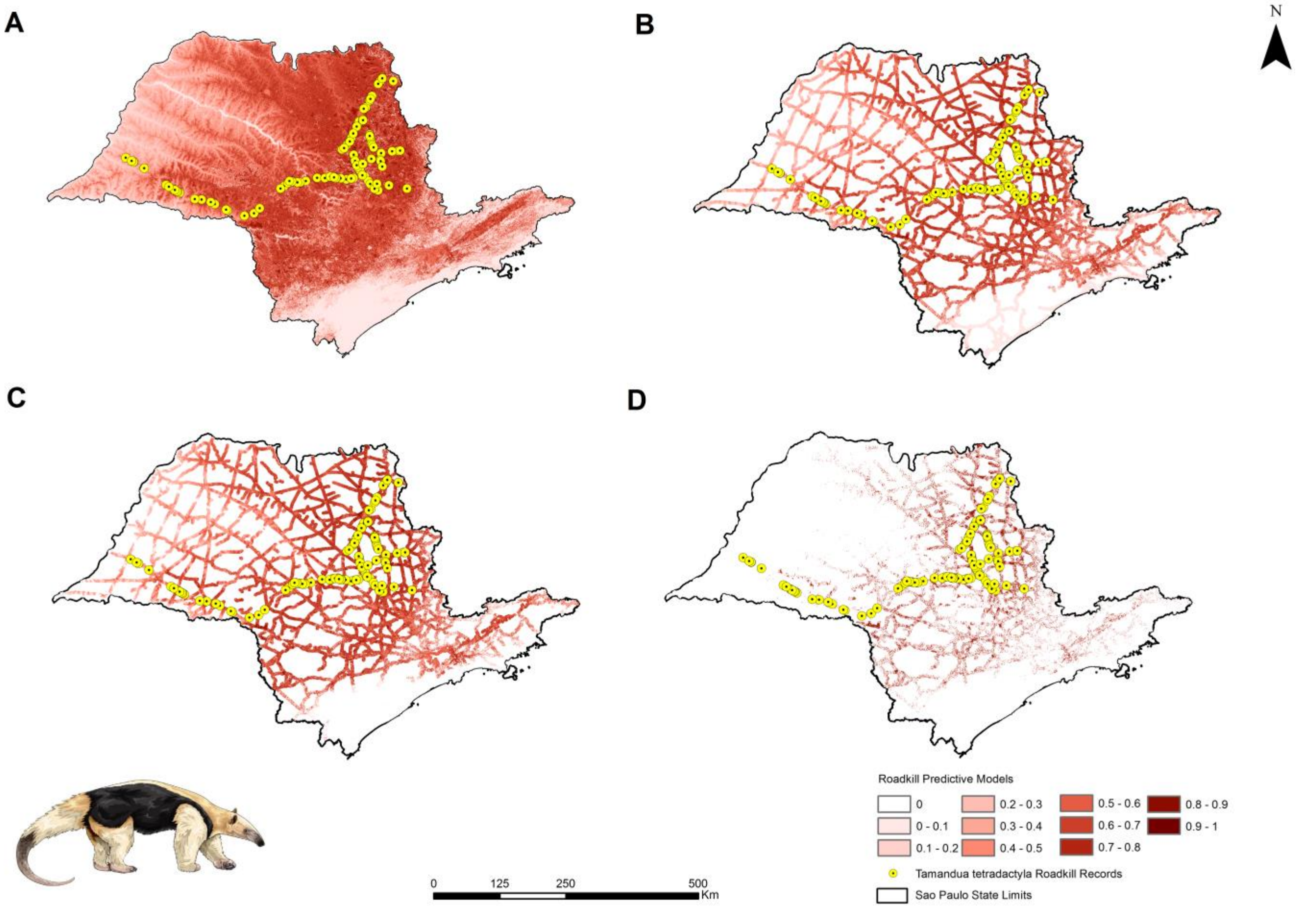

Figure 9. Roadkill predictive model (RPM) for Southern tamandua (*Tamandua tetradactyla)*: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

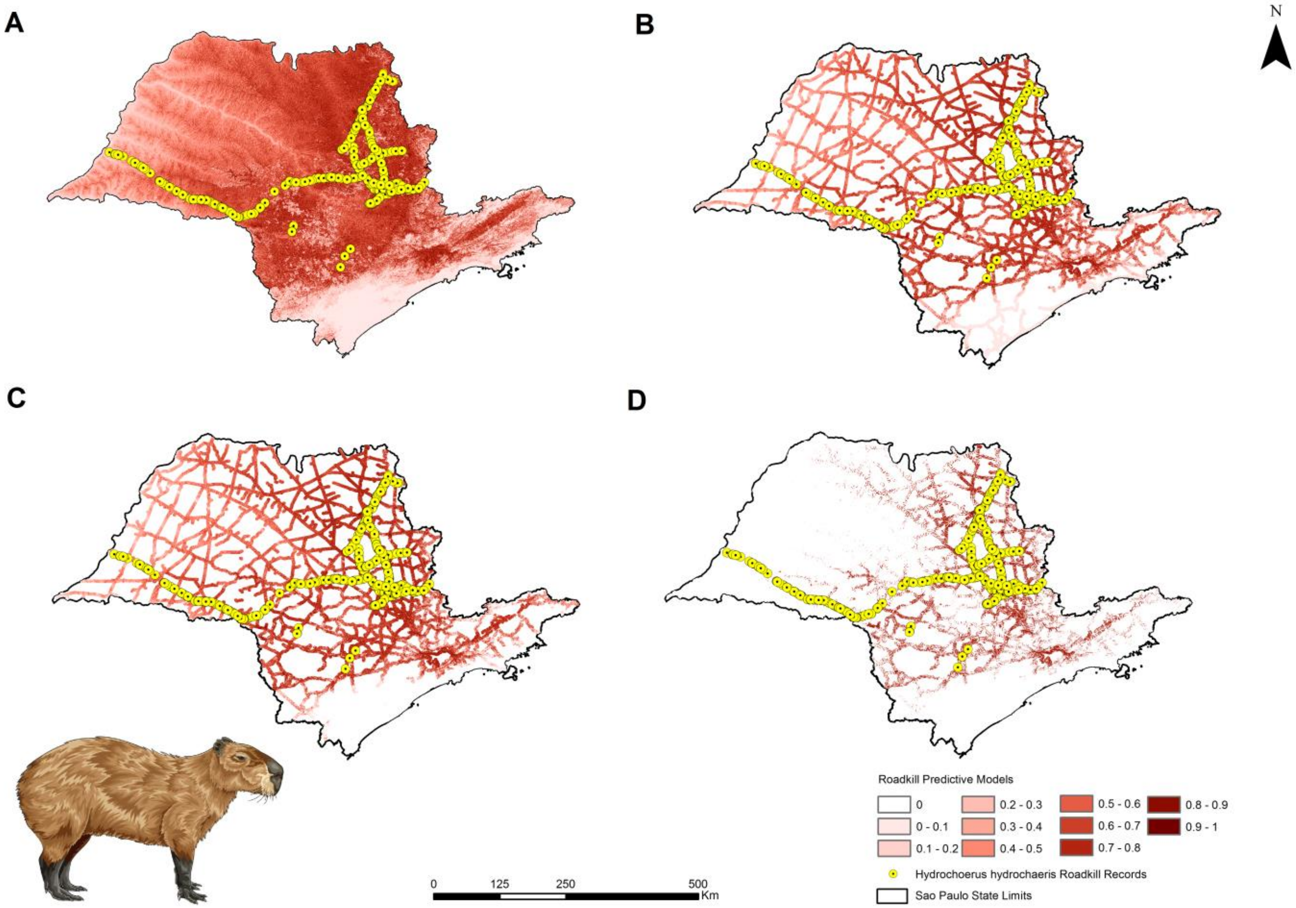

Figure 10. Roadkill predictive model (RPM) for Capybara (*Hydrochoerus hydrochaeris)*: A) final RPM, B) final RPM in the buffer zone of paved roads, C) RPM indicating the risk for roadkill in the buffer zone of paved roads, and D) RPM indicating higher probabilities for roadkill (≥70%) in the buffer zone of paved roads.

RPM that indicate roadkill risk showed lower probability of roadkill on the west region of the state. The main roadkill critical areas for target species are the northeast region of São Paulo state, as well as some municipalities and adjacent areas from Center, Centerwest and Southeast region. In general, altitude, land use and tree cover were the predictors that most explained the RPMs per species (Table 4, Fig. 11 and 12).

Table 4. Contribution of predictor variables to the roadkill predictive models per species. Legend: Dist_PA = distance to protected areas, Dist_water = distance to water.

Species	Predictor variable_1 (%)	Predictor variable_2 (%)	Predictor variable_3 (%)
Hydrochoerus hydrochaeris	Altitude (37.20)	Tree cover (26.07)	-
Chrysocyon brachyurus	Altitude (52.30)	Land use (11.50)	-
Tamandua tetradactyla	Altitude (40.00)	Slope (21.97)	-
Myrmecophaga tridactyla	Altitude (38.46)	Dist_water (23.50)	-
Lycalopex vetulus	Dist_PA (38.95)	Land use (23.87)	-
Leopardus pardalis	Altitude (22.70)	Tree cover (20.32)	Land use (17.03)
Cerdocyonthous thous	Altitude (22.42)	Dist_PA (22.13)	Land use (19.26)
Puma concolor	Altitude (27.98)	Tree cover (22.60)	Land use (18.33)

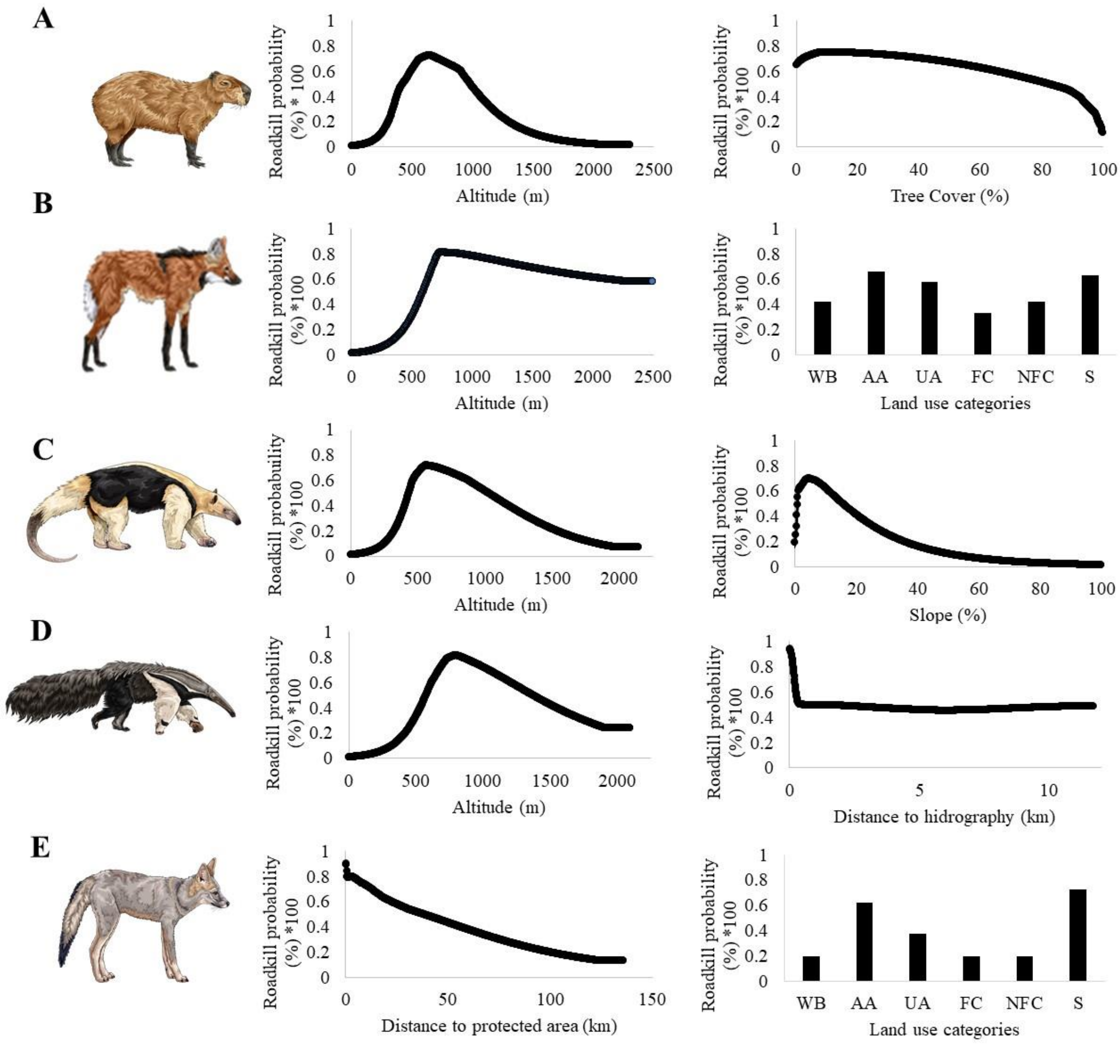

Figure 11. Response curves of predictors with higher contribution to the models. A) Capybara (*Hydrochoerus hydrochaeris*), B) Maned wolf (*Chrysocyon brachyurus*), C) Southern tamandua (*Tamandua tetradactyla*), D) Giant anteater (*Myrmecophaga tridactyla*), E) Hoary fox (*Lycalopex vetulus*). (WB= water bodies, AA = anthropic area, UA = urban area, FC = forest cover, NFC = non forest cover, S = silviculture).

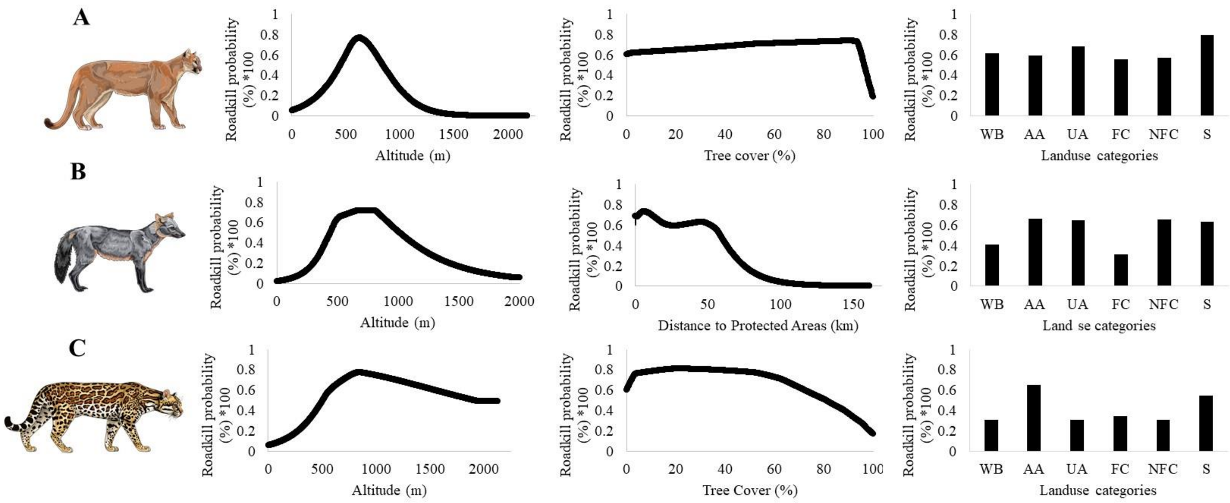

Figure 12. Response curves of predictors with higher contribution to the models to A) Puma (*Puma concolor*), B) Crab eating fox (*Cerdocyon thous*), C) Ocelot (*Leopardus pardalis*). (WB= water bodies, AA = anthropic area, UA = urban area, FC = forest cover, NFC = non forest cover, S = silviculture).

4.3.1.1. Consensus models

The three consensus models showing probability of roadkill ≥ 70% were concentrated on Northeast, Center and Southeast regions of São Paulo state stressing the priority of road mortality reduction on specific cities as Ribeirão Preto, Garça, Bauru, São Carlos, Mogi das Cruzes, São João da Boa Vista, Brotas, among others adjacent areas (Fig. 13 to 15).

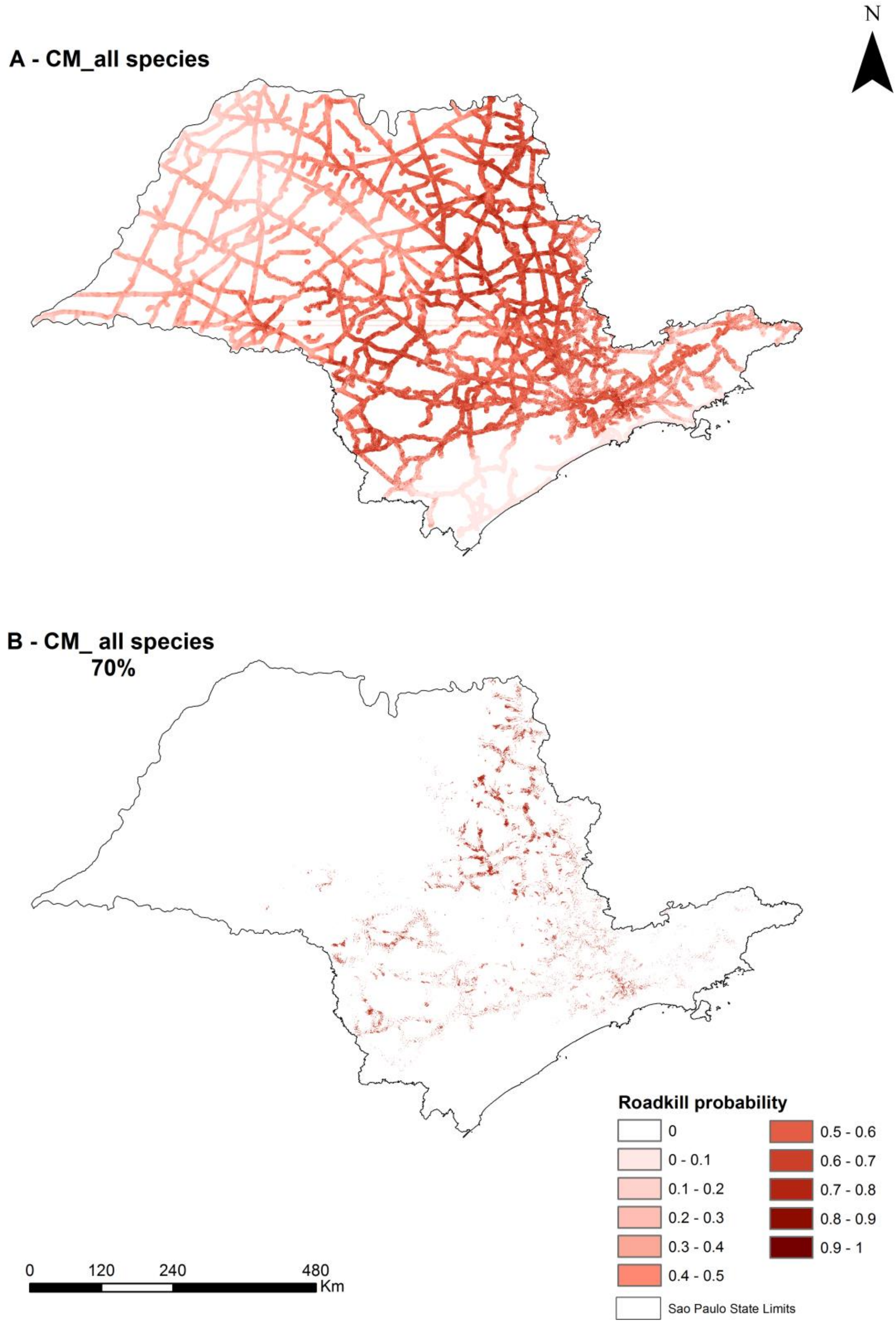

Figure 13. Consensus model for all seven species combined. A) Model with arithmetic mean of seven AUC values combined with 3 km road buffer, B) Model with arithmetic mean of seven AUC values cut by 0.7 showing critical areas equal or above 70% with probability of roadkill.

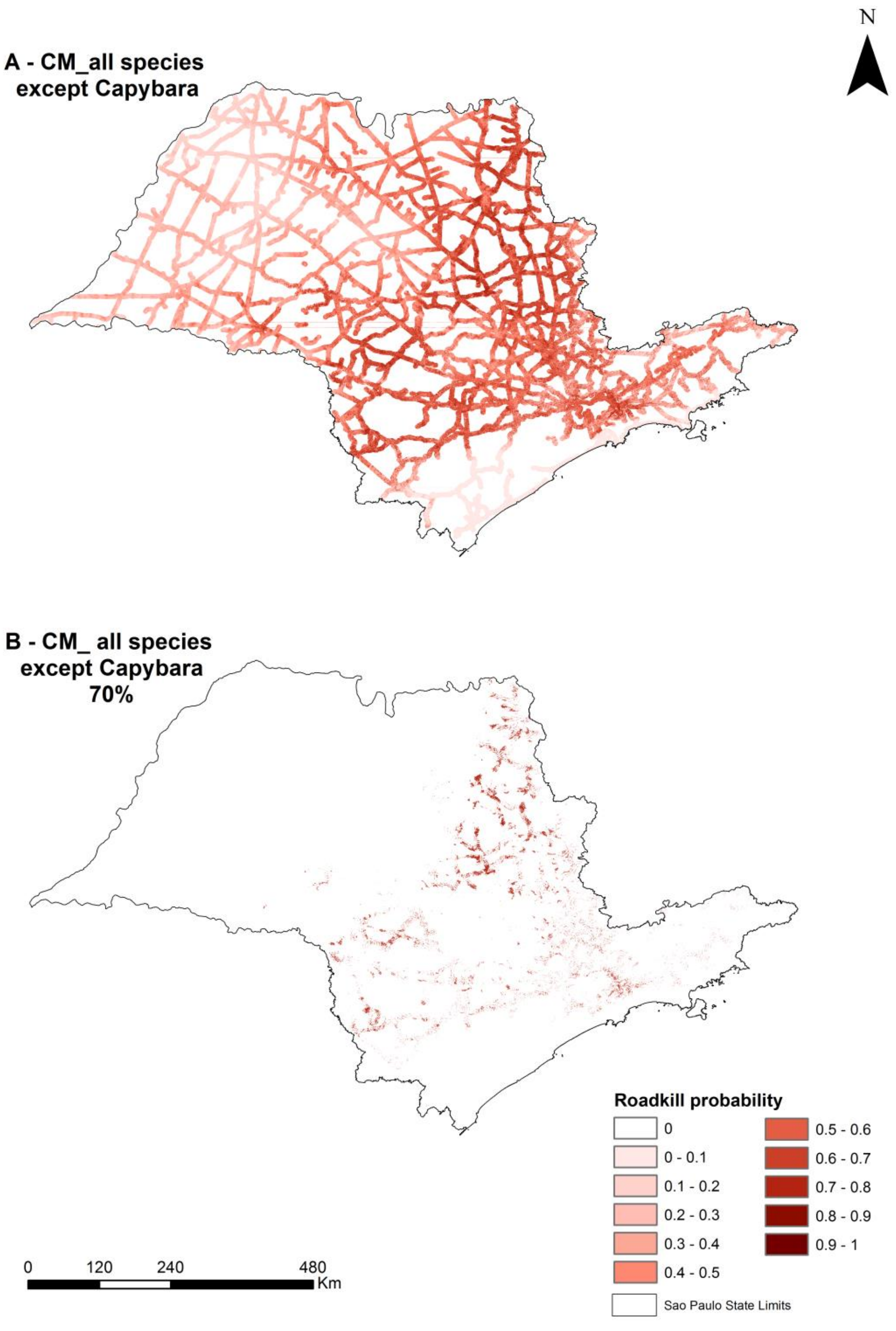

Figure 14. Consensus model for all seven species combined except Capybara. A) Model with arithmetic mean of seven AUC values combined with 3 km road buffer, B) Model with arithmetic mean of seven AUC values cut by 0.7 showing critical areas equal or above 70% with probability of roadkill.

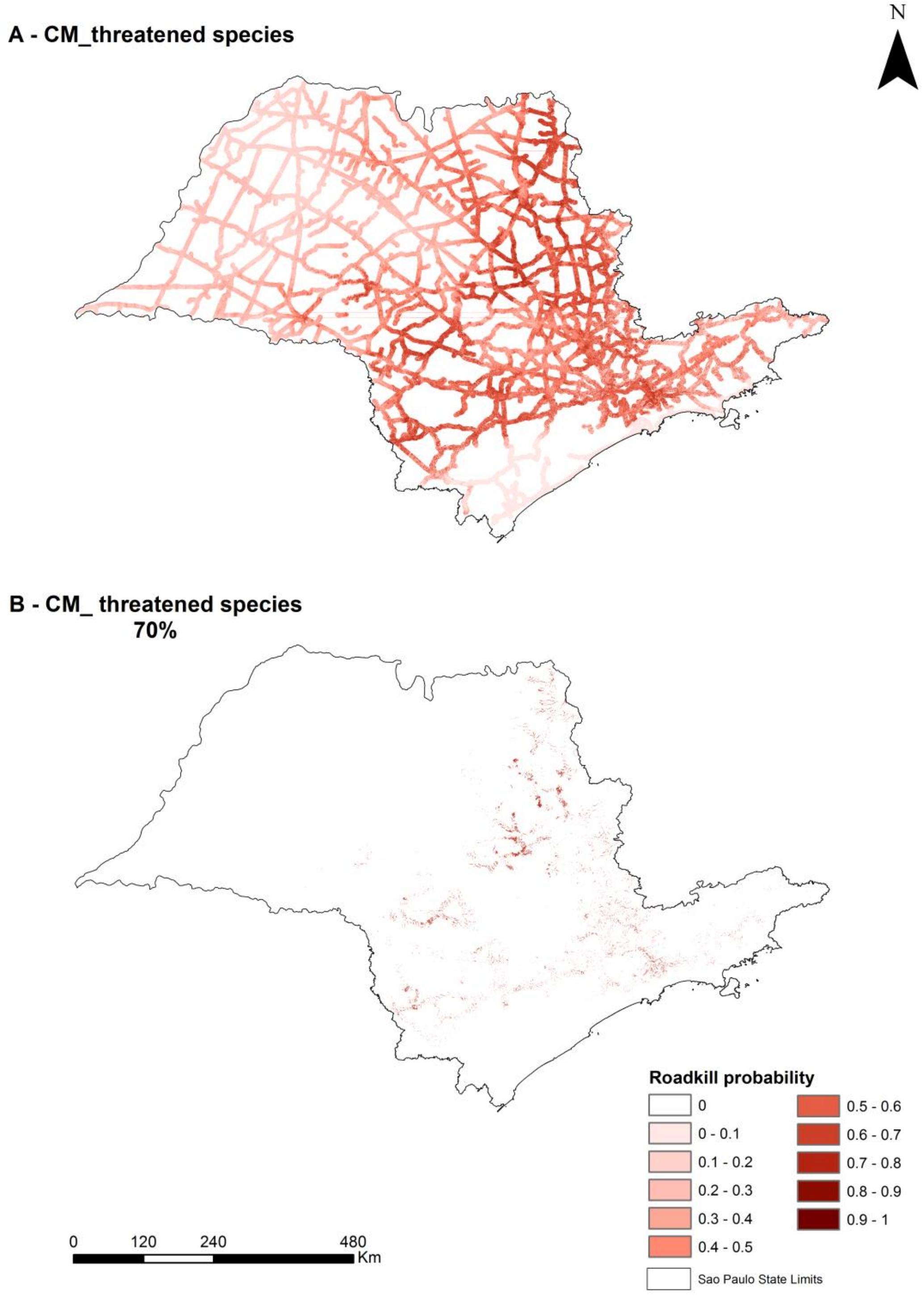

Figure 15. Consensus model for threatened species. A) Model with arithmetic mean of seven AUC values combined with 3 km road buffer, B) Model with arithmetic mean of seven AUC values cut by 0.7 showing critical areas equal or above 70% with probability of roadkill.

A total of 7,273 km, corresponding to 19.93% of paved road network in São Paulo State were evaluated as equal or above 70% of Capybara roadkill risk, which was the mammal with higher risk between the non-threatened species. The Maned wolf has 3,662 km of critical road section, totalizing 10.03% of all road network (Fig 16 and 17). From consensus model of all species combined, except Hoary fox, 1,323 km of roads are risky for roadkill totalizing 3.62% of all paved roads network in São Paulo state, incorporating 260 Municipalities (Table 5; Appendix F).

Table 5. Length of critical road sections with roadkill probability ≥ 70% for RPM from eight target species and for three consensus models. Legend: CM = consensus models, CB = Capybara, HF = Hoary fox.

Common name/Consensus models	**Species**	**Roadkill risk ≥ 70% (km)**	**Frequency of total paved road network (%)**	**Municipalities (n)**
Puma	*Puma concolor*	1,617	4.43	360
Southern tamandua	*Tamandua tetradactyla*	4,690	12.85	465
Giant anteater	*Myrmecophaga tridactyla*	1,267	3.47	343
Capybara	*Hydrochoerus hydrochaeris*	7,273	19.93	471
Maned wolf	*Chrysocyon brachyurus*	3,662	10.03	306
Ocelot	*Leopardus pardalis*	1,647	4.51	298
Hoary fox	*Lycalopex vetulus*	1,116	3.14	144
Crab eating fox	*Cerdocyon thous*	5,763	15.79	449
CM_all species combined except HF	-	1,323	3.62	260
CM_all species combined except HF and CB	-	1,077	2,95	234
CM_Threatened species combined except HF	-	524	1.43	200

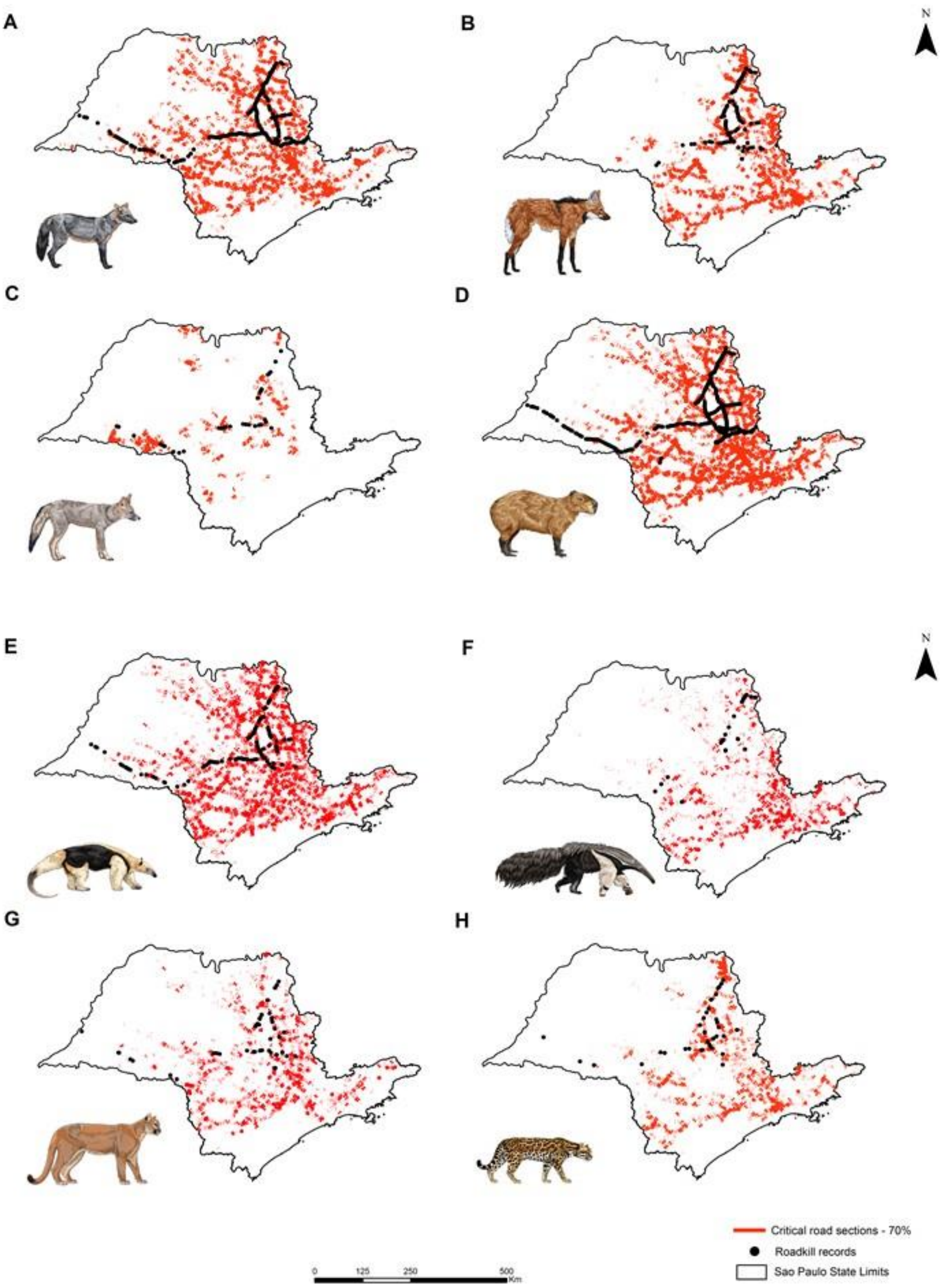

Figure 16. Critical road sections equal or up to 70% of roadkill probability. A) Crab eating fox (*Cerdocyon thous*), B) Maned wolf (*Chrysocyon brachyurus*), C) Hoary fox (*Lycalopex vetulus*), Capybara (*Hydrochoerus hydrochaeris*), Southern tamandua (*Tamandua tetradactyla*), Giant anteater (*Myrmecophaga tridactyla*), Puma (*Puma concolor*), Ocelot (*Leopardus pardalis*).

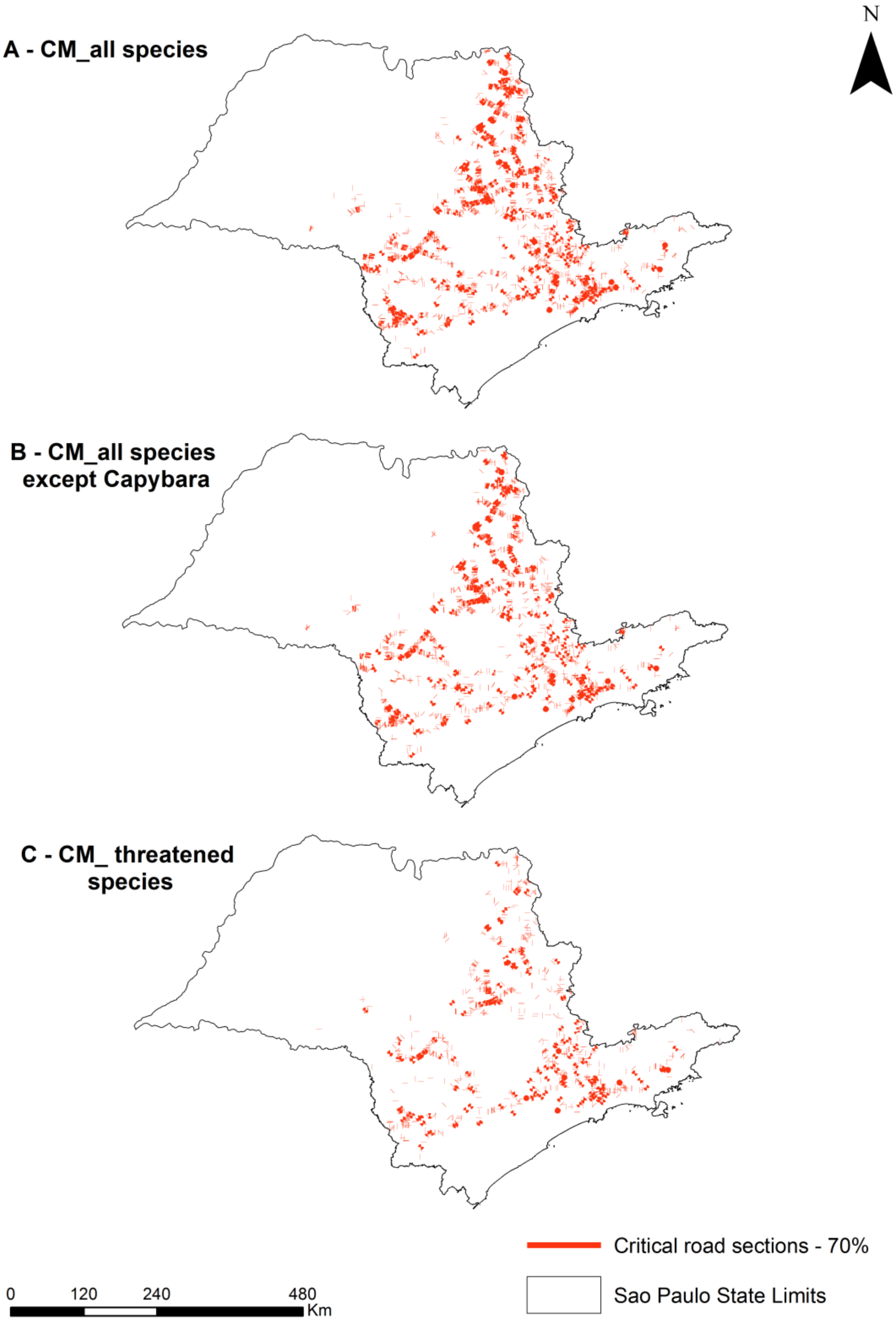

Figure 17. Critical road sections equal or up to 70% of roadkill probability. A) all species combined, B) all species combined except Capybara, C) threatened species.

4.3.1.2. Roadkill hotspot analysis

The kernel analysis using KDE+ returned 1,998 roadkill clusters for all mammals combined with a total of 485.254 km length and 54.05% (n = 20,354) of roadkill data in some intensity of clustering (Fig. 18; Appendix G). For capybara alone, we had 858 clusters with total length of 205.322 km and 53.85% (n = 6,743) of data on clusters (Fig. 19; Appendix H).

The intensity of the clusters can be observed on Table 6.

Table 6. Number of sections with different intensity of roadkill clustering for all mammals combined and Capybara only.

Intensity of cluster	Very low (N (%))	Low (N (%))	Medium (N (%))	High (N (%))	Very high (N (%))
All mammals_Nº clusters	1,625 (81.33)	301 (15.06)	58 (2.90)	11 (0.55)	3 (0.15)
All mammals_Nº roadkills (n)	12,268 (60.27)	5,486 (26.95)	1,792 (8.80)	536 (2.63)	316 (1.55)
All mammals_Lengh of clusters (m)	370.868 (76.42)	90.365 (18.62)	18.806 (3.87)	3.638 (0.74)	1.574 (0.32)
Capybara_Nº clusters (n)	724 (84.38)	104 (12.12)	23 (2.68)	5 (0.58)	2 (0.23)
Capybara_Nº roadkills	3,838 (56.91)	1,774 (26.30)	659 (9.77)	254 (3.76)	218 (3.23)
Capybara_Lengh of clusters (m)	157.958 (76.93)	34.868 (16.98)	8.775 (4.27)	2.462 (1.19)	1.259 (0.61)

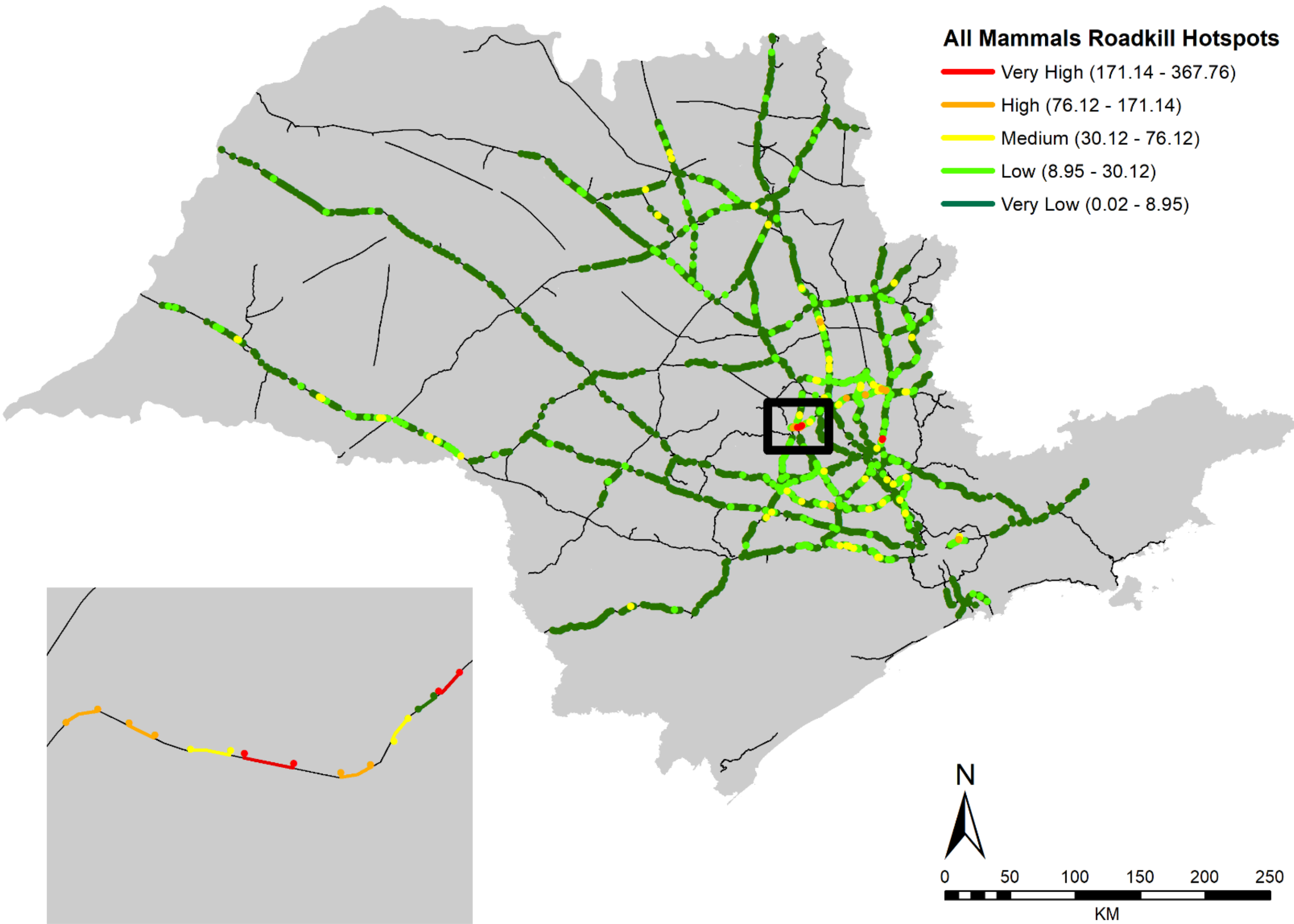

Figure 18. Roadkill cluster of all mammals combined classified by intensity (STR_Dense2) on toll paved roads in São Paulo state.

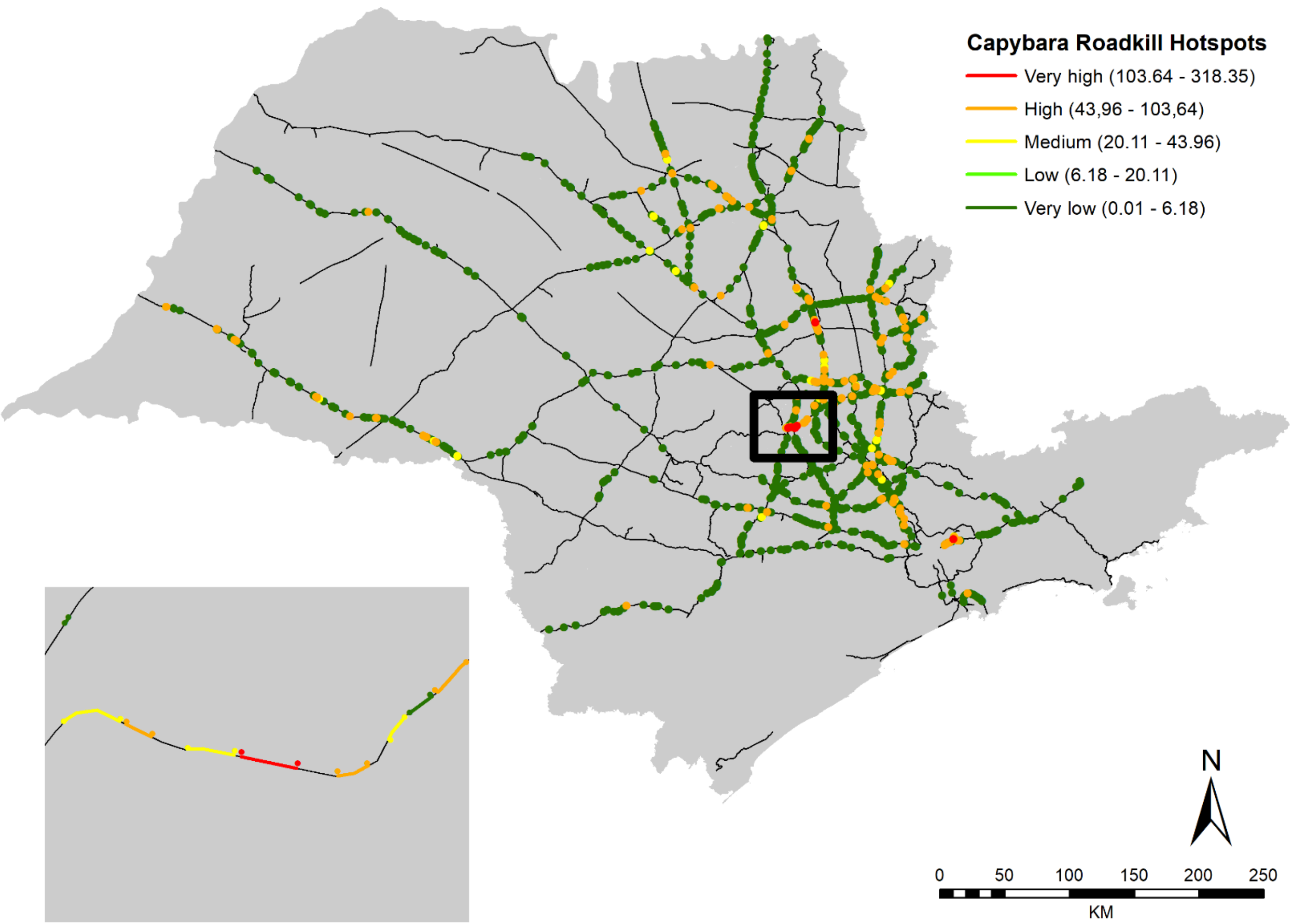

Figure 19. Capybara roadkill cluster classified by intensity (STR_Dense2) on toll paved roads in São Paulo state.

4.4. DISCUSSION

4.4.1. Roadkill predictive model

The presence of paved roads in São Paulo state offer roadkill risk with varied intensity for many mammal species. However, the main critical area, with equal or above 70% of roadkill risk for the target mammal species, is mostly concentrated on northeast region of the state, called as Metropolitan Region of Ribeirão Preto, formed by 34 municipalities (EMPLASA, 2019). This region is an important road junction with access to the important highways of the State of Minas Gerais, Distrito Federal and access to harbor of Santos. From the biological point of view, it has one of the most expressive remnants of Cerrado biome of the State and a transition area of Cerrado and Atlantic Forest biomes which we can highlight full protected areas as Vassununga, Porto Ferreira, Furnas do Bom Jesus state parks, Ribeirão Preto and Jataí Ecological stations (FUNDAÇÃO FLORESTAL, 2019). The critical roadkill areas, for all species combined incorporate in total, 260 municipalities in the State and cover 3.62% of all paved road network.

In general, the predictors that mostly contributed to the RPM in this study were altitude, tree cover and land use. Because we are modelling the risk of roadkill, the altitude is highly associated with the presence of roads, in this case (FREITAS et al., 2010). Although the roads are not explicit in the models, the roadkill records were sampled on the roads and there is a subjective bias related to altitude. When roads are planned and designed, the least cost path, low risk of landslides among other concerns are taken in account and this is highly associated with altitude and slope because these attributes assure a flat longitudinal dimension to the road, higher safety and low costs of road construction. From the biological point of view, wildlife movements tend to travel along a path of least resistance (SCHIPPERS et al., 1996; LARKIN et al., 2004) and that´s why many studies showed the risk of wildlife-vehicle collisions increased when roads bisected monotonous topography terrain (CLEVENGER et al., 2003; MALO et al., 2004; RAMP et al., 2005). Land use also an important predictor, similarly with presented by roadkill predictor models by Malo et al. 2004 and Garrote et al. (2018).

Following the same rationale, the high percentage of tree cover is only present in the full protected areas in São Paulo state and, for some specific cases, also have the highest elevation in São Paulo state (e.g. Serra do Mar, Serra de Paranapiacaba, Serra da Mantiqueira and Serra da Bocaina; FUNDAÇÃO FLORESTAL, 2019), with low density of roads and traffic or are classified as roadless areas (IBISCH et al., 2016). This may explain why most of the models showed a negative relation between high risk of roadkills when the percentage of tree cover was lower.

Capybara is one of the most roadkilled mammal species in São Paulo state (Chapter 2 of this document; HUIJSER et al., 2013, ABRA et al., 2018). This species is now the most common living mammal in HMLs at the São Paulo State, overabundant in landscapes dominated by sugarcane crops in Southeastern Brazil (VERDADE & FERRAZ, 2006; FERRAZ et al., 2007), explained by food availability and natural predators decline (FERRAZ et al., 2007; VERDADE et al., 2012; BOVO et al., 2016). The risk of Capybara roadkills were higher when the tree cover was lower. Currently, the landscape in the State is so highly fragmented, that the riparian habitats, describe as preferable habitats for Capybara, are constant surrounded by anthropic areas as agriculture crops or urban areas. Landscape characteristics found to be relevant are indeed related to the habitat of these social and semi-aquatic mammals, highly associated with water bodies and in the HML, disturbed areas (BUENO et al., 2013; ASCENSÃO et al., 2017).

For the Maned wolf, the risk of roadkill was higher in higher elevations. It may be explained by the presence of the last remnants of natural vegetation in these areas. Interestingly, altitude was the major predictor for environmental habitat suitability to the occurrence of the Maned wolf in different Brazilian biomes (de PAULA, 2016). Also, the risk of been roadkilled were higher for landscapes as anthropic, urban areas and silviculture. Freitas et al. (2015) also found a relationship of Maned wolf roadkill close to urban and anthropic area on a specific toll road in the center west of São Paulo state.

Altitude was an important predictor for Puma roadkill in this study, but also for habitat suitability in São Paulo state (ANGELIERI et al., 2016). The probability of roadkill for Puma was constant for different percentages of tree cover, excepting for areas where the percentage of tree cover was higher than 90%. The puma has high capacity to adapt to various environments and despite to be threatened and endangered carnivore species, is not a strictly forest dependent, mainly in São Paulo state (DOTTA & VERDADE, 2007; MIOTTO et al., 2012; MAGIOLI et al., 2014).

Our results showed that the risk of Crab eating fox roadkill were higher closer to protect areas, but the categories of land use as predictor also showed that the risk of roadkill are high for urban areas, non-forest cover, silviculture and anthropic areas. Accordingly, with Freitas et al. (2015), the forest cover is an important predictor that influences the Crab eating fox roadkill and the authors stated that this may indicates that this canid species may prefer more forested habitat than previously thought. In our opinion, the Crab eating fox has higher risk of roadkill on specific areas that mixes forest cover, on protect areas as the model shown, close to HDL as silviculture, pastures or even urban areas. This canid is common meso-predator with generalist diet and habitat use (LYRA-JORGE et al., 2008; FERRAZ et al., 2010).

For the Southern tamandua, slope demonstrated the higher risk of roadkill for road surfaces in areas with lower inclination. For Ocelot, the probability of roadkill was between 60-80% where percentage of tree cover varied between 0-40% and most important categories of land use were anthropic areas and silviculture. The higher risk of roadkill on areas with lower forest cover may be due to a higher movement that the felid need to perform foraging, looking for preys, sexual partners or dispersing.

Altitude varying between 600-1200 m were riskier to Giant anteater, as well as the presence of water bodies close to the roads, what corroborates with Ascensão et al. (2017). Bertassoni et al. (2019) found that the habitat suitability for Giant anteater occurrence in São Paulo state are more related to protected areas and forest cover that also includes riparian forests. We believe that riparian forests can act as a refuge to Giant anteater, but when these habitats are cut by roads, the anteater get exposed to the traffic. When animals cross the roads close to riparian forests, the roadkill risk increases because these are the lower area on the road where cars can get a higher speed. The combination of highspeed traffic, slow movements, poor vision of Giant anteaters make these specific areas, critical zones on roads. Is also interesting to note that Giant anteater are been recorded using drainage culverts on roads in the center west of São Paulo (Osnir Giacon, *person comn.*) state which strength the use of riparian forests by anteaters and the necessity to provide safe crossings opportunities on these specific habitats beyond to other areas or preferable habitats.

For Hoary fox, there is a negative relationship between the proximity to protected areas with a higher risk of roadkill. Because Hoary fox is a threatened and endangered species, the only really endemic to Cerrado biome in Brazil (JÁCOMO et al., 2004), may the species be more present on protected areas or adjacent open habitats (natural or anthropic), specifically in São Paulo state, so there are higher risk of mortality on roads close to these areas.

In general, the RPM for the target species did not predict the roadkill on the northwest and southwest roads in São Paulo state with same intensity from the rest part of the state. This could be due to a lack of roadkill records in this region, a different set of specific predictors for the region or both.

In this study, the selection of predictors for modeling was all related to the attributes of the São Paulo landscape. Because we are modelling prediction of roadkills on paved roads in São Paulo state, variables as speed limit and road hierarchy doesn´t varies much in the same way presented on Garrote et al. (2018), for example. Still, despite the referred authors included speed limit and road hierarchy on the modelling, they were not the major contributors to the final model. Finally, from a practical point of view, the wildlife-vehicle collision only can be totally avoided for large mammals with a speed lower than 65 km/h in nocturnal period (SULLIVAN, 2011). In São Paulo state, the post speed limit varies between 50 to 120 km/h, but the majority of paved roads operates between 80 to 120 km/h. Anyway, speed limit would not be relevant to RPM in this study.

All RPM were considered satisfactory either by the good AUC values and also by the higher percentage of predictability. Although, the RPM for Hoary fox was able to predict only part of the independent dataset (58.33%) what confirms that this model was not a good enough to predict roadkill for this species and need to be rethink and redone.

The use of SDM as a tool to predict areas of higher probability roadkill was useful in identifying the critical regions of the state of São Paulo, the landscape predictors that explain these areas, the species most vulnerable to road mortality, as well as identifying the locations and along roads with more than 70% roadkill risk. The presented results of this study strength that the Maxent algorithm is suitable to model the risk of roadkill, similarly with the prediction of Iberian lynx (*Lynx pardinus)* road mortality in Southern Spain, when the algorithm was used for the first time for this specific purpose (GARROTE et al., 2018).

4.4.2. Roadkill hotspots analysis

Toll road sections that were critical to roadkill of all mammals combined, totalized 485.254 km of roads (7.5% of toll roads in the state), and they also highlights the concentration of critical areas in northeast region of São Paulo state as well as the Metropolitan areas as Campinas and São Paulo cities, where the density of paved toll roads are higher.

This analysis also showed 205 km of critical areas for Capybara (3.15% of toll roads in the state). The identification of critical section with intensity of clusters as medium, high and very high can help road administrators to implement mitigation measures as fences and underpasses to reduce capybara road mortality and increase human safety at these areas (HUIJSER et al., 2013; ABRA et al., 2019). Because capybara is highly associated with water bodies, riparian forests surrounded by disturbed areas, the adaptation of existent culverts should result in a reduction of collision with a positive cost-bennefit (HUIJSER et al., 2013).

The analyses of hotspots differ from the RPM because present a real condition of roadkill clusters, but in our study both analyses were complementary and stress an urgency of mitigation in the same areas, most of the cases.

4.4.3. Predictive modelling, hotspots analyses and considerations for mitigation planning

The main complaint from road administrators to implement mitigation measures is the associated costs, but models that predict the best location for mitigation measures as well as roadkill hotspots analysis can improve wildlife survival, human safety but also can prioritize financial resources on mitigation where is more needed (MALO et al., 2004). For critical road sections pointed by roadkill hotspot analysis or critical sections pointed by PRM with higher risk, we suggest the implementation of effective mitigation measures as fences, underpasses, overpasses and animal detection systems (CLEVENGER & WALTHO, 2000; RYTWINSKI et al., 2016; HUIJSER et al., 2016). We also recommend that the roadkill predictive modelling could be required by environmental agencies on environmental licensing for road construction or duplication in local or regional scales during the process of road design and planning of mitigation measures. From a practical conservation point of view, this technique becomes an important mechanism for particularly in the absence of a quantity of data or in the urgency of the decision-making, helping to identify the potentially dangerous stretches of roads on a large scale.

4.5. FINAL CONSIDERATIONS

Species distribution models (SDMs) can be useful for different conservation purposes and in this chapter, we demonstrated the use of the toll to predict mammal roadkill on paved roads in São Paulo State. The RPM can be useful to environmental and transportation agencies aiming to advice mitigation measures for specific road sections and for specific species. The models presented on this chapter can attend to human safety, biological conservation, or both combined concerns. The consensus models and the roadkill hotspots analyses showed that the northeast of São Paulo State is more critical for road mortality in general, but also for threatened and endangered species. We encourage the use of roadkill predictive modelling during environmental licensing for road construction or duplication in local or regional scales during the process of road design and planning of mitigation measures.

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APPENDIX

Appendix A. Results of RPM for the target mammal species (AUC for testing = area under curve, LPT = low presence threshold). All selected models showed $p \leq 0.05$ associated to the LPT, except for Hoary fox ($p = 0.08$). “*” Models selected as Final RPM.

Species_BiasGrid	**Training samples**	**Test samples**	**AUC ± SD**	**LPT**
**Cerdocyon thous*_bias03	276	118	0.789 ± 0.017	0.2031
*Cerdocyon thous*_bias04	276	118	0.790 ± 0.018	0.2141
*Cerdocyon thous*_bias05	276	118	0.790 ± 0.018	0.2341
*Cerdocyon thous*_bias06	276	118	0.774 ± 0.019	0.2220
*Chrysocyon brachyurus*_bias03	90	38	0.890 ± 0.020	0.1645
*Chrysocyon brachyurus*_bias04	90	38	0.874 ± 0.022	0.2460
*Chrysocyon brachyurus*_bias05	90	38	0.864 ± 0.022	0.2375
**Chrysocyon brachyurus*_bias06	90	38	0.874 ± 0.022	0.1689
*Leopardus pardalis*_bias03	29	12	0.779 ± 0.054	0.2598
*Leopardus pardalis*_bias04	29	12	0.798 ± 0.052	0.2761
**Leopardus pardalis*_bias05	29	12	0.802 ± 0.051	0.2576
*Leopardus pardalis*_bias06	29	12	0.778 ± 0.057	0.3429
*Lycalopex vetulus*_bias01	26	10	0.706 ± 0.068	0.2737
*Lycalopex vetulus*_bias03	26	10	0.722 ± 0.067	0.3351
**Lycalopex vetulus*_bias04	26	10	0.730 ± 0.075	0.3036
*Myrmecophaga tridactyla*_bias03	24	9	0.823 ± 0.060	0.1537
*Myrmecophaga tridactyla*_bias04	24	9	0.823 ± 0.060	0.1537
*Myrmecophaga tridactyla*_bias05	24	9	0.817 ± 0.060	0.1854
**Myrmecophaga tridactyla*_bias06	24	9	0.864 ± 0.058	0.2301
**Puma concolor*_bias04	36	15	0.727 ± 0.051	0.3279
*Puma concolor*_bias05	36	15	0.719 ± 0.053	0.3424
*Puma concolor*_bias06	36	15	0.704 ± 0.060	0.3773
*Tamandua tetradactyla*_bias01	102	43	0.718 ± 0.031	0.1947
**Tamandua tetradactyla*_bias02	102	43	0.729 ± 0.030	0.2246
*Tamandua tetradactyla*_bias03	102	43	0.725 ± 0.031	0.2299
*Tamandua tetradactyla*_bias04	102	43	0.712 ± 0.031	0.2555
**Hydrochoerus hydrochaeris*_bias01	541	231	0.761 ± 0.013	0.1621
*Hydrochoerus hydrochaeris*_bias02	541	231	0.716 ± 0.014	0.3240

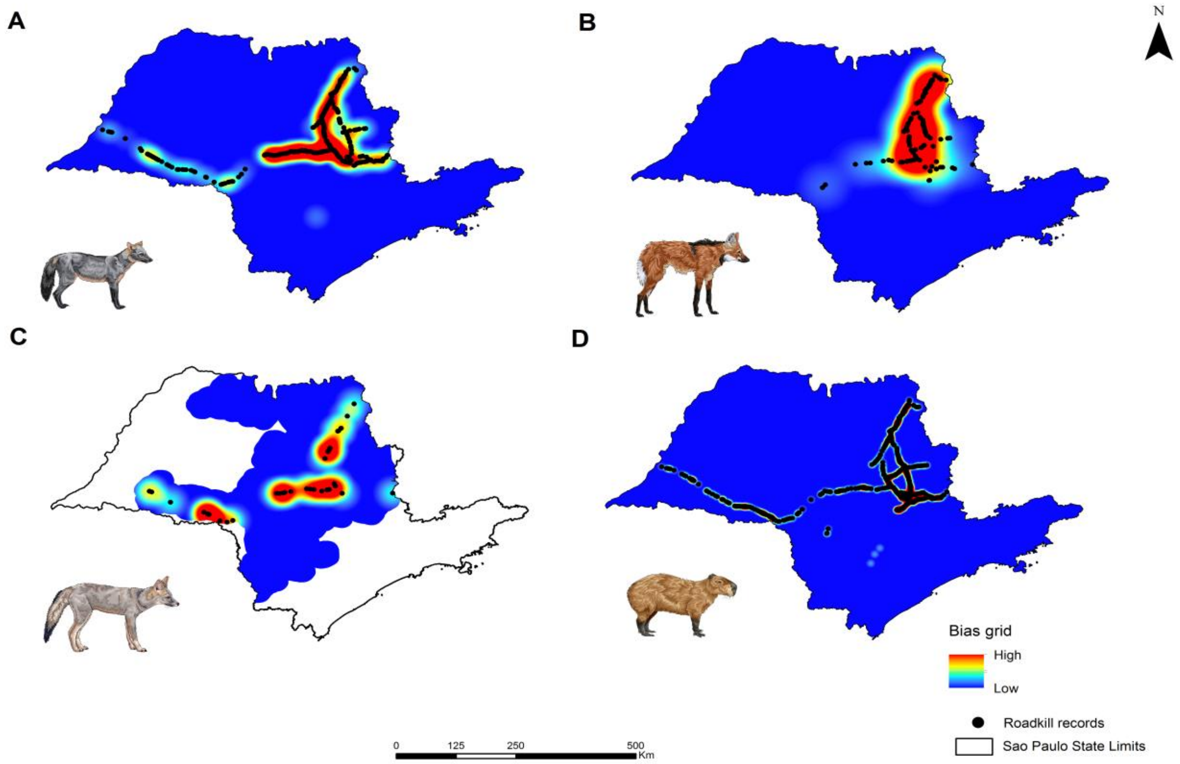
Appendix B. Correlation matrix of variables used on modelling. Legend: Dist_water = distance to water, PA_Dist = distance to protected areas.

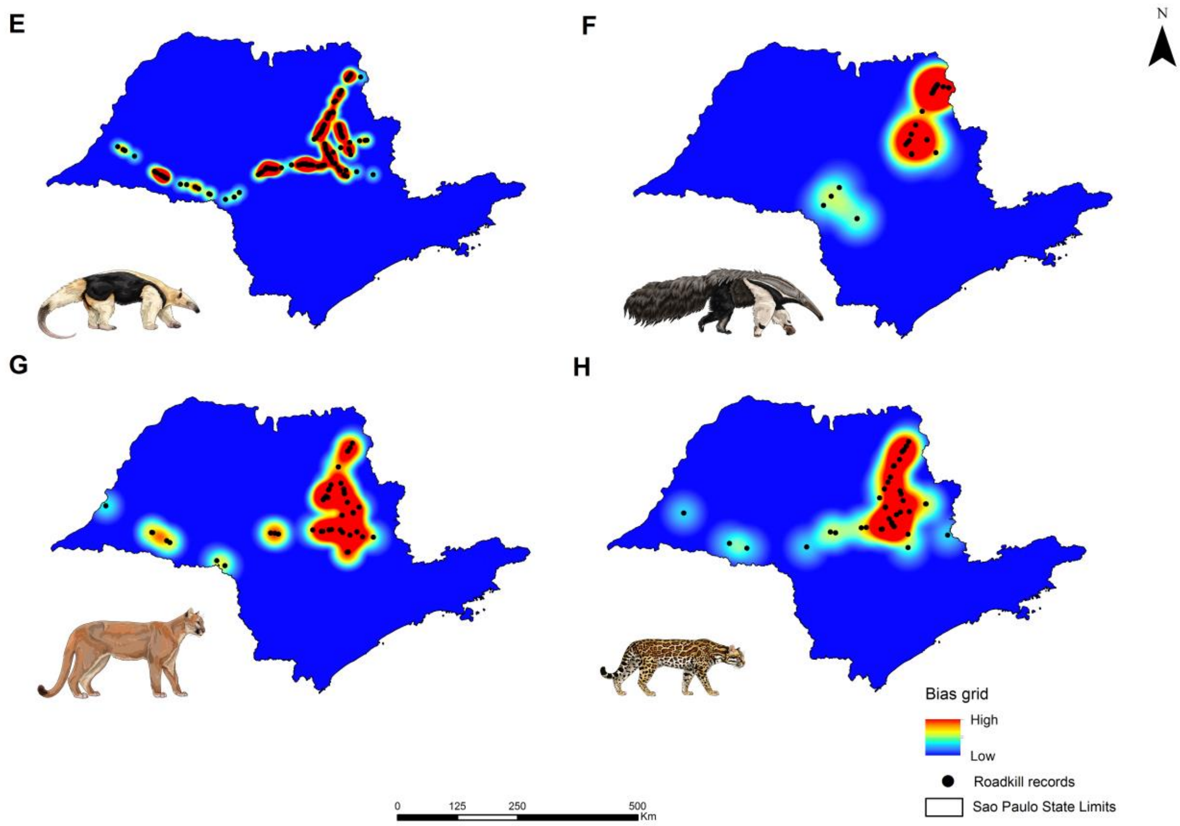
Variables	Dist_water	PA_Dist	Slope	Tree cover	Land use	Altitude
Dist_water	1.00	-0.04	0.08	0.03	0.04	0.09
PA_Dist	-0.04	1.00	-0.27	-0.34	-0.26	-0.20
Slope	0.08	-0.27	1.00	0.46	0.34	0.30
Tree cover	0.03	-0.34	0.46	1.00	0.69	0.16
Land use	0.04	-0.26	0.34	0.69	1.00	0.17
Altitude	0.09	-0.20	0.30	0.16	0.17	1.00

Appendix C. Species bias grid with reference values in degrees and kilometers.

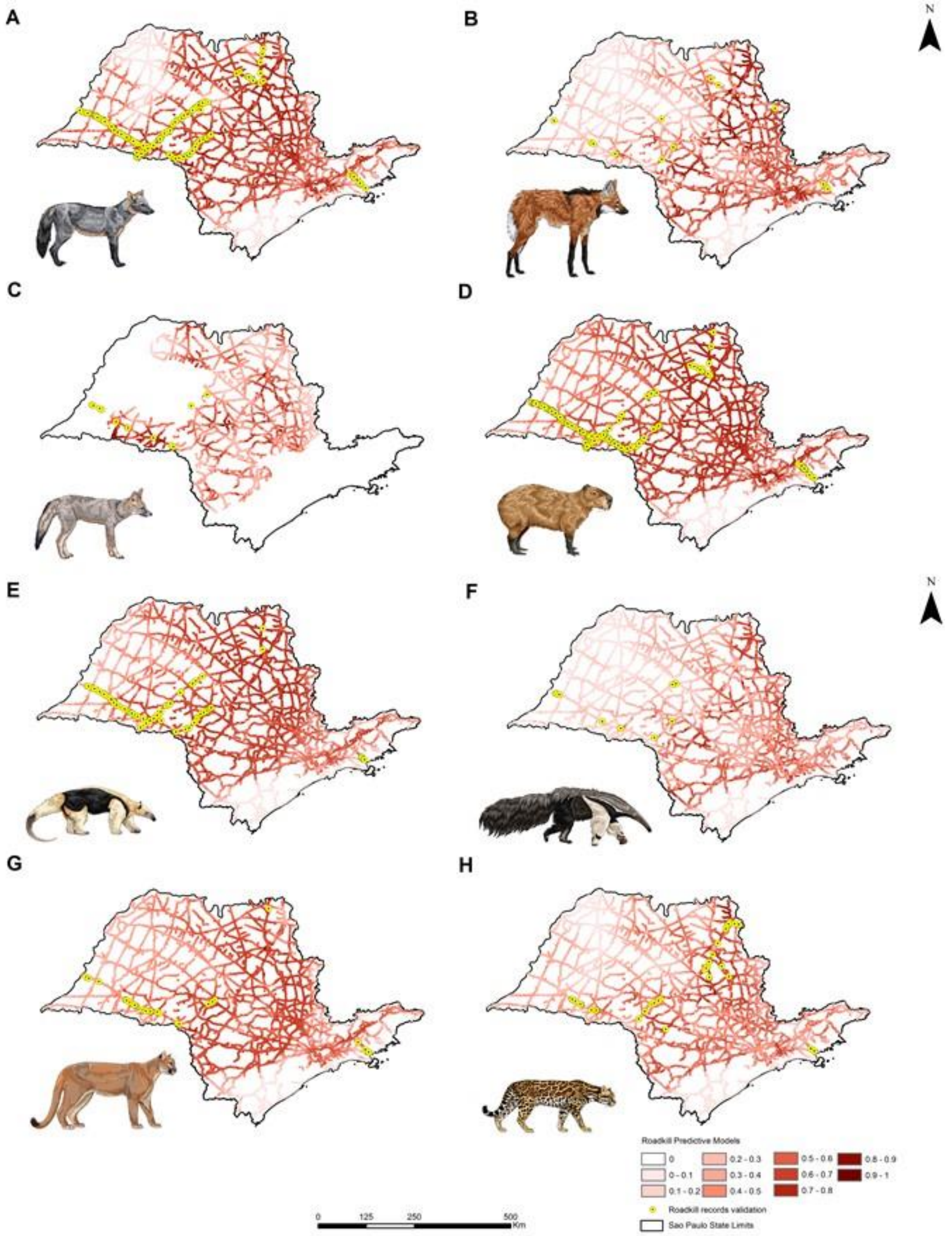
ID	Species	Degrees	Equivalence in km
1	*Hydrochoerus hydrochaeris*	0.1	11.130
2	*Tamandua tetradactyla*	0.2	22.265
3	*Cerdocyon thous*	0.3	33.400
4	*Puma concolor*	0.4	44.530
5	*Lycalopex vetulus*	0.4	44.530
6	*Leopardus pardalis*	0.5	55.660
7	*Myrmecophaga tridactyla*	0.6	66.790
8	*Chrysocyon brachyurus*	0.6	66.790

Appendix D. Bias Grid selected for the target species. A) Crab eating fox (*Cerdocyon thous*), B) Maned wolf (*Chrysocyon brachyurus*), C) Hoary fox (*Lycalopex vetulus*), D) Capybara (*Hydrochoerus hydrochaeris*), E) Southern tamandua (*Tamandua tetradactyla*), F) Giant anteater (*Myrmecophaga tridactyla*), G) Puma (*Puma concolor*), H) Ocelot (*Leopardus pardalis*).





Appendix E. Independent roadkill records for RPM validation. A) Crab eating fox (*Cerdocyon thous*), B) Maned wolf (*Chrysocyon brachyurus*), C) Hoary fox (*Lycalopex vetulus*), D) Capybara (*Hydrochoerus hydrochaeris*), E) Southern tamandua (*Tamandua tetradactyla*), F) Giant anteater (*Myrmecophaga tridactyla*), G) Puma (*Puma concolor*), H) Ocelot (*Leopardus pardalis*).



Appendix F. List of Municipalities where probability to have critical road sections for roadkill ≥ 70% for target species or Consensus models. Legend: CM_All = Consensus model with all species combined expect Hoary fox, CM_AllnoHydro = Consensus model with all species combined expect Hoary fox and Capybara, CM_Threat = Consensus model with all threatened species combined expect Hoary fox, CB = *Chrysocyon thous*, CT = *Cerdocyon thous*, HH = *Hydrochoerus hydrochaeris*, LP = *Leopardus pardalis*, LV = *Lycalopex vetulus*, MT = *Myrmecophaga tridactyla*, PC = *Puma concolor*, TT = *Tamandua tetradactyla*.

Municipalities	**CM_All**	**CM_AllnoHydro**	**CM_Threat**	**CB**	**CT**	**HH**	**LP**	**LV**	**MT**	**PC**	**TT**
ADAMANTINA						x				x	
ADOLFO					x						
AGUAÍ	x	x	x	x	x	x	x		x	x	x
ÁGUAS DA PRATA				x		x	x		x	x	x
ÁGUAS DE LINDÓIA	x			x		x			x		x
ÁGUAS DE SANTA BÁRBARA	x	x	x	x	x	x	x	x	x	x	x
ÁGUAS DE SÃO PEDRO					x						x
AGUDOS	x	x	x	x	x	x	x	x	x	x	x
ALAMBARI	x	x		x	x	x	x	x	x	x	x
ALTAIR					x	x			x		x
ALTINÓPOLIS	x	x	x	x	x	x	x		x	x	x
ALTO ALEGRE					x	x					
ALUMÍNIO	x	x	x	x	x	x	x		x	x	x
ÁLVARES FLORENCE						x					x
ÁLVARES MACHADO					x						
ÁLVARO DE CARVALHO				x	x	x			x	x	x
ALVINLÂNDIA	x	x		x	x	x	x	x		x	x
AMERICANA				x	x	x	x			x	x
AMÉRICO BRASILIENSE	x	x	x	x	x	x	x		x	x	x
AMÉRICO DE CAMPOS					x	x					x
AMPARO	x	x	x	x	x	x	x		x	x	x
ANALÂNDIA	x	x	x	x	x	x	x		x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
ANGATUBA	x	x	x	x	x	x	x	x	x	x	x
ANHEMBI				x	x	x	x	x	x	x	x
ANHUMAS					x			x		x	
APARECIDA					x						x
APIAÍ	x	x	x	x	x	x	x		x	x	x
ARAÇARIGUAMA	x	x	x	x	x	x	x		x	x	x
ARAÇOIABA DA SERRA	x	x		x	x	x	x		x	x	x
ARAMINA				x	x	x	x		x	x	x
ARANDU	x	x	x	x	x	x	x	x	x	x	x
ARAPEÍ					x	x	x		x	x	x
ARARAQUARA	x	x	x	x	x	x	x		x	x	x
ARARAS	x	x	x	x	x	x	x	x	x	x	x
ARCO-ÍRIS										x	
AREALVA					x	x	x	x	x		x
AREIAS	x	x	x	x	x	x	x		x	x	x
AREIÓPOLIS				x	x	x			x	x	x
ARIRANHA					x	x				x	x
ARTUR NOGUEIRA	x	x		x	x	x	x	x		x	x
ARUJÁ	x	x	x	x	x	x	x		x	x	x
ASSIS	x	x	x	x	x	x	x	x	x	x	x
ATIBAIA	x	x	x	x	x	x	x		x	x	x
AURIFLAMA						x					
AVAÍ					x	x		x		x	x
AVANHANDAVA					x						
AVARÉ	x	x	x	x	x	x	x	x	x	x	x
BADY BASSITT					x	x		x			x
BALBINOS					x	x					x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
BÁLSAMO					x	x	x	x		x	x
BANANAL			x	x	x	x	x		x	x	x
BARÃO DE ANTONINA					x	x				x	x
BARIRI					x	x		x	x	x	x
BARRA BONITA	x			x	x	x		x		x	x
BARRA DO CHAPÉU									x		
BARRA DO TURVO					x	x	x		x	x	x
BARRETOS					x	x		x	x	x	x
BARRINHA					x	x					x
BARUERI	x	x	x	x	x	x	x		x	x	x
BASTOS										x	x
BATATAIS	x	x	x	x	x	x	x		x	x	x
BAURU	x	x		x	x	x	x	x		x	x
BEBEDOURO	x			x	x	x	x		x	x	x
BERNARDINO DE CAMPOS	x	x		x	x	x	x			x	x
BILAC						x					x
BIRIGUI						x					
BIRITIBA-MIRIM	x	x	x	x	x	x	x		x	x	x
BOA ESPERANÇA DO SUL					x	x			x		x
BOCAINA	x	x	x	x	x	x			x	x	x
BOFETE	x	x	x	x	x	x	x	x	x	x	x
BOITUVA	x	x		x	x	x	x			x	x
BOM JESUS DOS PERDÕES	x	x	x	x	x	x	x		x	x	x
BOM SUCESSO DE ITARARÉ	x	x	x	x	x	x	x	x	x		x
BORÁ					x	x					

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
BORACÉIA					x			x			x
BORBOREMA						x					x
BOREBI	x	x	x	x	x	x	x	x	x	x	x
BOTUCATU	x	x	x	x	x	x	x	x	x	x	x
BRAGANÇA PAULISTA	x	x	x	x	x	x	x		x	x	x
BRODOWSKI	x	x	x	x	x	x	x		x		x
BROTAS	x	x	x	x	x	x	x	x	x	x	x
BURI	x	x	x	x	x	x	x	x	x	x	x
BURITIZAL	x	x	x	x	x	x	x		x	x	x
CABRÁLIA PAULISTA					x	x	x		x	x	x
CABREÚVA	x	x	x	x	x	x	x		x	x	x
CAÇAPAVA	x		x	x	x	x			x	x	x
CACHOEIRA PAULISTA	x	x		x	x	x	x		x	x	x
CACONDE				x		x			x	x	x
CAFELÂNDIA					x	x					x
CAIEIRAS	x	x	x	x	x	x	x		x	x	x
CAJAMAR	x	x	x	x	x	x	x		x	x	x
CAJOBI					x	x	x			x	x
CAJURU	x	x	x	x	x	x	x		x	x	x
CAMPINA DO MONTE ALEGRE	x	x		x	x	x	x		x	x	x
CAMPINAS	x	x	x	x	x	x	x	x	x	x	x
CAMPO LIMPO PAULISTA	x	x		x	x	x	x		x		x
CAMPOS DO JORDÃO				x			x		x		x
CAMPOS NOVOS PAULISTA				x	x	x			x	x	x
CANAS					x	x					x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
CÂNDIDO MOTA					x	x		x			x
CÂNDIDO RODRIGUES						x				x	x
CANITAR					x	x				x	x
CAPÃO BONITO	x	x	x	x	x	x	x	x	x	x	x
CAPELA DO ALTO	x			x	x	x	x	x	x	x	x
CAPIVARI	x	x		x	x	x	x		x	x	x
CARAGUATATUBA	x				x	x	x		x	x	x
CARAPICUÍBA	x	x	x	x	x	x	x			x	x
CARDOSO								x			
CASA BRANCA	x	x	x	x	x	x	x		x	x	x
CÁSSIA DOS COQUEIROS	x	x	x	x	x	x	x		x		x
CATANDUVA				x	x	x			x	x	x
CATIGUÁ					x	x			x		x
CEDRAL					x	x		x	x		x
CERQUEIRA CÉSAR	x	x	x	x	x	x	x	x	x	x	x
CERQUILHO					x	x	x		x	x	x
CESÁRIO LANGE	x				x	x			x	x	x
CHARQUEADA				x	x	x	x	x	x	x	x
CHAVANTES					x	x				x	x
CLEMENTINA											x
COLINA					x	x	x	x	x	x	x
COLÔMBIA					x	x					x
CONCHAL	x	x	x	x	x	x	x	x	x	x	x
CONCHAS				x	x	x			x	x	x
CORDEIRÓPOLIS	x	x	x	x	x	x	x	x	x	x	x
CORONEL MACEDO	x	x	x	x	x	x	x	x	x	x	x
CORUMBATAÍ	x	x	x	x	x	x	x	x	x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
COSMÓPOLIS	x	x		x	x	x	x	x	x	x	x
COSMORAMA					x	x			x		x
COTIA	x	x	x	x	x	x	x		x	x	x
CRAVINHOS	x	x	x	x	x	x	x	x	x	x	x
CRISTAIS PAULISTA	x	x	x	x	x	x	x	x	x		x
CRUZÁLIA					x			x			x
CRUZEIRO	x	x	x	x	x	x	x		x	x	x
CUBATÃO					x	x	x		x	x	x
CUNHA	x	x	x	x	x	x	x		x		x
DESCALVADO	x	x	x	x	x	x	x		x	x	x
DIADEMA	x	x	x	x	x	x	x		x		x
DIVINOLÂNDIA				x		x			x		x
DOBRADA				x	x	x			x	x	x
DOIS CÓRREGOS	x	x	x	x	x	x	x		x	x	x
DOLCINÓPOLIS						x					x
DOURADO	x	x	x	x	x	x	x			x	x
DUARTINA					x	x			x	x	x
DUMONT	x	x	x	x	x	x	x	x		x	x
ECHAPORÃ				x	x	x		x		x	x
ELIAS FAUSTO	x	x		x	x	x			x	x	x
EMBU	x	x	x	x		x	x		x	x	x
EMBU-GUAÇU	x	x	x	x	x	x	x		x	x	x
ENGENHEIRO COELHO	x	x	x	x	x	x	x		x	x	x
ESPÍRITO SANTO DO PINHAL	x	x	x	x	x	x	x		x	x	x
ESPÍRITO SANTO DO TURVO					x	x	x	x	x		x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
ESTIVA GERBI	x	x	x	x	x	x	x		x	x	x
ESTRELA D'OESTE						x				x	x
EUCLIDES DA CUNHA PAULISTA					x						
FARTURA				x		x			x		x
FERNANDO PRESTES					x	x			x	x	x
FERNANDÓPOLIS						x				x	x
FERNÃO		x	x		x	x	x	x	x	x	x
FLOREAL						x					x
FLÓRIDA PAULISTA					x						
FLORÍNIA								x			
FRANCA	x	x	x	x	x	x	x		x	x	x
FRANCISCO MORATO	x	x	x	x	x	x					
FRANCO DA ROCHA	x	x	x	x	x	x	x		x	x	x
GABRIEL MONTEIRO						x					x
GÁLIA	x	x	x	x	x	x	x	x	x	x	x
GARÇA	x	x	x	x	x	x	x	x	x	x	x
GAVIÃO PEIXOTO				x	x	x			x		x
GETULINA					x	x					x
GUAIÇARA					x						
GUAIMBÊ					x						
GUAÍRA					x	x				x	x
GUAPIAÇU					x	x			x	x	x
GUAPIARA	x	x	x	x	x	x	x		x	x	x
GUARÁ	x	x		x	x	x	x		x	x	x
GUARACI					x	x			x		x
GUARANI D'OESTE						x					x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
GUARANTÃ					x	x				x	x
GUARAREMA	x	x	x	x	x	x	x		x	x	x
GUARATINGUETÁ	x	x	x	x	x	x	x		x	x	x
GUAREÍ	x	x	x	x	x	x	x	x	x	x	x
GUARIBA	x			x	x	x	x		x	x	x
GUARULHOS	x	x	x	x	x	x	x		x	x	x
GUATAPARÁ	x	x		x	x	x	x	x		x	x
HERCULÂNDIA					x	x					x
HOLAMBRA	x	x		x	x	x	x	x		x	x
HORTOLÂNDIA	x	x		x	x	x	x	x		x	x
IACANGA					x	x		x		x	x
IARAS	x	x	x	x	x	x	x	x	x	x	x
IBATÉ	x	x	x	x	x	x	x	x	x	x	x
IBIRÁ					x	x				x	x
IBIRAREMA					x			x			x
IBITINGA					x	x					x
IBIÚNA	x	x	x	x	x	x	x		x		x
ICÉM						x		x			x
IEPÊ					x			x			x
IGARAÇU DO TIETÊ					x	x		x			x
IGARAPAVA	x	x		x	x	x	x	x		x	x
IGARATÁ	x	x	x	x	x	x	x		x	x	x
INDAIATUBA				x	x	x	x		x	x	x
INDIANA								x			
INÚBIA PAULISTA						x					
IPAUSSU	x	x		x	x	x				x	x
IPERÓ					x	x				x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
IPEÚNA				x	x	x	x		x	x	x
IPIGUÁ					x	x		x	x		x
IPORANGA					x				x		
IPUÃ				x		x			x	x	x
IRACEMÁPOLIS				x	x	x	x				x
IRAPUÃ					x	x					x
IRAPURU									x		
ITABERÁ	x	x	x	x	x	x	x	x	x	x	x
ITAÍ	x	x	x	x	x	x	x		x	x	x
ITAJOBI						x					x
ITAJU					x	x				x	x
ITAPECERICA DA SERRA	x	x	x	x	x	x	x		x	x	x
ITAPETININGA	x	x	x	x	x	x	x		x	x	x
ITAPEVA	x	x	x	x	x	x	x	x	x	x	x
ITAPEVI	x	x	x	x	x	x	x		x	x	x
ITAPIRA	x	x	x	x	x	x	x		x	x	x
ITÁPOLIS						x					x
ITAPORANGA	x			x	x	x	x		x	x	x
ITAPUÍ					x	x		x			x
ITAQUAQUECETUBA	x	x	x	x	x	x	x		x	x	x
ITARARÉ	x	x	x	x	x	x	x	x	x	x	x
ITATIBA	x	x	x	x	x	x	x		x	x	x
ITATINGA	x	x	x	x	x	x	x		x	x	x
ITIRAPINA	x	x	x	x	x	x	x	x	x	x	x
ITIRAPUÃ	x	x	x	x	x	x	x		x		x
ITOBI	x	x		x	x	x	x		x	x	x
ITU	x	x	x	x	x	x	x		x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
ITUPEVA	x	x	x	x	x	x	x		x	x	x
ITUVERAVA	x	x		x	x	x	x		x	x	x
JABORANDI					x	x	x			x	x
JABOTICABAL	x	x		x	x	x	x		x	x	x
JACAREÍ	x	x		x	x	x	x		x	x	x
JACI					x	x			x	x	x
JAGUARIÚNA	x	x	x	x	x	x	x		x	x	x
JALES						x					x
JAMBEIRO	x	x	x	x	x	x	x		x	x	x
JANDIRA				x	x	x			x	x	x
JARDINÓPOLIS	x	x	x	x	x	x	x	x	x	x	x
JARINU	x	x	x	x	x	x	x		x	x	x
JAÚ	x	x		x	x	x	x	x	x	x	x
JERIQUARA	x	x	x	x	x	x	x	x	x		x
JOANÓPOLIS	x	x	x	x	x	x	x		x		x
JOÃO RAMALHO					x	x			x	x	x
JOSÉ BONIFÁCIO					x	x					x
JÚLIO MESQUITA	x				x	x	x			x	x
JUMIRIM					x	x				x	x
JUNDIAÍ	x	x	x	x	x	x	x		x	x	x
JUQUITIBA				x	x	x	x		x	x	x
LAGOINHA	x	x	x	x	x	x	x		x		x
LARANJAL PAULISTA					x	x				x	x
LAVRINHAS				x	x	x	x		x		x
LEME	x	x		x	x	x	x		x	x	x
LENÇÓIS PAULISTA	x	x		x	x	x	x	x	x	x	x
LIMEIRA	x	x	x	x	x	x	x	x	x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
LINDÓIA				x	x	x	x		x	x	x
LINS					x				x	x	x
LORENA					x	x	x			x	x
LOUVEIRA	x	x	x	x	x	x	x		x	x	x
LUCIANÓPOLIS					x	x	x	x		x	x
LUÍS ANTÔNIO	x	x	x	x	x	x	x	x	x	x	x
LUPÉRCIO	x	x	x	x	x	x	x	x		x	x
LUTÉCIA					x	x			x	x	x
MACATUBA					x	x		x	x	x	x
MACAUBAL					x					x	
MACEDÔNIA						x			x		x
MAGDA						x					x
MAIRINQUE	x	x	x	x	x	x	x		x	x	x
MAIRIPORÃ	x	x	x	x	x	x	x		x	x	x
MANDURI	x	x	x	x	x	x	x		x	x	x
MARABÁ PAULISTA										x	
MARACAÍ					x	x		x			x
MARÍLIA	x			x	x	x	x		x	x	x
MARTINÓPOLIS					x	x		x		x	x
MATÃO				x	x	x	x		x	x	x
MAUÁ	x	x	x	x	x	x	x		x		x
MENDONÇA					x	x					x
MERIDIANO						x				x	
MIGUELÓPOLIS					x	x				x	x
MINEIROS DO TIETÊ	x	x		x	x	x	x		x	x	x
MIRA ESTRELA										x	
MIRANTE DO					x						

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
PARANAPANEMA											
MIRASSOL				x	x	x	x	x		x	x
MIRASSOLÂNDIA					x			x		x	x
MOCOCA	x			x	x	x	x		x	x	x
MOGI DAS CRUZES	x	x	x	x	x	x	x		x	x	x
MOGI GUAÇU	x	x	x	x	x	x	x	x	x	x	x
MOJI MIRIM	x	x	x	x	x	x	x		x	x	x
MOMBUCA				x	x	x					x
MONÇÕES						x					
MONTE ALEGRE DO SUL				x	x	x			x	x	x
MONTE ALTO	x	x	x	x	x	x	x		x	x	x
MONTE APRAZÍVEL					x	x		x	x	x	x
MONTE AZUL PAULISTA					x	x	x		x	x	x
MONTE MOR					x	x	x			x	x
MONTEIRO LOBATO	x	x	x	x		x	x		x	x	x
MORRO AGUDO				x	x	x			x	x	x
MORUNGABA	x	x	x	x	x	x	x		x		x
NANTES					x			x		x	
NARANDIBA								x			
NATIVIDADE DA SERRA	x	x	x	x	x	x	x		x		x
NAZARÉ PAULISTA	x	x	x	x	x	x	x		x	x	x
NEVES PAULISTA					x	x		x		x	x
NHANDEARA					x	x				x	x
NIPOÃ						x		x		x	
NOVA ALIANÇA					x			x			
NOVA CAMPINA			x	x		x	x	x	x		x
NOVA EUROPA					x	x			x		x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
NOVA GRANADA					x	x			x	x	x
NOVA ODESSA	x	x		x	x	x	x	x	x	x	x
NOVO HORIZONTE						x					x
NUPORANGA	x	x	x	x	x	x	x		x		x
OCAUÇU				x	x	x					x
ÓLEO	x	x		x	x	x	x		x	x	x
OLÍMPIA					x	x			x	x	x
ONDA VERDE					x	x			x		x
ORIENTE	x			x	x	x	x			x	x
ORINDIÚVA					x			x			
ORLÂNDIA	x	x	x	x	x	x			x	x	x
OSASCO	x	x	x	x	x	x	x		x	x	x
OSCAR BRESSANE					x	x		x			x
OURINHOS						x				x	x
OUROESTE						x					x
PALESTINA					x	x		x	x	x	x
PALMARES PAULISTA					x	x			x	x	x
PALMITAL				x	x	x		x	x	x	x
PARAGUAÇU PAULISTA					x	x	x	x	x	x	x
PARAIBUNA	x	x	x	x	x	x	x		x	x	x
PARAÍSO					x	x			x	x	x
PARANAPANEMA	x	x	x	x	x	x	x	x	x	x	x
PARAPUÃ						x				x	x
PARDINHO	x	x	x	x	x	x	x		x	x	x
PATROCÍNIO PAULISTA	x	x	x	x	x	x	x		x	x	x
PAULÍNIA	x	x	x	x	x	x	x	x	x	x	x
PAULISTÂNIA				x	x	x	x	x	x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
PAULO DE FARIA					x	x		x			x
PEDERNEIRAS				x	x	x	x	x	x	x	x
PEDRA BELA				x			x				x
PEDRANÓPOLIS						x					
PEDREGULHO	x	x	x	x	x	x	x	x	x	x	x
PEDREIRA	x	x	x	x	x	x	x		x	x	x
PENÁPOLIS					x						
PEREIRAS	x				x	x			x	x	x
PIEDADE	x	x	x	x	x	x	x		x	x	x
PILAR DO SUL	x	x	x	x	x	x	x		x	x	x
PINDAMONHANGABA				x	x	x	x		x	x	x
PINDORAMA					x	x			x	x	x
PINHALZINHO	x	x	x	x	x	x	x		x		x
PIQUETE				x	x	x	x		x	x	x
PIRACAIA	x	x	x	x	x	x	x		x		x
PIRACICABA	x			x	x	x	x	x	x	x	x
PIRAJU	x	x		x	x	x	x		x	x	x
PIRAJUÍ					x	x				x	x
PIRANGI					x	x	x		x	x	x
PIRAPORA DO BOM JESUS	x	x	x	x	x	x	x		x	x	x
PIRAPOZINHO						x		x			x
PIRASSUNUNGA	x	x	x	x	x	x	x	x	x	x	x
PIRATININGA	x			x	x	x	x	x	x	x	x
PITANGUEIRAS				x	x	x			x	x	x
PLANALTO					x				x		
PLATINA					x	x		x		x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
POÁ				x	x	x					
POLONI					x	x		x	x	x	x
POMPÉIA					x	x			x	x	x
PONGAÍ						x					x
PONTAL					x	x				x	x
PONTES GESTAL						x		x			
POPULINA						x					x
PORANGABA				x	x	x	x		x	x	x
PORTO FELIZ	x	x		x	x	x	x		x	x	x
PORTO FERREIRA	x	x	x	x	x	x	x	x	x	x	x
POTIRENDABA					x	x		x			
PRADÓPOLIS					x	x	x	x			x
PRATÂNIA	x	x	x	x	x	x	x		x	x	x
PRESIDENTE ALVES					x	x			x	x	x
PRESIDENTE PRUDENTE					x						
PROMISSÃO					x						
QUADRA	x		x	x	x	x			x	x	x
QUATÁ					x	x			x		x
QUEIROZ					x						
QUELUZ				x	x	x	x		x	x	x
QUINTANA					x	x					x
RAFARD	x				x	x			x	x	x
RANCHARIA					x	x		x		x	x
REDENÇÃO DA SERRA	x	x	x	x	x	x	x		x	x	x
REGENTE FEIJÓ					x	x		x	x	x	x
REGINÓPOLIS					x	x			x		x
RESTINGA	x	x	x	x	x	x	x		x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
RIBEIRA									x		
RIBEIRÃO BONITO	x	x	x	x	x	x	x	x	x	x	x
RIBEIRÃO BRANCO	x	x	x	x	x	x	x		x	x	x
RIBEIRÃO CORRENTE	x	x	x	x	x	x	x		x		x
RIBEIRÃO DO SUL					x	x					
RIBEIRÃO GRANDE	x	x	x	x	x	x	x		x	x	x
RIBEIRÃO PIRES	x	x	x	x	x	x	x		x	x	x
RIBEIRÃO PRETO	x	x	x	x	x	x	x	x	x	x	x
RIFAINA				x	x	x		x		x	x
RINCÃO	x	x		x	x	x	x	x	x	x	x
RIO CLARO	x	x	x	x	x	x	x	x	x	x	x
RIO DAS PEDRAS	x			x	x	x	x		x	x	x
RIO GRANDE DA SERRA	x			x	x	x	x		x	x	x
RIOLÂNDIA					x	x	x	x		x	x
RIVERSUL				x	x	x	x		x	x	x
ROSEIRA					x	x	x			x	x
SALES					x						
SALES OLIVEIRA	x	x	x	x	x	x	x		x	x	x
SALESÓPOLIS	x	x	x	x	x	x	x		x	x	x
SALTINHO	x		x		x	x	x		x	x	x
SALTO				x	x	x	x		x	x	x
SALTO DE PIRAPORA	x	x	x	x	x	x	x		x	x	x
SALTO GRANDE					x						
SANTA ADÉLIA					x	x			x	x	x
SANTA BÁRBARA D'OESTE					x	x	x		x	x	x
SANTA BRANCA	x	x	x	x	x	x	x		x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
SANTA CRUZ DA CONCEIÇÃO	x	x	x	x	x	x	x		x	x	x
SANTA CRUZ DA ESPERANÇA	x	x	x	x	x	x	x	x		x	x
SANTA CRUZ DAS PALMEIRAS	x	x	x	x	x	x	x	x	x	x	x
SANTA CRUZ DO RIO PARDO				x	x	x	x		x	x	x
SANTA ERNESTINA				x	x	x			x	x	x
SANTA GERTRUDES	x	x		x	x	x	x	x	x	x	x
SANTA ISABEL	x	x	x	x	x	x	x		x	x	x
SANTA LÚCIA	x	x	x	x	x	x	x	x	x	x	x
SANTA MARIA DA SERRA				x	x	x	x	x		x	x
SANTA RITA DO PASSA QUATRO	x	x	x	x	x	x	x	x	x	x	x
SANTA ROSA DE VITERBO	x	x	x	x	x	x	x	x	x	x	x
SANTANA DE PARNAÍBA	x	x	x	x	x	x	x		x	x	x
SANTO ANDRÉ	x	x	x	x	x	x	x		x		x
SANTO ANTÔNIO DA ALEGRIA	x	x	x	x	x	x	x		x	x	x
SANTO ANTÔNIO DE POSSE	x	x		x	x	x	x	x	x	x	x
SANTO ANTÔNIO DO JARDIM	x	x	x	x	x	x	x		x		x
SANTO ANTÔNIO DO PINHAL	x	x	x	x		x	x		x		x
SÃO BENTO DO SAPUCAÍ	x	x	x	x	x	x	x		x		x
SÃO BERNARDO DO CAMPO	x	x	x	x	x	x	x		x	x	x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
SÃO CARLOS	x	x	x	x	x	x	x	x	x	x	x
SÃO JOÃO DA BOA VISTA	x	x	x	x	x	x	x		x	x	x
SÃO JOAQUIM DA BARRA			x	x	x	x			x	x	x
SÃO JOSÉ DA BELA VISTA	x	x	x	x	x	x	x		x	x	x
SÃO JOSÉ DO BARREIRO					x	x	x		x	x	x
SÃO JOSÉ DO RIO PARDO	x	x	x	x	x	x	x		x	x	x
SÃO JOSÉ DO RIO PRETO					x	x		x			x
SÃO JOSÉ DOS CAMPOS	x	x	x	x	x	x	x		x	x	x
SÃO LOURENÇO DA SERRA	x	x	x	x		x	x		x		x
SÃO LUÍS DO PARAITINGA	x	x	x	x	x	x	x		x	x	x
SÃO MANUEL	x	x	x	x	x	x	x		x	x	x
SÃO MIGUEL ARCANJO	x	x	x	x	x	x	x		x	x	x
SÃO PAULO	x	x	x	x	x	x	x		x	x	x
SÃO PEDRO	x	x	x	x	x	x	x	x	x	x	x
SÃO PEDRO DO TURVO					x	x					x
SÃO ROQUE	x	x	x	x	x	x	x		x	x	x
SÃO SEBASTIÃO									x		
SÃO SEBASTIÃO DA GRAMA				x		x			x		x
SÃO SIMÃO	x	x	x	x	x	x	x	x	x	x	x
SÃO VICENTE	x	x			x	x	x		x		x
SARAPUÍ					x	x			x	x	x
SARUTAIÁ	x	x		x	x	x	x		x	x	x
SEBASTIANÓPOLIS DO SUL					x	x					

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
SERRA AZUL	x			x	x	x	x	x		x	x
SERRA NEGRA	x	x		x	x	x	x		x	x	x
SERRANA	x			x	x	x	x	x		x	x
SERTÃOZINHO	x	x	x	x	x	x	x	x	x	x	x
SETE BARRAS						x	x		x		
SEVERÍNIA					x	x	x	x	x	x	x
SILVEIRAS	x	x	x	x	x	x	x		x	x	x
SOCORRO	x	x	x	x	x	x	x		x	x	x
SOROCABA	x	x	x	x	x	x	x		x	x	x
SUMARÉ	x			x	x	x	x		x	x	x
SUZANO	x	x	x	x	x	x	x		x	x	x
TABAPUÃ					x	x			x	x	x
TABATINGA						x				x	x
TACIBA					x	x		x			x
TAGUAÍ					x	x				x	x
TAIAÇU						x					x
TAIÚVA	x				x	x			x	x	x
TAMBAÚ	x	x	x	x	x	x	x	x	x	x	x
TANABI					x	x			x	x	x
TAPIRAÍ	x	x	x	x	x	x	x		x		x
TAPIRATIBA				x		x			x	x	x
TAQUARAL					x	x			x	x	x
TAQUARITINGA	x			x	x	x			x	x	x
TAQUARITUBA	x	x	x	x	x	x	x		x	x	x
TAQUARIVAÍ	x	x	x	x	x	x	x	x	x	x	x
TARABAI					x						
TARUMÃ					x	x		x			x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
TATUÍ	x	x		x	x	x	x		x	x	x
TAUBATÉ	x	x	x	x	x	x	x		x	x	x
TEJUPÁ	x	x		x	x	x	x		x	x	x
TEODORO SAMPAIO					x		x				
TERRA ROXA					x	x				x	x
TIETÊ	x			x	x	x			x	x	x
TIMBURI	x	x	x	x	x	x	x			x	x
TORRE DE PEDRA						x			x		x
TORRINHA	x	x	x	x	x	x	x	x	x	x	x
TRABIJU					x	x					x
TREMEMBÉ				x	x	x	x			x	x
TUIUTI	x	x	x	x	x	x	x		x		x
TUPÃ						x				x	x
TURIÚBA						x					x
TURMALINA						x					
UBATUBA									x		
UBIRAJARA					x	x		x			x
UCHOA					x	x			x		x
UNIÃO PAULISTA					x					x	
URÂNIA						x					x
URUPÊS					x						
VALENTIM GENTIL						x					x
VALINHOS	x	x	x	x	x	x	x	x	x	x	x
VARGEM	x	x	x	x	x	x	x		x		x
VARGEM GRANDE DO SUL	x	x	x	x	x	x			x	x	x
VARGEM GRANDE	x	x	x	x	x	x	x		x		x

Municipalities	CM_All	CM_AllnoHydro	CM_Threat	CB	CT	HH	LP	LV	MT	PC	TT
PAULISTA											
VÁRZEA PAULISTA	x	x	x	x	x	x	x			x	x
VERA CRUZ	x	x		x	x	x	x			x	x
VINHEDO	x	x	x	x	x	x	x		x	x	x
VIRADOURO					x	x			x		x
VISTA ALEGRE DO ALTO				x	x	x			x	x	x
VITÓRIA BRASIL						x					x
VOTORANTIM	x	x	x	x	x	x	x		x	x	x
VOTUPORANGA					x	x					x

Appendix G. Address information for roadkill clusters of all mammal species combined with cluster intensity equal as Medium, High and Very High. Length_m = Length in meters.

ID	Cluster_Intensity	Road	Km_Initial	Km_Final	Lenght_M	X_Coord_Initial	Y_Coord_Initial	X_Coord_Final	Y_Coord_Final
1	Medium	SP-019	002+000	002+200	217.71	-46.490435	-23.453837	-46.491168	-23.451991
2	Medium	SP-063	002+029	002+033	13.12	-46.949589	-23.089788	-46.949602	-23.08967
3	High	SP-191	003+000	003+100	97.38	-47.026119	-22.431577	-47.02706	-22.431496
4	Medium	SP-191	005+001	005+200	194.69	-47.041181	-22.423019	-47.043018	-22.4226
5	Medium	SP-191	010+800	011+001	197.27	-47.088388	-22.402174	-47.089848	-22.401021
6	Medium	SP-255	012+400	011+880	603.16	-47.815164	-21.297398	-47.812607	-21.29251
7	Medium	SP-063	014+000	014+100	100.28	-46.859589	-23.044859	-46.858742	-23.044406
8	Medium	SP-127	020+200	019+800	406.57	-47.598201	-22.615084	-47.597317	-22.611507
9	Medium	SP-101	038+000	037+792	229.85	-47.428356	-23.001036	-47.426155	-23.001419
10	Medium	SP-330	045+793	046+003	197.80	-46.865655	-23.292512	-46.865522	-23.29073
11	Medium	SP-270	046+903	047+200	245.55	-47.045042	-23.598027	-47.047432	-23.597806
12	Medium	SP-270	047+800	048+200	396.14	-47.052485	-23.596991	-47.055631	-23.59569
13	Medium	SP-147	048+000	046+801	1215.75	-46.867115	-22.453039	-46.855412	-22.45243
14	Medium	SP-191	056+401	057+001	535.80	-47.473602	-22.375351	-47.478595	-22.374
15	Medium	SP-191	057+800	058+001	180.67	-47.485213	-22.372209	-47.486897	-22.371754
16	Medium	SP-330	057+814	058+000	192.26	-46.902519	-23.200678	-46.902969	-23.199
17	Medium	SP-075	062+000	062+100	103.48	-47.144286	-23.053049	-47.143588	-23.052374
18	High	SP-147	064+200	063+800	400.63	-47.000984	-22.443055	-46.997428	-22.441587
19	Medium	SP-147	068+100	067+800	301.50	-47.038391	-22.44295	-47.0355	-22.443386
20	Medium	SP-147	069+202	068+800	386.10	-47.048799	-22.441666	-47.045069	-22.441943
21	Medium	SP-147	070+200	069+800	399.86	-47.056434	-22.446693	-47.053598	-22.444226
22	Medium	SP-300	073+800	074+100	324.14	-47.021176	-23.217308	-47.023391	-23.2194
23	Medium	SP-333	074+434	327+400	611.47	-47.909043	-21.166918	-47.914885	-21.166794
24	Medium	SP-270	076+800	077+153	352.89	-47.256648	-23.51774	-47.258808	-23.515324
25	Medium	SP-270	077+990	078+200	231.88	-47.266953	-23.514864	-47.269203	-23.514601

ID	Cluster_Intensity	Road	Km_Initial	Km_Final	Lenght_M	X_Coord_Initial	Y_Coord_Initial	X_Coord_Final	Y_Coord_Final
26	High	SP-147	080+000	079+800	202.03	-47.143199	-22.473305	-47.141248	-22.473501
27	Medium	SP-300	084+999	085+196	199.88	-47.117168	-23.263449	-47.119056	-23.263894
28	High	SP-147	094+000	093+801	208.80	-47.274222	-22.496058	-47.272446	-22.49515
29	Medium	SP-147	101+200	101+000	205.66	-47.327169	-22.539959	-47.325971	-22.538473
30	Medium	SP-127	110+200	109+800	407.64	-47.827901	-23.320587	-47.826066	-23.317322
31	High	SP-300	114+805	115+000	194.90	-47.378581	-23.240483	-47.380479	-23.240359
32	Medium	SP-300	119+900	120+000	100.53	-47.424901	-23.230227	-47.425883	-23.230232
33	Medium	SP-300	120+700	121+000	296.90	-47.432597	-23.23026	-47.435497	-23.230279
34	Medium	SP-340	120+801	121+501	689.36	-47.029836	-22.787199	-47.026297	-22.781911
35	Very High	SP-340	121+700	122+195	485.82	-47.025233	-22.780443	-47.022911	-22.776645
36	Medium	SP-280	127+897	128+001	103.61	-47.790067	-23.283675	-47.791079	-23.283673
37	Medium	SP-147	128+001	127+950	52.43	-47.52637	-22.659459	-47.525945	-22.659197
38	High	SP-147	134+302	133+901	383.75	-47.579028	-22.683513	-47.575618	-22.682244
39	Very High	SP-147	135+205	134+800	405.62	-47.585065	-22.689339	-47.582522	-22.686545
40	Medium	SP-147	136+197	135+801	399.46	-47.591714	-22.695665	-47.589528	-22.692707
41	High	SP-147	137+129	136+697	463.18	-47.598575	-22.700658	-47.594404	-22.699232
42	Very High	SP-147	138+500	137+800	696.44	-47.611608	-22.69804	-47.604996	-22.699412
43	Medium	SP-147	139+258	138+700	548.36	-47.618739	-22.697066	-47.613488	-22.697649
44	High	SP-147	140+201	139+801	398.85	-47.62714	-22.69368	-47.623721	-22.695383
45	High	SP-147	141+201	140+688	473.92	-47.635397	-22.693301	-47.631253	-22.691775
46	High	SP-147	142+201	141+807	389.22	-47.641625	-22.69994	-47.638908	-22.697509
47	Medium	SP-300	154+000	154+030	29.77	-47.682821	-23.138027	-47.683079	-23.137904
48	Medium	SP-348	168+000	168+063	63.25	-47.427035	-22.493954	-47.426714	-22.493467
49	Medium	SP-332	170+801	170+999	192.79	-47.176401	-22.424249	-47.175476	-22.422748
50	Medium	SP-332	171+800	172+095	282.32	-47.1731	-22.416136	-47.172628	-22.413641
51	Medium	SP-332	172+800	173+100	292.72	-47.173203	-22.407743	-47.174027	-22.405214
52	Medium	SP-330	176+302	177+101	798.60	-47.392792	-22.297079	-47.393332	-22.289887

ID	Cluster_Intensity	Road	Km_Initial	Km_Final	Lenght_M	X_Coord_Initial	Y_Coord_Initial	X_Coord_Final	Y_Coord_Final
53	Medium	SP-330	183+703	184+202	500.14	-47.391635	-22.230699	-47.391808	-22.226187
54	Medium	SP-330	208+900	209+200	302.86	-47.441777	-22.010213	-47.442662	-22.007607
55	Medium	SP-330	212+951	213+001	52.95	-47.453404	-21.975191	-47.453551	-21.974733
56	High	SP-330	213+600	214+100	502.79	-47.455276	-21.969573	-47.456782	-21.965257
57	Medium	SP-342	214+900	215+200	314.67	-46.82037	-22.074717	-46.820412	-22.071876
58	Medium	SP-350	253+700	254+000	302.47	-46.94237	-21.700437	-46.940622	-21.698248
59	Medium	SP-258	269+100	268+900	208.25	-48.766584	-23.933287	-48.764555	-23.933102
60	Medium	SP-270	387+900	388+200	302.92	-49.940099	-22.896416	-49.942478	-22.894808
61	Medium	SP-270	408+800	409+080	283.05	-50.103751	-22.79049	-50.106165	-22.789272
62	Medium	SP-270	414+800	415+200	403.13	-50.155083	-22.764583	-50.15852	-22.762848

Appendix H. Address information for roadkill clusters of Capybara with cluster intensity equal as Medium, High and Very High. Legend: Length_m = Length in meters.

ID	Cluster_Intensity	Road	Km_Initial	Km_Final	Lenght_M	X_Coord_Initial	Y_Coord_Initial	X_Coord_Final	Y_Coord_Final
1	Medium	SP-019	2+000	2+200	226.88	-46.48992	-23.45366	-46.490649	-23.451816
2	Medium	SP-255	11+880	12+400	622.82	-47.81239	-21.29261	-47.814924	-21.297508
3	Medium	SP-191	56+401	57+001	513.08	-47.47337	-22.37459	-47.478382	-22.373289
4	Medium	SP-191	57+800	58+001	173.01	-47.48501	-22.37156	-47.486708	-22.371119
5	Medium	SP-330	57+814	58+000	201.32	-46.90183	-23.20046	-46.902423	-23.19883
6	Medium	SP-147	63+800	64+100	291.34	-46.99753	-22.44136	-47.000199	-22.442487
7	Medium	SP-127	109+800	110+100	316.23	-47.82593	-23.31739	-47.827311	-23.319841
8	Medium	SP-340	120+801	121+501	706.89	-47.02972	-22.78725	-47.02614	-22.781998
9	Very High	SP-340	121+700	122+195	499.62	-47.02512	-22.78052	-47.022669	-22.776746
10	High	SP-147	134+600	135+205	609.32	-47.58115	-22.6853	-47.585365	-22.689057
11	Medium	SP-147	135+801	136+197	407.59	-47.5895	-22.69274	-47.591386	-22.69578
12	High	SP-147	136+697	137+129	446.52	-47.59453	-22.69897	-47.598512	-22.699993
13	Very High	SP-147	137+700	138+500	758.93	-47.6039	-22.69895	-47.61146	-22.697427
14	Medium	SP-147	138+600	139+258	616.65	-47.6124	-22.69724	-47.61873	-22.696889
15	High	SP-147	139+801	140+201	388.10	-47.62351	-22.69499	-47.626958	-22.693347
16	Medium	SP-147	140+301	141+201	826.36	-47.62782	-22.69294	-47.635435	-22.693281
17	High	SP-147	141+807	142+201	389.32	-47.63858	-22.69781	-47.641536	-22.700045
18	Medium	SP-348	168+000	168+063	64.88	-47.42701	-22.49397	-47.426707	-22.493469
19	Medium	SP-330	176+302	177+101	840.37	-47.39188	-22.297	-47.39256	-22.289828
20	Medium	SP-330	179+161	179+525	364.01	-47.39128	-22.27138	-47.391278	-22.271379
21	Medium	SP-330	183+703	184+003	317.10	-47.39068	-22.23064	-47.390874	-22.227925
22	High	SP-330	213+500	214+100	628.69	-47.45458	-21.97031	-47.456343	-21.965124
23	Medium	SP-350	253+700	254+000	307.62	-46.94239	-21.70043	-46.940666	-21.698218

5. CHAPTER 4: PAY OR PREVENT? HUMAN SAFETY, COSTS TO SOCIETY AND LEGAL PERSPECTIVES ON ANIMAL-VEHICLE COLLISIONS IN SÃO PAULO STATE, BRAZIL

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Capítulo 4: Pagar ou prevenir? Segurança humana, custos para a sociedade e as perspectivas legais em colisões envolvendo animais no Estado de São Paulo, Brasil.

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RESUMO

Mortalidade direta por atropelamento em rodovia e o efeito barreira são tipicamente identificados como uma das maiores ameaças a fauna silvestre. Além disso, colisões com mamíferos de grande porte também afetam a segurança humana e representam custos economicos à sociedade. Nós documentamos e exploramos os efeitos dos acidentes rodoviários envolendo animais na segurança humana no Estado de São Paulo, Brasil. Nós estimamos os custos destes acidentes para a sociedade e nós elencamos as perspectivas legais sobre este assunto. Em média, a Polícia Militar Rodoviária do Estado de São Paulo registrou 2.611 acidentes envolvendo animais por ano (3,3% do total de acidentes), e 18,5% destes acidentes resultaram em vítimas com ferimentos ou vítimas fatais. O custo anual para a sociedade foi estimado em R$ 56.550,64 (US$ 25,144,794). A média do custo de um acidente envolvendo animal independente se gerou vítimas humanas foi de R$ 21,656 (US$ 9,629). O sistema judicial Brasileiro responsabilizou o administrador rodoviário por colisões de animais, tanto com espécies silvestres quanto domésticas em 91,7% dos casos estudados. Em média, os administradores rodoviários gastaram R$ 2,463,380 (US$ 1,005,051) por ano compensando vítimas de acidentes. A conclusão lógica é que o Sistema judiciário Brasileiro espera que os administradores rodoviários mantenham os animais, silvestres e domésticos, fora das rodovias. Nós sugerimos que haja uma melhor coordenação entre as leis que sejam relacionadas as colisões de animais em rodovias e a segurança humana com o processo do licenciamento ambiental focado na redução de colisões de animais silvestres e provisão de aumento de conectividade do habitat. Ainda, nós sugerimos melhores práticas de manejo, aumentando a sensibilização e mudanças sociais sobre animais abandonados como cavalos, bois a cachorros domésticos. Tais ações deverão resultar em um sistema rodoviário com maior segurança humana, redução de mortalidade não natural para animais silvestres e domésticos, aumento de travessias seguras de fauna e redução de custos monetários para a sociedade.

Palavras-chave: Colisões com animais; Rodovias; Segurança humana; Custos financeiros; Compensação financeira; Perspectivas legais

Chapter 4: Pay or prevent? Human safety, costs to society and legal perspectives on animal-vehicle collisions in São Paulo state, Brazil

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ABSTRACT

Direct road mortality and the barrier effect of roads are typically identified as one of the greatest threats to wildlife. In addition, collisions with large mammals are also a threat to human safety and represent an economic cost to society. We documented and explored the effects of animal-vehicle crashes on human safety in São Paulo State, Brazil. We estimated the costs of these crashes to society, and we summarized the legal perspectives. On average, the Military Highway Police of São Paulo reported 2,611 animal-vehicle crashes per year (3.3% of total crashes), and 18.5% of these resulted in human injuries or fatalities. The total annual cost to society was estimated at R$ 56,550,642 (US$ 25,144,794). The average cost for an animal-vehicle crash, regardless of whether human injuries and fatalities occurred, was R$ 21,656 (US$ 9,629). The Brazilian legal system overwhelmingly (91.7 % of the cases) holds the road administrator liable for animal-vehicle collisions, both with wild and domestic species. On average, road administrators spent R$ 2,463,380 (US$ 1,005,051) per year compensating victims. The logical conclusion is that the Brazilian legal system expects road administrators to keep animals, both wild and domestic species, off the road. We suggest an improved coordination between the laws that relate to animal-vehicle collisions and human safety, and the process for environmental licenses that focusses on reducing collisions with wildlife and providing habitat connectivity. In addition, we suggest better management practices, raising awareness and social change with regard to abandoned domesticated animals including horses, cattle, and dogs. This should ultimately result in a road system with improved human safety, reduced unnatural mortality for both domestic and wild animal species, safe crossing opportunities for wildlife, and reduced monetary costs to society.

Keywords: Animal-vehicle collisions; Roads; Human safety; Financial costs; Financial compensation; Legal perspectives

5.1. INTRODUCTION

On a global scale, roads have necessary and important benefits for society as they allow for the transportation of people and goods. However, they also represent one of biggest threats to biodiversity (Forman & Alexander, 1998; Trombulak & Frissell, 2000; Bond & Jones, 2008). For animals, the effects of roads and traffic are varied and range from habitat loss (Forman et al., 2003), direct mortality through collisions with vehicles (Forman & Alexander, 1998; Fahrig & Rytwinski, 2009), barrier effects (Nellemann et al., 2001; Lesbarrères & Fahrig, 2012) and a reduction in habitat quality in a zone adjacent to the road (e.g. noise, lights, pollution, visual disturbance) (Eigenbrod et al., 2009; Forman et al., 2003; Parris et al., 2009).

Animal-vehicle collisions are not only a biological conservation concern, but they are also a threat to human safety and the associated economic costs are high. The total number of large mammal-vehicle collisions (≥ 15 kg) per year has been estimated at one to two million in the United States and about 507,000 in Europe (Conover et al., 1995; Groot Bruinderink & Hazebroek, 1996; Huijser et al., 2008). These types of collisions have increased substantially over the last few decades (Groot Bruinderink & Hazebroek, 1996; Huijser et al., 2008). While specific roads can be part of a research project or a citizen science project, most roads usually only have two sources for animal-vehicle collision data. These two sources each have their own terminology. One source is through law enforcement personnel who report on “animal-vehicle crashes”. Another source is through road maintenance personnel who inspect the roads on a regular basis, including the removal and reporting of “animal carcasses” on and immediately adjacent to the road. We applied this terminology throughout this manuscript; when we refer to crash data, this relates to data collected by law enforcement personnel, whilst carcass data refers to data collected by road maintenance personnel. The combination of these two data types (or other potential sources that include either “animal crash data” or animal carcass removal or observation data) we use the term “collision data”.

Animal-vehicle crashes account for 4-5% of all reported crashes in the United States (NHTSA, 2003; Huijser et al., 2008). However, this percentage can be much higher in rural or natural areas with more abundant habitat and wildlife populations (Bovo et la., 2018; Magioli et al., 2016). For example, in Sweden, ungulate-vehicle-collisions accounted for over 60% of all road accidents reported to the police during the 1990s (Seiler, 2004). In the United States and Europe, most of the large wild mammal-vehicle collisions occur in the fall (October-

December) with a smaller peak in the spring and early summer (May-June) (Groot Bruinderink & Hazebroek, 1996; Huijser et al., 2008).

Large mammal-vehicle collisions predominantly occur in the dark, especially around dusk till midnight, and around dawn (Groot Bruinderink & Hazebroek, 1996; Huijser et al., 2008). In the United States and Canada, 2.8-9.7% of reported deer-vehicle crashes (*Odocoileus* sp.) resulted in human injuries, but the risk increased to 18-23% for larger species such as moose (*Alces americanus*) (Huijser et al., 2009). Similarly, the risk of human fatalities associated with an animal-vehicle collision also increased with the size of the animal; 0.0003% for deer and 0.004% for moose (Huijser et al., 2009).

In the United States, large mammal-vehicle collisions were estimated to cause 211 human fatalities and 29,000 human injuries per year with associated costs between US$ 6-12 billion (Conover et al., 1995; Huijser et al., 2007). In Europe, collisions with ungulates resulted in about 300 human fatalities and 30,000 human injuries per year, and over one billion dollars in vehicle repair costs (Groot Bruinderink & Hazebroek, 1996).

In South America, little information is available on the threat that animal-vehicle collisions pose to human safety and the associated costs to society. However, in 2014, the Brazilian Federal Highway Police reported 3,174 animal-vehicle crashes on the Brazilian Federal Highway system (IPEA, 2015). Animal-vehicle crashes represented 1.9% of all reported crashes, of which 40.9% resulted in human injuries, and 2.6% resulted in human fatalities (IPEA, 2015). This suggests that the probability of an animal-vehicle crash resulting in a human injury or fatality is higher in Brazil than in North America. This may be related to potential differences in the size of the animal species involved, vehicle type, presence and use of seatbelts and airbags, road design characteristics, driving style, and response time of emergency services. Differences in reporting thresholds for animal-vehicle crashes between the United States and Brazil may also be a reason for reports of animal-vehicle crashes

In the United States and Canada, it is typically the more severe animal-vehicle collisions that are included in the crash database. Severe collisions typically include human injuries or fatalities, an estimate of at least US$ 1000 in vehicle repair costs, or a disabled vehicle that needs to be towed (Seiler, 2004). In contrast, in Brazil, for an animal-vehicle collision to be included in the crash database, a collision must be reported to law enforcement personnel, either by the occupants of the vehicle involved in the collision, or by people who happen to pass by the scene of a collision. There are no minimum damage thresholds for an animal-vehicle collision in the crash database in Brazil, which suggests that the thresholds for an animal-vehicle collision to be included in a crash database are lower in Brazil than in the United States and Canada.

Animal species that have been documented as possible greatest concern to human safety on highways in Brazil are lowland tapir (*Tapirus terrestris*), capybara (*Hydrochoerus hydrochoeris*), and large domesticated species such as cattle (*Bos taurus*) and horses (*Equus caballus*) (Bueno et al., 2013; Huijser et al., 2013; Medici et al., 2016), *Pedro Romanini*, Agência de Transporte do Estado de São Paulo (ARTESP), pers. comm., 2018). The vehicle repair costs associated with capybara-vehicle collisions have been estimated at about R$ 2,885 (US $ 1,418, in 2012) (IRS, 2018). Collisions with larger species such as lowland tapir (~200 – 300 kg), cattle (~250 – 750 kg) and horses (~300 – 500 kg), are likely to present a greater threat to human safety and have higher associated costs.

In this paper we document and explore the effects of animal-vehicle crashes on human safety in São Paulo State in Brazil. In addition, we estimate the costs of these animal-vehicle crashes to society, and we summarize the legal perspectives with regard to liability and associated financial compensation for animal-vehicle collisions.

5.2. MATERIALS AND METHODS

5.2.1. Study area

São Paulo State is located in the southeast of Brazil, South America. In general, the region has a tropical climate with seasonal differences in temperature and precipitation (22 - 28 ºC on average; 1450 - 2050 mm precipitation annually) (INMET, 2019). In addition, there are regional differences in weather patterns because of elevation, slope and distance to the Atlantic Ocean. These differences result in varying vegetation cover from the savannah in the interior to the Atlantic forest along the coast (INMET, 2019). São Paulo State is home to approximately 44 million people, 21,6% of the total population in Brazil.

During the 20th century, São Paulo State experienced rapid land use change due to an expansion of urban areas, human population growth and agricultural development, as well as an expansion of existing road networks (33% increase in length between 1988 to 2013) (Dean, 1995). With one of the highest road densities in Brazil, São Paulo State has 0.8 km roads/km^2 (37,000 km paved roads and 163,000 unpaved roads) (IBGE, 2017).

This process has resulted in severe natural habitat loss and fragmentation of two of the world’s biodiversity hotspots, the Brazilian Savanah and Atlantic Forest (Myers et al., 2000). In São Paulo State only 17,5% of the Atlantic Forest and the Brazilian Savanah remain (IF, 2010). Currently, the land use in São Paulo State is dominated by agriculture (~59% - mostly sugar cane, pastures, and eucalyptus plantations) and urban areas (~5%) (IBGE, 2017).

5.2.2. Animal-vehicle crash numbers and temporal patterns

Crash data gathered over an eleven-year period (2003 to 2013) was obtained from the Military Highway Police of São Paulo State (Polícia Militar do Estado de São Paulo - PMRSP). These data comprise a total of 37,000 km of major state highways managed by the transportation agency of São Paulo (Departamento de Estradas de Rodagem (DER)) (~30,500 km) and toll road companies (~ 6,500 km).

The roads managed by DER usually have two lanes (each lane is ~3.5 m wide), narrow or non-existent clear zones, posted legal speed limit varying between 30 to 110 km/h, frequent absence of street lights, and relatively slow and poor medical assistance. In comparison, toll roads tend to be major four lane highways that have been reconstructed over the last few decades (ARTESP, 2018). These highways tend to have wide clear zones, guard rails and median barriers (e.g. concrete Jersey median barriers), street lights in selected areas, and relatively fast and modern medical and mechanical assistance provided by the toll road companies. The traffic volume on toll roads is typically higher than on DER roads, and the posted legal speed limit usually varies between 80 -120 km/h) (ARTESP, 2018).

For animal-vehicle crashes, the following parameters were recorded: date, time, municipality, road name or number, road administrator (toll road company or DER), location based on km post, vehicle type, number of vehicles involved in the crash, number of humans with minor or severe injuries, and number of human fatalities. Crash data did not include information on the animal species involved, nor whether the species was wild or domesticated.

The vehicle type categories included bicycle, motorcycle, passenger car, pick-up truck, truck, bus and other (semi-truck).The victim categories included: 1) no victims: driver and potential occupants of the vehicle do not present physical injuries or unconsciousness; 2) minor injuries: minor physical injuries or post-traumatic stress disorder; 3) severe injuries: Incapacitating physical injuries, unconsciousness and, 4) fatalities: driver or occupants of the vehicle die on site or later because of the crash.

For a crash to be included in the PMRSP database, the crash had to be reported to law enforcement personnel. Vehicle occupants involved in a crash, or people who happen to pass by the scene of a crash can make a request by phone to law enforcement for assistance and for issuing a police report of the crash. Each crash is recorded only once; there is no possibility for duplicates for the crash records collected by the PMRSP, in addition, the reporting effort remained the same throughout the study period. Note that the number of crashes in the PMRSP dataset is only a small portion of the number of animal carcasses that are removed from the highways by road maintenance personnel because most of the animal-vehicle collisions are not reported to PMRSP. From 2003 to 2013, the total number of animal-vehicle crashes (domestic and wild species combined) in the PMRSP dataset was 28,724 (average of 2,611 animal-vehicle crashes per year), whilst the toll road companies reported 32,258 carcasses (average of 3,584 carcasses per year) of wild mammal species [29] between 2005-2013 (1.4 times that of the reported crashes by the PMRSP). Note the toll roads only covered 17.6% of the total road length covered by the PMRSP, 6,500 km of toll roads out of a total of 37,000 km of roads). These carcass removal data were obtained by toll road maintenance personnel that checked the general road condition, including the potential presence of animal carcasses, at least once every three hours, on a daily basis. This illustrates that not every animal that is hit by a vehicle results in substantial vehicle damage or human injuries and fatalities, nor does it result in a request for police assistance, or a record in the crash database of the PMRSP.

5.2.3. Data analyses

5.2.3.1. Animal-vehicle crash numbers and temporal patterns

We conducted an exploratory analysis and calculated the percentage of animal-vehicle crashes for all reported crashes in São Paulo State based on the PMRSP crash database. We calculated the total number of animal-vehicle crashes, the number of crashes with human injuries and fatalities, and the frequency distribution for both time of day and month, by road administrator (managed by either toll road companies or DER), and by vehicle type. We ran two linear regression analyses to investigate potential changes in the total number of crashes (all types of crashes) and the number of animal-vehicle crashes for the data period (2003-2013).

5.2.3.2. Costs of animal-vehicle crashes to society

Based on the animal-vehicle crashes in the PMRSP database and the IPEA report "Traffic Accidents along Brazilian Federal Roads: Characterization, Trends and Costs to Society" (IPEA, 2015), we calculated the costs associated with each of the reported animal-vehicle crashes between 2003-2013.

The costs of an animal-vehicle crash in the IPEA report is based on three cost components; costs associated with people, vehicles, and public service and damage to public property (Table 1). We summarized the costs for each component by vehicle type in S1 Table.

Table 1. Description of components for each category of costs (IEPA, 2015).

People costs	**Vehicle costs**	**Public service and public property costs**
Pre-hospital care	Vehicle removal	Crash assistance
Hospital care	Material damage	Property damage to road or roadside objects
Post-hospital care	Commercial cargo loss (if applicable)	-
Loss of productivity		-
Transport of victim	-	-

For crashes without human injuries or fatalities, the IPEA report (IPEA, 2015) provides cost estimates based on associated cost with people, vehicles, and public service and public property damage. For example, even when there is no victim with apparent injuries, there is still a cost associated when there is a loss of productivity in cases of psychological trauma that may require professional treatment. Furthermore, vehicle costs include vehicle removal and vehicle repair costs, and costs associated with the loss of commercial cargo. Public service and public property damage relate to crash assistance by law enforcement, road management, and road assistance personnel, and repair costs to the road or roadside objects such as signs or guard rails. We calculated the costs of crashes without victims based on the values summarized in S2 Table.

For crashes with one or more human injuries or human fatalities, and crashes that involved multiple vehicles, the data did not specify what vehicle type the human injuries and fatalities related to. Since the associated costs depend on the vehicle type (see S3 Table)

(IPEA, 2015), we allocated the costs associated with human injuries and fatalities to the smallest vehicle type involved in the crash (e.g. bicycle < motorcycle < car < pick-up truck < truck < bus < other). This resulted in a conservative (i.e. low – see S2 Table) cost estimate of the crash as we erred towards the smaller vehicle types which have lower costs associated with a crash than the larger vehicle types. If there were multiple human injuries or fatalities, we allocated potential human fatalities and human injuries to the smallest vehicle type, up to the maximum number of occupants for that type of vehicle (see S3 Table).

Additional human fatalities were allocated to the second smallest vehicle and so forth. For example, if the crash included an animal, and both a motorcycle and a passenger car, and if the crash resulted in one human fatality and two humans with severe injuries, we allocated the costs associated with the human fatality and one human with severe injuries to the motorcycle (the maximum number of occupants for a motorcycle was set at two) and the costs associated with the second human with severe injuries to the passenger car (the maximum number of occupants for a passenger car was set at five). The costs for each type of accident with or without human injuries and fatalities was based on the values summarized in S2 Table.

5.2.3.3. Legal perspectives and financial compensation

We examined records of the Court of Appeal of the State of São Paulo (TJSP – Tribunal de Justiça do Estado de São Paulo - 2° instância) and selected court cases that related to animal-vehicle collisions. We investigated which laws and legal perspectives were applied in court cases where plaintiffs requested financial compensation for the damage and losses associated with an animal-vehicle collision.

Though other courts in São Paulo State (e.g. Small Claims Court (Juizado Especial de Pequenas Causas) and the 1st Instance of the Court of the State of São Paulo (Tribunal de Justiça do Estado de Sao Paulo – 1° instância)), may judge similar cases, we argue that TJSP´s decisions are most relevant for the purpose of this article because those case laws supersede decisions from the small claims court and the 1st Instance Court, the arguments of the plaintiffs and defendants are better developed since they have already been processed through other courts, and we were able to access the position of the court with regard to where the legal responsibility lies for animal-vehicle collisions based on the laws in São Paulo State. In addition, the decisions by the judges of TJSP were available in electronic format which allowed us to select and investigate a large number of cases.

We searched the TJSP database with the following Portuguese keywords: “animal”, “acidente”, “rodovia” and “colisão” and identified 2,261 court cases. For a case to be included in our analyses, it had to meet the following criteria:

1) The collision occurred on a paved road;
2) The collision involved at least one vehicle and one animal (domesticated or wild species);
3) The road administrator (toll road company or DER) was the defendant;

These criteria resulted in 797 court cases, from which we created a database with the following parameters for each court case (if specified in the documents): year of the verdict, road administrator (managed by either a toll road company or DER), animal species or species group involved in the accident, verdict of the court, laws and regulations on which the verdict was based, and the total amount of R$ awarded to the plaintiffs. We calculated the number of cases and human fatalities per year and per road administrator type (i.e. toll road companies or DER). We also listed the animal species or species groups involved with the collisions and we summarized the costs in a box plot for species with at least 10 court cases.

For each court case we identified the total amount awarded by the court (if specified in the documents). The awarded amounts can consist of the following components: i) moral and mental suffering (impact on psychological, moral and intellectual mood, whether by offense to their honor, their privacy, intimacy, image, name or in their own physical body), ii) physical injuries and aesthetics (direct offense to the physical integrity of the human person), iii) material damage (damage caused to material property), and iv) loss of income (losses caused by the interruption of work and associated income).

In addition to these four components, the awarded amount can also include compensation for legal fees and a life pension (pensão vitalícia). Brazilian courts can award a life pension in cases where a person is disabled or killed because of the actions of another party (see S4 Text for further details). However, most verdicts do not specify amounts for the compensation for legal fees and a life pension. Instead they refer to the 1st Instance of the Court of the State of São Paulo to calculate the amounts based on certain guidelines. Therefore, for our analyses, we excluded awarded amounts that related to legal fees and a life pension and, the awarded values we used for our analyses represent a very conservative estimate of the costs associated with animal-vehicle collisions. Whilst we recognize that this method of analysis has limitations, we believe that this does not influence the main points we make in this article; animal-vehicle collisions are a threat to human safety, there is an economic cost associated with these animal-vehicle collisions to society, and there is a legal perspective on the responsibility for these types of collisions.

5.3. RESULTS

5.3.1. Animal-vehicle crash numbers and temporal patterns

Over an eleven-year period (2003-2013), the PMRSP database included 889,797 records of crashes (all types) in São Paulo State, including 28,724 (3.3%) animal-vehicle crashes (Fig. 1).

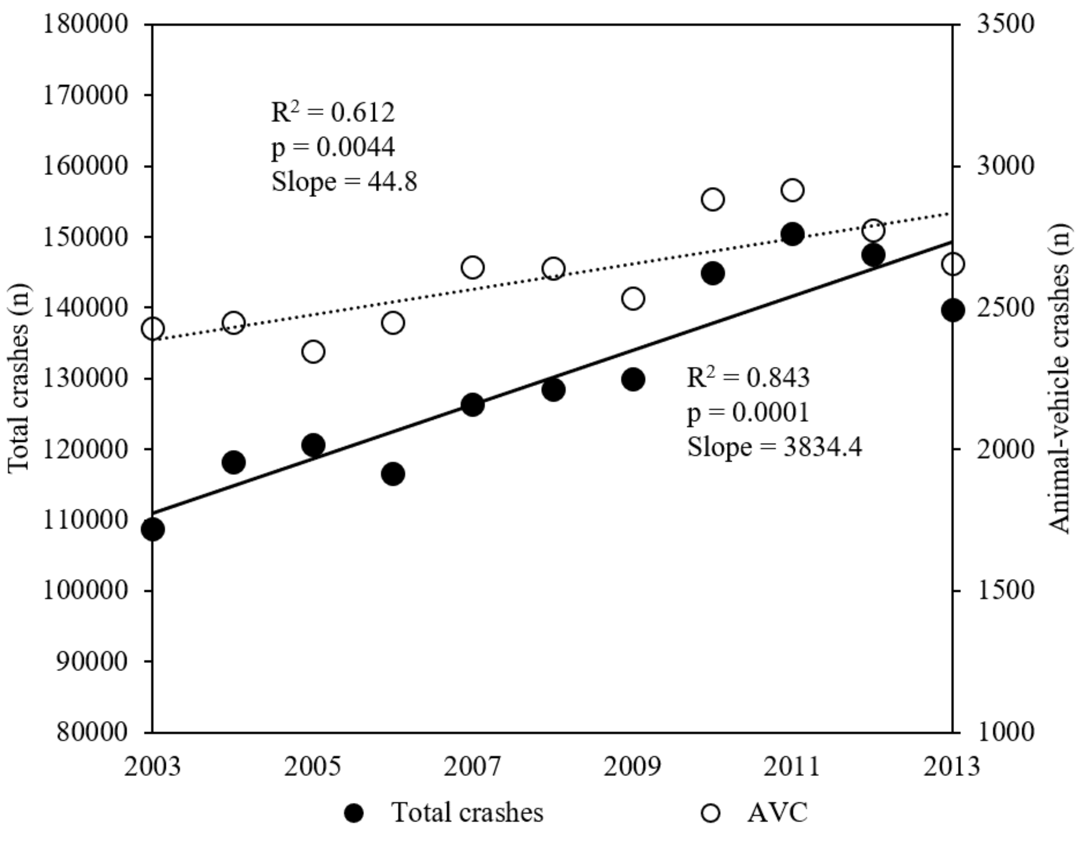

Figure 1. Results of linear regressions models. Dots represent the total number of crashes (all types) and animal-vehicle crashes (AVC) per year (from 2003-2013) on both private and public state roads in São Paulo State.

On average, there were 2,611 reported animal-vehicle crashes per year (minimum number 2,347, maximum number 2,916), resulting in an average of 483 crashes (18.5%) involving human injuries or fatalities. Based on the regression analyses there was an average increase of 3,834.4 total reported crashes per year (R^2 = 0.84, p = 0.0001) and an average increase of 44.8 reported animal-vehicle crashes per year (R^2 = 0.61, p = 0.004) (Fig. 1). The crashes with human victims resulted in a yearly average of 531 humans with minor injuries, 116 humans with severe injuries, and 20 human fatalities.

Animal-vehicle crashes with bicycles and motorcycles almost always resulted in human injuries and fatalities (> 90% of cases; Fig. 2). There were 201 crashes with human fatalities, regardless of vehicle type. Motorcycles were most often involved with these fatal crashes (n=94, 46.8% of all crashes with human fatalities). Crashes with passenger cars, pick-up trucks, trucks, and buses were much less likely to result in human injuries and fatalities (around 10%).

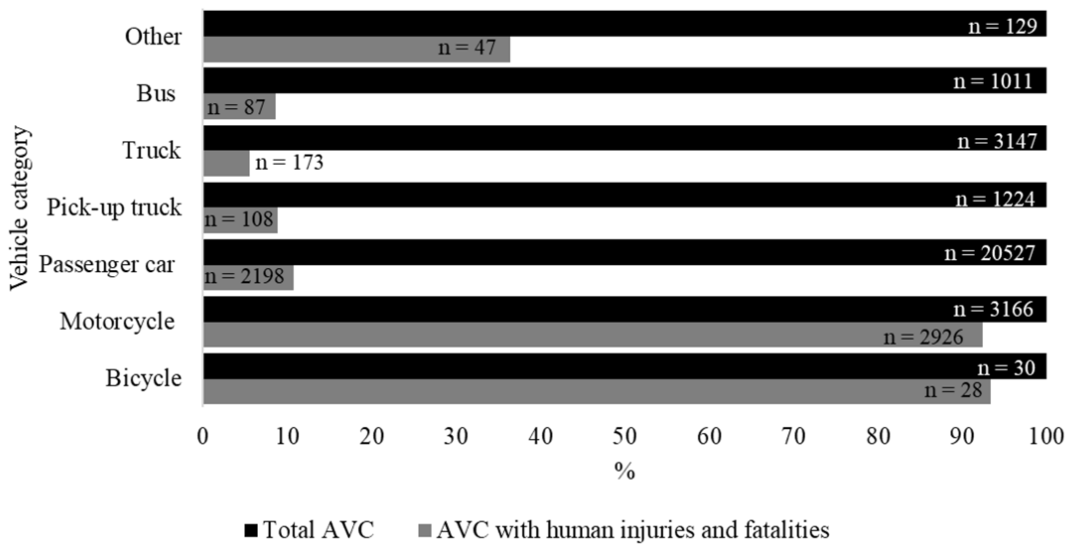

Figure 2. The total number of animal-vehicle crashes per vehicle type (set at 100%) and the percentage of those crashes with human injuries and fatalities on both private and public state roads in São Paulo State.

A total of 52% (n = 14,876) of the crashes were recorded on toll roads and 48% (n = 13,819) on state roads managed by DER. Though the total number of animal-vehicle crashes was similar for roads managed by toll road companies and DER, the number of animal-vehicle crashes with human injuries or fatalities on DER roads was more than double the number recorded along toll roads (Fig. 3).

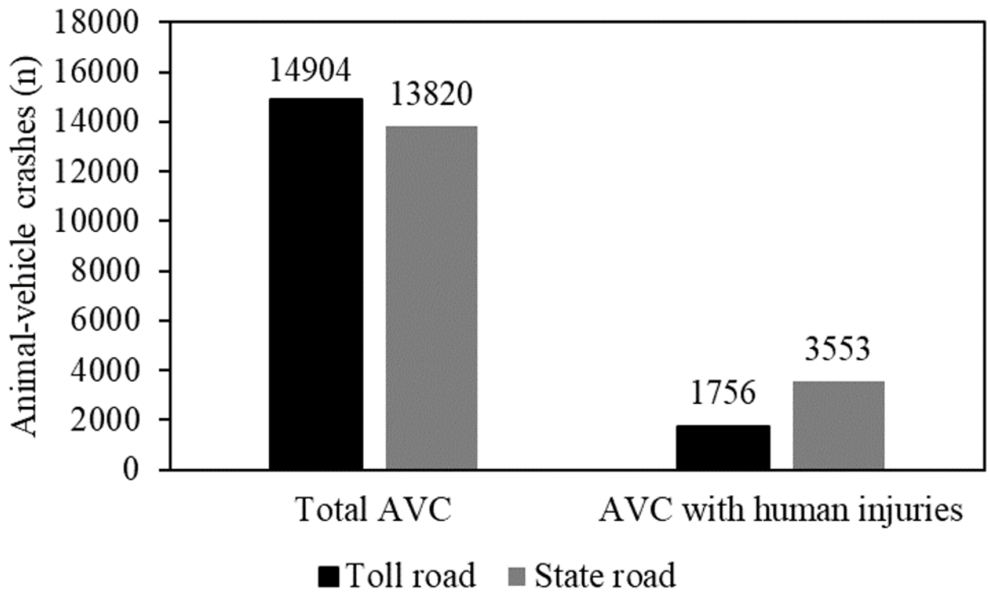

Figure 3. Total of number of animal-vehicle crashes and animal-vehicle crashes with human injuries and fatalities (2003-2013) on both private and public state roads in São Paulo State.

The number of animal-vehicle crashes showed some seasonal variation between the months of the year (Fig. 4) with slightly fewer crashes during the wet season (October-March) compared to the dry season (April-September).

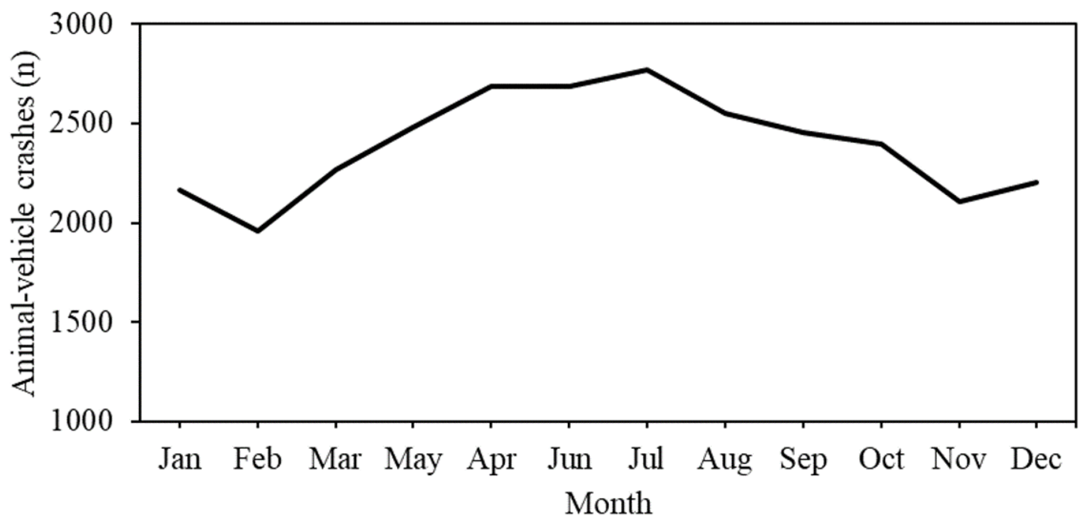

Figure 4. Total number of animal-vehicle crashes (2003-2013) per month on both private and public state roads in São Paulo State.

Of the 28,724 crashes, 71,62% (n= 20,575) occurred at night between the hours of 19:00h and 6:00h, with peaks around dawn and dusk (Fig. 5).

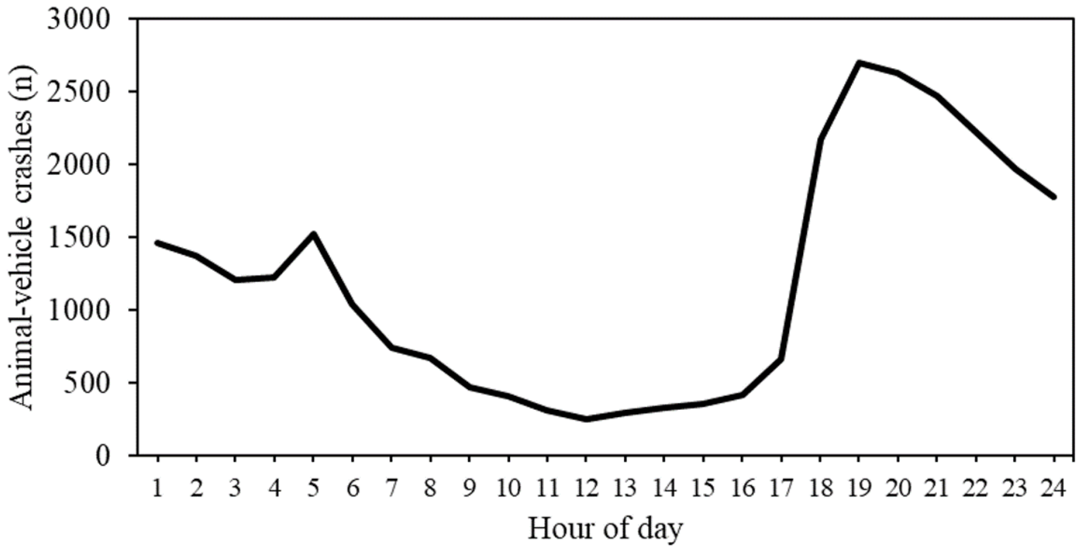

Figure 5. Total number of animal-vehicle crashes (2003-2013) by hour of day on both private and public state roads in São Paulo State.

5.3.2. Costs of animal-vehicle crashes to society

The total annual costs to society associated with the reported animal-vehicle crashes in São Paulo State was R$ 56,550,642 (US $ 25,144,794 in 2013) (IRS, 2018). In comparison, the average cost for an animal-vehicle crash, regardless of whether human injuries and fatalities occurred, was R$ 21,656 (US $ 9,629). The average cost for an animal-vehicle crash without human injuries or fatalities (82% of the 23,415 animal-vehicle crashes) was almost 50% lower; R$ 11,364 (US $ 5,053), whereas the average cost for a crash with human injuries or fatalities (18% of the animal-vehicle crashes) was R$ 67,048 (US $ 29,813). However, most of the costs (57%) were associated with crashes that involved human injuries or fatalities.

5.3.3. Legal perspectives and financial compensation

The number of court cases related to animal-vehicle collisions increased substantially between 2005 and 2014 (Fig. 6; S5 Table). The average increase in court cases was 14.8 per year. Of the 797 court cases, 14.4% included human fatalities (n= 115 in total, mean = 11.5 per year). Most of the court cases (69.5%, n = 554) were related to animal-vehicle collisions on roads managed by toll road companies, whereas 30.1% (n = 240) were on state roads managed by DER, and only 0.4% (n = 3) on city roads.

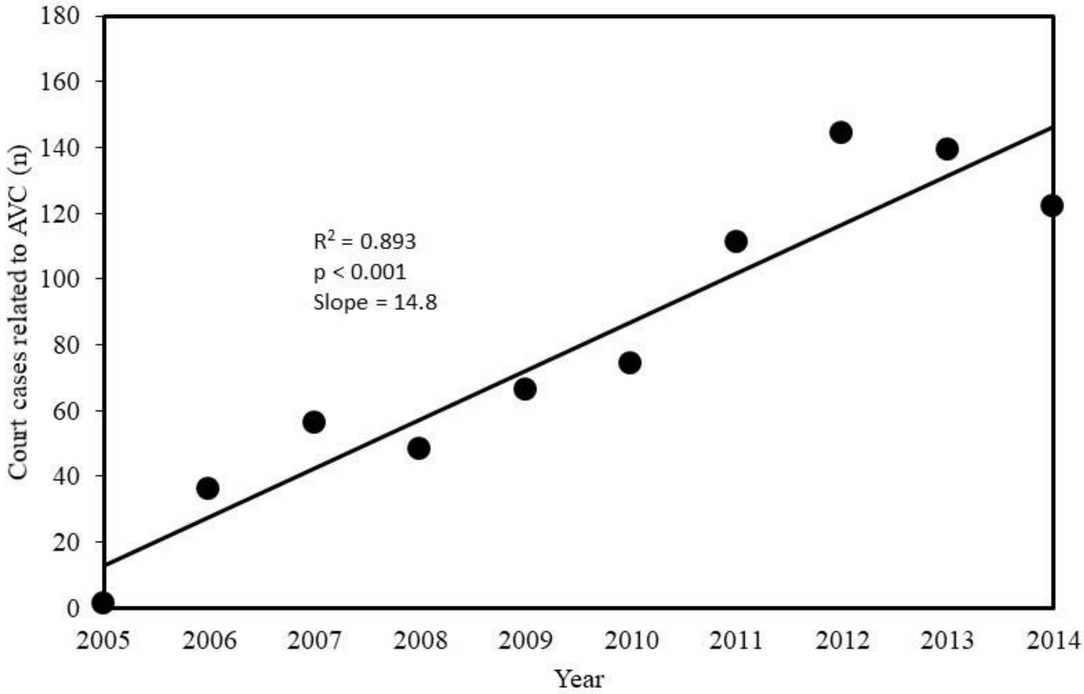

Figure 6. Number of court cases per year related to animal-vehicle collisions at the Court of Appeal of the State of São Paulo (TJSP – Tribunal de Justiça do Estado de São Paulo - 2° instância).

Most of the court cases related to collisions with domesticated species (64.4%, n = 513), followed by non-identified animal species (31.8%, n = 253), and wild species native to Brazil (3.9%, n = 31) (Fig 7, S5 Table). Horses (37.5%, n = 299), cattle (18.4%, n = 147), and dogs (*Canis lupus familiaris*) (7.2%, n = 37) were the most frequently reported species in the court cases (Fig. 7). The most frequently reported wild animal species was capybara (3.5%, n = 28), followed by maned-wolf (*Chrysocyon brachyurus*) (0.3 %, n = 2) and lowland-tapir (0.1%, n= 1).

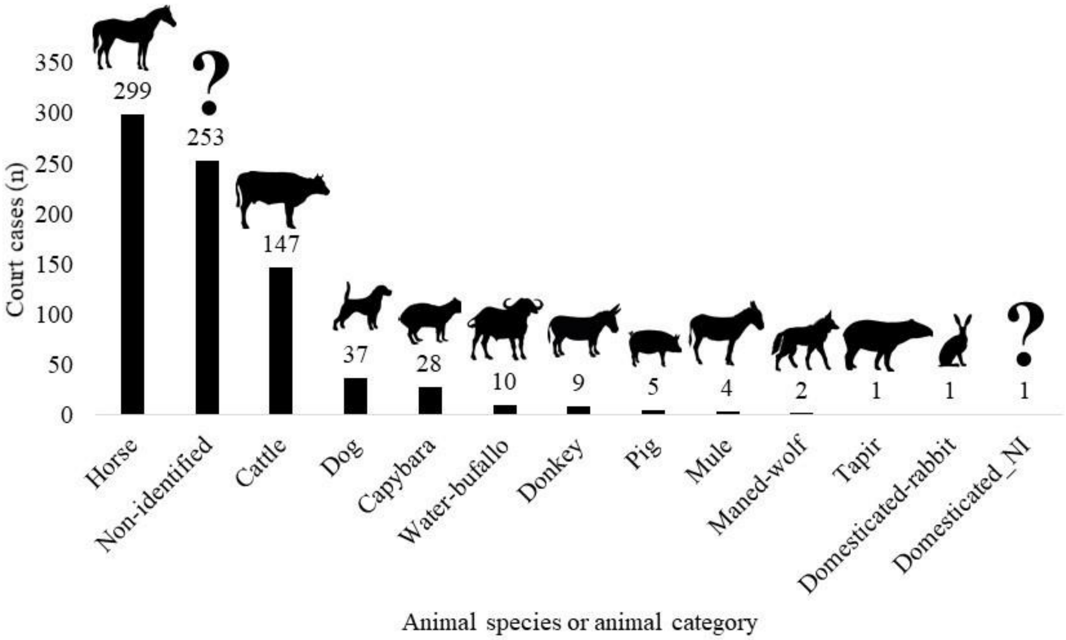

Figure 7. The animal species or animal group mentioned in the court cases related to animal-vehicle collisions in São Paulo State (2005-2014).

Of the 797 court cases, the vast majority (91.7%, n = 731) were awarded in favor of the plaintiffs with associated financial compensation. The court records indicated that the awards in favor of the plaintiffs were based on Article. 37, §6 of the Brazilian Federal Constitution (CFB, 1988) and the Code of Consumer Protection (BCDC, 1990).

Brazilian Federal Constitution, 1988

"Article 37. The governmental entities and entities owned by the Government in any of the powers of the Union, the states, the Federal District and the Municipalities shall obey the principles of lawfulness, impersonality, morality, publicity, and efficiency, and also the following: (CA No. 19, 1998; CA No. 20, 1998; CA No. 41, 2003; CA No. 42, 2003; CA No. 47, 2005)"

"§6. Public legal entities and private legal entities rendering public services shall be liable for damages that any of their agents, acting as such, cause to third parties, ensuring the right of recourse against the liable agent in cases of malice or fault."

Brazilian Consumer Defense Code (Federal Law nº 8.078/1990)

"Art. 2. A consumer is any physical person or corporate entity who acquires or uses a product or service as a final user."

"Art. 14. The service supplier will be responsible, regardless of the existence of guilt, for providing the necessary reparations for the damage caused to consumers due to any defects pertaining to service provision, as well as for insufficient or inadequate information about the nature of the service and the risks involved."

"Art. 22. Public agencies, by themselves or through their companies, service providers, or any other form of entrepreneurship, will be required to provide products that are adequate, efficient, safe and, regarding the essential, continuous."

"Sole paragraph. In the case that the obligations mentioned in this article are not followed, totally or partially, corporate entities will be compelled to obey them and provide reparations for any damages caused, in accordance to what is set forth by this Code."

Only 8.3% (n = 66) of the court cases were awarded in favor of the road administrator, and financial compensation to the plaintiffs was denied. Just over half of the cases (51,5%, n = 34) in which financial compensation was denied to the plaintiff suffered from procedural problems, including lack of sufficient evidence, ineptitude of the initial petition for the case, or the case was time barred. For the remaining 32 cases (48.8%), the judge ruled that the road administrator could not be held legally responsible for animals entering the road. The judge considered these animal movements to be fortuitous, and, as a consequence, the animal-vehicle collisions could not necessarily be prevented, at least not along the entirety of the road network.

Between 2005 and 2014, a total of R$ 24,633,798 (US$ 10,050, in 2014) (IRS, 2018) was awarded to the plaintiffs. On average, the defendants spent R$ 2,463,380 (US$ 1,005,051) per year compensating the plaintiffs. The average value awarded in a court case related to an animal-vehicle collision, regardless of the animal species, was R$ 43,452 (US$ 17,728) (n = 578 court cases with a known awarded value). For capybara-vehicle collisions the average value awarded was R$ 10,888 (US $ $4,442) (n = 22 court cases with a known awarded value), cattle was R$ 32,511 (US $ 13,462, n = 110), dog was R$ 8,151 (US $ 3,326, n = 24), and for horse was R$ 52,563.62 (US $ 21,446, n = 234) (Fig. 8).

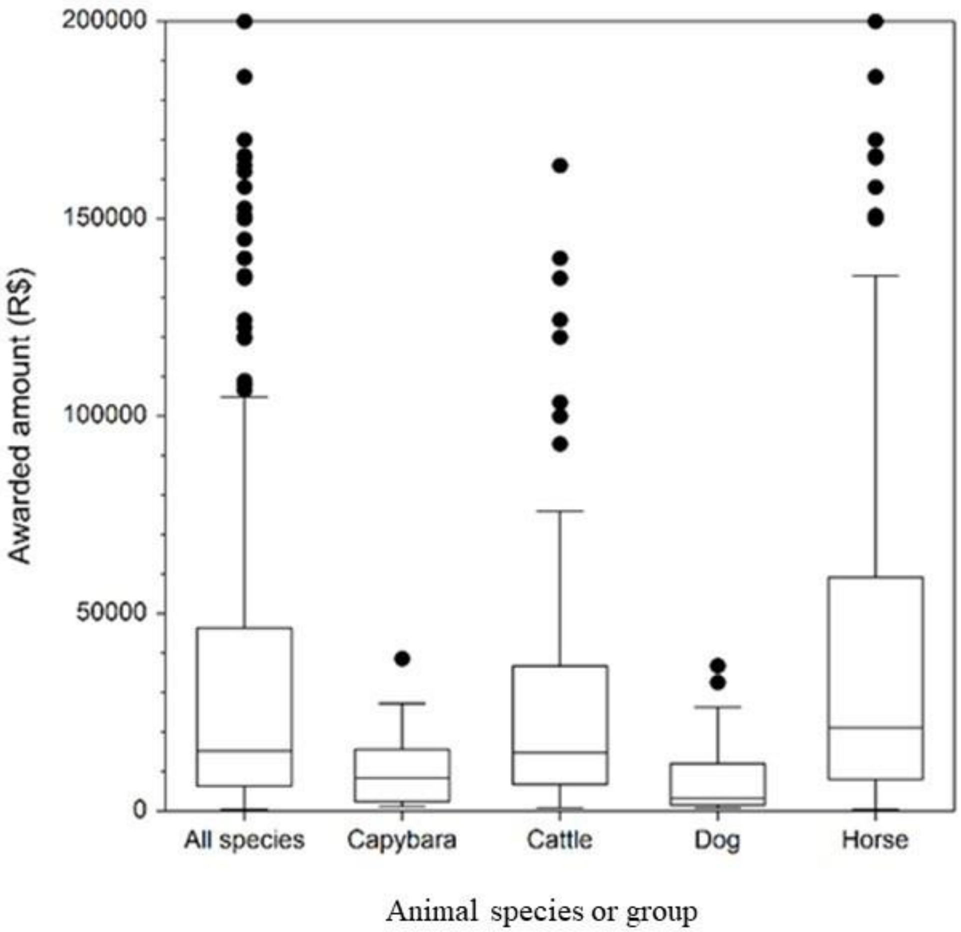

Figure 8. Box plot of the amount awarded to the plaintiffs by animal species. Box: middle 50% of the data (25th-75th percentile); horizontal line: median; whisker boundaries: 1.5 times inter-quartile range; dots: outliers.

5.4. DISCUSSION

The crash data from the Military Highway Police of São Paulo State (PMRSP) showed that the number of reported animal-vehicle crashes are increasing and represent 3.3% of the total number of reported crashes in São Paulo State. This percentage is higher than the national crash data in Brazil (1.9%; IPEA, 2015), but lower than the national crash data in the United States (about 4-5%; NGTSA, 2003; Huijser et al., 2008). An increase in traffic volume, new roads in remote areas, and increasing populations of species that adapt to living in agricultural and residential areas are all likely contributing factors to the increase of the reports.

In São Paulo State, 18.5% of the reported animal-vehicle crashes resulted in human injuries or fatalities. This is similar to the rate for human injuries for crashes with very large mammal species (e.g. moose) in the United States (Huijser et al., 2009), but lower than the

40.9% for the national crash data in Brazil (IPEA, 2015). These data suggest that the national animal-vehicle crash data in Brazil are restricted to the more severe cases, at least when compared to the animal-vehicle crash data in São Paulo State. The data also suggest that the reported animal-vehicle crashes in São Paulo State have a human injury rate (40.9% of the reported animal-vehicle crashes) that is substantially higher than the United States (2.8-9.7% of reported deer-vehicle crashes and about 18-23% for larger species such as moose) (Huijser et al., 2009; IPEA, 2015). The court cases related to animal-vehicle crashes in São Paulo State predominantly dealt with domesticated horses and cattle, rather than deer that dominate the reported wildlife-vehicle crashes in the United States (Huijser et al., 2009). The high rate of human injuries for animal-vehicle crashes in São Paulo State may also be related to the high percentage of motorcycles (19.2%) compared to the United States (3.2% motorcycles) (DENATRAN, 2018; FHWA, 2017). Animal-vehicle crashes with lighter vehicles, especially motorcycles, are more likely to result in human injuries and fatalities because the driver is easily launched from a motorcycle and not protected from direct physical impact by the "protective cage" associated with cars heavier vehicles. For example, the Center for Disease Control and Prevention (CDC, 2004) in USA reported relatively few non-fatal hospitalizations from motorcycle-animal collisions, which suggests that a motorcycle crash with an animal is likely to be fatal to the operator of the motorcycle. Other factors that may contribute to the relatively high rate for human injuries in Brazil are the potentially low presence and use of seatbelts and airbags (Gomez, 2000), narrow lanes and road shoulders, other road design characteristics that present a relatively high risk to human safety, dangerous driving styles, and the comparatively slow response time of emergency services. Note that air bags have been standard equipment in all new passenger cars in the United States since 1998. However, airbags did not become mandatory for new vehicles in Brazil until 2014 (DENATRAN, 2018).

Though the total number of animal-vehicle crashes was similar for roads managed by toll road companies and DER (public state roads), the number of animal-vehicle crashes with human injuries or fatalities was much higher on roads managed by DER. This is most likely because DER has fewer modern roads with a safer road design, slower medical and mechanical assistance and lower presence of Military Highway police than toll roads. Interestingly, while toll roads represent about one third of all paved roads in São Paulo State, they received most of the reported animal-vehicle crashes (52%) (DER, 2018). This is probably related to the relatively high traffic volume, high vehicle speed, and relatively high night-time use compared to DER roads. While the number of animal-vehicle crashes with human injuries or fatalities was much higher on roads managed by DER than roads managed by toll road companies, 62.5% of the court cases related to animal-vehicle collisions on toll roads. Furthermore, there is no difference concerning the liability between private and public road administrators for animal-vehicle collision, and the traveling public is more likely to sue toll road companies than public road administrators. This may be related to the toll fee that needs to be paid each time when using a toll road; the act of paying may make the roles of a service provider and a consumer more current and explicit.

There were slightly fewer crashes during the wet season (October-March) compared to the dry season (April-September) when animals generally expand their range in search of food (Silveira et al., 2010). However, there was relatively little variation in the number of animal-vehicle crashes over the course of a year in the tropical and sub-topical region of São Paulo State compared to temperate regions with greater seasonal differences in weather and associated differences in animal behavior such as a more defined mating season with higher activity (Groot Bruinderink & Hazebroe, 1996; Langley et al., 2006; Huijser et al., 2008). The weak seasonal pattern in animal-vehicle crashes in São Paulo State may also be due to the crash data from the Military Highway Police of São Paulo State which were based on a combination of domestic and wild species. Our analysis identified capybara as the wild mammal species most frequently involved in collisions in São Paulo State. The capybaras do not have a distinct mating season (Ojasti, 1968), which contrasts with white-tailed-deer (*Odocoileus virginianus*) which is the wild mammal species most frequently hit in the United States. White-tailed deer have a distinct mating season that is associated with relatively high occurrence of collisions (Huijser et al., 2008; Stewart et al., 2018). However, the time of day during which most animal-vehicle collisions occurred was similar to that in temperate regions; predominantly in the dark, especially around dusk till midnight, and around dawn (Groot Bruinderink & Hazebroe, 1996; Huijser et al., 2008).

Costs associated with animal-vehicle crashes increased during the time frame this study was carried in São Paulo State. While crashes with human injuries or fatalities only represented 18% of the animal-vehicle crashes, they accounted for the majority of the costs (57%). This suggests that, from both a human safety and a financial perspective, efforts to reduce animal-vehicle collisions should not only be directed at reducing the number of animal-vehicle crashes, but also their severity.

From a legal perspective, road administrators (private or public) are usually (91.7 % of the cases) held responsible for animal-vehicle collisions. Therefore, in São Paulo State, toll road companies or DER are typically required to provide monetary compensation for the damages and losses to the plaintiffs in court cases related to animal-vehicle collisions. On average, the defendants spent R$ 2,463,380 (US$ 1,005,051) per year compensating the plaintiffs. However, since animal-vehicle crashes have been increasing, the costs have likely been substantially higher in recent years. The awarded amounts were highest for large domesticated species such as horses and cattle.

Road administrators are generally held responsible for animal-vehicle collisions as they provide a service to the traveling public and are obligated to protect their customers. This type of liability does not suggest actual negligence or intent to harm on the part of the road administrators (Rodrigues, 2007), rather, it is based on protecting the "customer" who is considered the more vulnerable of the two parties. The view of the courts is that the recipient of the service (the traveling public) can expect safe transportation. If an animal (wild or domesticated) enters the roadway and is involved in a vehicle collision, the road administrator is considered to be non-compliant regarding the obligation to provide safe travel, free and unimpeded. Note that if the owner of a domesticated animal is known and found, the road administrator can sue the owner of the domestic animal. In these select cases, both the road administrator and the owner of the domestic animal can be held legally responsible for the collision. However, the owner is typically unknown or hard to find, and most law suits only involve the road administrator. Similarly, in Italy, the road administrator is held liable for wildlife-vehicle collisions (Studio Cataldi, 2016), where the legal base is similar to Brazilian legal system. When a collision involves a domesticated animal, and the owner is known, the owner is held responsible, however, still in Italy, if there is no owner of the domesticated animal, the municipality where the animal was hit is held responsible as the municipality failed to prevent the abandonment of the animals and exposed the road users to a risk. Variations in legal responsibility for animal-vehicle collisions is different in other countries. For example, in Spain animal-vehicle collisions are considered the driver's responsibility and the road administrator may be liable if the road was poorly signed (e.g. few animal crossing signs) or if there was no or poor maintenance of the fences (MAAMA, 2015). In the United Kingdom, liability for animal-vehicle collisions with domesticated animals lie with the animal's owner. If the animal has no owner, there is no responsible party, and thus no possibility of compensation (Animals Act, 1971). In comparison, in the United States, the responsibility for animal-vehicle collisions are typically with the driver, damages are usually covered by insurance companies and, in general, the road administrator assumes no responsibility and pays no compensation to the victims (USDT, 2008; Car Insurance, 2018).

The Brazilian legal system overwhelmingly holds the road manager liable for animal-vehicle collisions, both with wild and domestic species. The logical conclusion is that the Brazilian legal system expects road administrators to keep animals off the road. This then suggests that road administrators are expected to fence the entire length of the road system. While the standard right-of-way fences are typically a barrier for large livestock species (e.g. cattle, horses), they are not an absolute barrier for most wild animal species because right-of-way fences tend to be more permeable for wild species. Since road administrators are also expected to prevent wild animals accessing the road, the Brazilian jurisprudence suggests that the right-of-way fences should also be an impermeable barrier to wild animal species. Whilst such fences would benefit human safety and reduce unnatural mortality for the animals, it would also increase the barrier effect of roads for wildlife (Jacger & Fahrig, 2004). In fact, it has the potential to make roads into an absolute barrier for wildlife, resulting in extreme habitat fragmentation, reduced population viability, and eventually the loss of many species from the landscape if no safe crossing opportunities are available.

In addition to the laws that relate to animal-vehicle collisions, Brazil also has an environmental licensing system for road construction and road upgrades (BFL, 1981). The environmental licensing process can result in the requirement of mitigation measures aimed at reducing direct road mortality and providing safe crossing opportunities for wildlife. In practice, Brazil and specifically in São Paulo State, such requirements are largely placed on toll road companies and rarely on DER. As a result, the toll road companies, especially in São Paulo State, are the leaders in the development and implementation of wildlife mitigation measures along highways in Brazil. Nonetheless, the requirements that result from the environmental licensing system, based on Environmental Impact Assessments or other instruments, are largely focused on biological conservation rather than human safety, and not on reducing collisions with large domestic species such as horses and cattle.

It appears that the Brazilian law regarding animal-vehicle collisions is focused on human safety while the environmental licensing system is largely focused on biological conservation. This results in a mismatch; the required mitigation measures for wildlife do not adequately match the legal responsibility for animal-vehicle collisions, and the legal responsibilities regarding animal-vehicle collisions do not adequately meet biological conservation requirements. In addition, the reality is that the legal system for animal-vehicle collisions in São Paulo State mostly deals with collisions involving domesticated species (64.4%) rather than wild animal species (3.9%). This results in further disconnection between the Brazilian legal system for animal-vehicle collisions, the environmental licensing process, and the need to not only improve human safety but also to address the impacts of roads and traffic on the environment, including habitat connectivity for wildlife. Is important to highlight that 31.8% of the court cases were with non-identified animal species. This may be related to the fact that police officers (non-experts) are not able to identify many wild animal species, and that the actual percentage of court cases involving collisions with wild animal species is much higher (Abra et al., 2018).

Abandoned domesticated animals are very common in Brazil, but there is no specific policy that addresses the problem. Low income people in rural areas are known to abandon old or injured horses and dogs so that they do not have to deal with the financial expenses associated with veterinary care (Osnir Ormon Giacon, Concessionária CART, pers. comm.). In addition, cattle and horses often enter the road corridor because the right-of-way fences are not present or poorly maintained. Many of these animals end up living on and alongside roads where they pose a serious threat to the traveling public. These abandoned animals can also pose a threat to wildlife, through the spread of diseases and predation (e.g. predation by feral dogs and cats) (Garcia et al., 2012; da Rosa et al., 2017).

In some areas of the western United States, especially in areas with low human population density there are still open range livestock laws in effect. In selected areas, livestock (e.g. cattle), can roam freely, regardless of land ownership. Land owners, including road administrators, who want to keep livestock off their property, are required to fence livestock out. This is the opposite to the more common situation where the owner of livestock is required to fence in their animals and keep them off property owned by others (NALC, 2018).

While the Brazilian legal system overwhelmingly holds the road administrators responsible for animal-vehicle collisions (91.7 % of the cases), there is a small percentage of cases (8.3 %) where compensation to plaintiffs was denied. In these select few cases, the judge ruled that the road administrator could not be held legally responsible for animals entering the road because these animal movements were fortuitous, and, as a consequence, animal-vehicle collisions could not necessarily be prevented, at least not along the entirety of the road network. While it is true that wildlife-vehicle collisions can be widespread, their location is not necessarily random. Hotspots (concentration of wildlife-vehicle collisions) can even be predicted based on a range of landscape and road variables (e.g. Found & Boyee, 2011; Maio et al., 2004; Garrote et al., 2018). Hotspots maps based on monitoring data and maps resulting from predictive modelling can help with the planning and decision process for the potential implementation of mitigation measures aimed at reducing wildlife-vehicle collisions and at providing safe crossing opportunities for wildlife. Several tools have been developed for this specific purpose (e.g. Clevenger et al., 2003; Clevenger et al., 2006; SIRIEMA, 2009; Bil et al., 2016; SANET, 2018). This means that society has the knowledge and tools to identify and prioritize road sections that have a concentration of wildlife-vehicle collisions and that action can be taken to substantially reduce this problem. For major highways with a high design speed and a high traffic volume, the most effective and robust measure aimed at reducing wildlife-vehicle collisions and providing safe crossing opportunities for wildlife is erecting wildlife fences in combination with underpasses and overpasses (Huijser et al., 2016; Rytwinski et al., 2016). It is critical that the design of the fences and crossing structures matches the biological characteristics and requirements of the target species. While the design of the crossing opportunities such as underpasses and overpasses should allow for a live span of about 70 years, fences require more regular maintenance and may last only for about two decades (Huijser et al., 2009). Fence inspections and repair should be integrated into daily road maintenance practices. Fences that are not an effective barrier to the target species put humans and animals at risk and jeopardize the investments in the mitigation measures including the crossing structures.

Implementation of mitigation measures for wildlife species can even make economic sense (Huijser et al., 2009; Huijser et al., 2013). Livestock-vehicle collisions can be reduced by obligating livestock owners and road administrators to fence roads effectively and keep livestock off the highway. Abandonment of domesticated animals including horses, cattle and dogs is more difficult to address. This may require different norms in society and a greater awareness of the potential consequences of abandoning animals, not only regarding animal welfare, but also with regard to human safety.

To address some of the challenges mentioned above, Campos et al. (2007) suggested the following management actions: (1) Informing people about diseases transmitted by free ranging dogs and cats, (2) Educating people about local biological diversity, (3) Making it illegal for people to abandon and feed (feral) domesticated species, (4) Establishing a deadline after which a removal program of free-ranging animals, specifically for dogs and cats, would be initiated (e.g. adoption or euthanasia programs).

5.5. CONCLUSION

Our study demonstrates that the number of reported animal-vehicle crashes and associated costs are increasing in São Paulo State. Animal-vehicle crashes with large animal species, wild or domestic, are dangerous to people, especially for occupants of light vehicles such as motorcycles. Interestingly, Brazilian law holds road managers responsible for animal-vehicle collisions. This suggests that road managers have the obligation to keep animals, wild and domestic, off the highway. We suggest a better coordination between the laws that relate to animal-vehicle collisions and human safety, and the process for environmental licenses that focuses on both reducing collisions with wildlife and maintaining or improving habitat connectivity. These actions should ultimately result in a road system with increased human safety, reduced unnatural mortality for both domestic and wild animal species, safe crossing opportunities for wildlife, and reduced monetary costs to society. Our analyses of animal-vehicle collisions in São Paulo State goes beyond the traditional perspective of road ecology papers that mostly focus on biological conservation. Our study is a first step to specifically address human safety, economic and legal issues associated with animal-vehicle collisions in Brazil. The results can be valuable in the decision process for the planning of the construction or reconstruction of roads. It would take human safety, wildlife, as well as monetary costs into account. We believe that this is better than accepting a continuing increase in animal-vehicle collisions, and associated impacts on human safety, economic parameters, and the environment.

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SUPPORTING INFORMATION

S1 Table. Cost components for animal-vehicle crashes (based on IPEA, 2015).

		With human victim		
	No human victim (R$)	**Minor injury (R$)**	**Severe Injury (R$)**	**Fatality (R$)**
Cost components				
Total people cost	**1086,14**	**8469,44**	**125133,91**	**433286,69**
Pre-hospital care	4,42	759,18	1.111,73	86,28
Hospital care	625,60	5.661,76	72.855,40	143,19
Post-hospital care	40,59	208,5	3.150,21	0
Loss of productivity	415,53	1.840,00	47.797,94	432.557,99
Transport of victim	0	0	218,64	499,24
Total passenger car cost	**7.159,12**	**12.126,82**	**12.126,82**	**19.323,91**
Removal	193,22	168,1	168,1	743,6
Material damage	6.965,90	11.958,72	11.958,72	18.580,31
Total motorcycle cost	**2.473,21**	**2.741,02**	**2.741,02**	**4.269,83**
Removal	51,59	145,28	145,28	181,09
Material damage	2.421,61	2.595,74	2.595,74	4.088,74
Total bicycle cost	**0**	**168,74**	**168,74**	**124,1**
Material damage	0	168,74	168,74	124,1
Total pick-up truck cost	**10.569,76**	**20.240,38**	**20.240,38**	**35.091,47**
Removal	110,76	162,96	162,96	127,14
Material damage	10.396,71	19.846,39	19.846,39	34.861,81
Commercial cargo loss	62,29	231,03	231,03	102,51
Total truck cost	**22313,92**	**65.656,01**	**65.656,01**	**47825,45**
Removal	178,33	351,53	351,53	461,89
Material damage	18.805,75	57.009,43	57.009,43	41.718,38
Commercial cargo loss	3329,84	8295,05	8295,05	5645,19
Total bus cost	**16069,3**	**10536,86**	**10536,86**	**20686,09**
Removal	64,39	218,46	218,46	522,97
Material damage	16004,91	10318,39	10318,39	20163,12
Total other cost	**10307,36**	**80108,63**	**80108,63**	**81209,29**
Removal	88,52	177,05	177,05	1403,74
Material damage	10218,84	79931,58	79931,58	52522,13
Commercial cargo loss	0	0	0	27283,43
Inst. property cost	**453,35**	**338,33**	**338,33**	**653,06**

S2 Table. Average costs for different categories of human injuries and human fatalities associated with a crash for each vehicle type (based on IPEA, 2015).

Type of AVC	**Average costs (R$)**
Passenger car_no human victim	8698,61
Pickup truck_no human victim	12109,25
Motorcycle_no human victim	4012,70
Bicycle_no human victim	1539,49
Truck_no human victim	23853,41
Bus_no human victim	17608,79
Other_no human victim	11846,85
Passenger car_minor human injury	20934,59
Pickup truck_minor human injury	29048,15
Motorcycle_minor human injury	11548,79
Bicycle_minor human injury	8976,51
Truck_minor human injury	74463,78
Bus_minor human injury	19344,63
Other_minor human injury	88916,40
Passenger car_severe human injury	137599,06
Pickup truck_severe human injury	145712,62
Motorcycle_severe human injury	128213,26
Bicycle_severe human injury	125640,98
Truck_severe human injury	191128,25
Bus_severe human injury	136009,10
Other_severe human injury	205580,87
Passenger car_human fatality	453263,66
Pickup truck_human fatality	469031,22
Motorcycle_human fatality	438209,58
Bicycle_human fatality	434063,85
Truck_human fatality	481765,20
Bus_human fatality	454625,84
Other_human fatality	515149,04

S3 Table. Maximum number of occupants for each vehicle type.

Vehicle type	Max. Occupants (n)
Bicycle	1
Motorcycle	2
Passenger car	5
Pick-up truck	5
Truck	2
Bus	46
Other	2

S4 Text. Clarification for Salário mínimo and Pensão vitalícia

Salário Mínimo

Brazil does not have a minimum hourly wage, but instead a minimum monthly salary (salário mínimo). Any regular worker (as opposed to a daily or hourly worker) must receive at least this minimum monthly salary from his or her employer. The value of the minimum salary is defined by a national law and is reassessed annually based on changes to the cost of living. Municipalities can choose to implement a higher minimum salary, but they cannot reduce the amount below the federal monthly rate. Under current Brazilian law, the minimum salary may be used to calculate minimum pensions for some retirees and older adults (e.g. their pension cannot be below the minimum salary), and/or to certain other people who are not employed.

Pensão vitalícia

Brazilian courts can award a life pension (pensão vitalícia) in cases where a person is disabled or killed because of the actions of another party. Life pension can be awarded to the person who is disabled or to the dependents of a person who is killed. Calculations of life pension are subjective and depend on a variety of both compensatory and punitive factors which may include, for example, the age of the dependent(s), average salary of the injured party (and/or minimum salary), potential earnings (thus potential lost earnings) of the injured party, and punitive damages. Once awarded, a life pension is then paid monthly for the remainder of the life the person to whom it is awarded (or the remainder of the childhood of child dependents (until age 18 or 21 depending on current law).

S5 Table. Court cases in São Paulo State per year, type of road, type of animal involved in the crash and the awarded amount to the plaintiff. NI = non-identified; n = number of individuals.

Year	Nº cases	Human deaths (n)	NI Animals (n)	Domesticated Animals (n)	Wild Animals (n)	Public roads (n)	Toll roads (n)	City roads (n)	Awarded amount (R$)
2005	1	1	1	0	0	0	1	0	300.000,00
2006	36	6	15	21	0	14	22	0	916.311,75
2007	56	8	27	28	1	16	40	0	2.485.501,21
2008	48	7	16	31	1	14	33	1	761.131,48
2009	66	12	17	45	4	30	36	0	1.815.236,09
2010	74	11	24	49	1	27	47	0	2.468.316,78
2011	111	14	30	79	2	47	64	0	2.768.600,64
2012	144	22	34	105	5	39	105	0	3945.765,04
2013	139	24	45	82	12	31	107	1	4.622.442,06
2014	122	10	44	73	5	22	99	1	4.976.479,64
Total	**797**	**115**	**253**	**513**	**31**	**240**	**554**	**3**	**25.059.784,69**

6. FINAL REMARKS

Understanding the impacts of roads and traffic at higher levels is necessary for a number of good reasons. The environmental agencies have the main objective to conserve biodiversity and natural resources, and the transportation agencies aims to provide safe traffic for people and goods, building better roads. When a wildlife-vehicle collision on the road occurs, both agencies failed, and economic costs is generated and shared by the society.

Reducing the negative effects of roads and traffic will only be possible if more dialogue is achieved between the scientific community, planners from environmental and transportation agencies and political decision-makers. The society also has a role in this process, shaping norms and values.

The aim of this thesis was to present data of medium and large mammals roadkilled on highways in the State of São Paulo with different approaches: demonstrating impacts for biodiversity conservation, human safety, legal and economic aspects of mammal-vehicle collisions. With the results of the thesis, environmental and transportation agencies of the state of São Paulo, can jointly articulate to reduce wildlife-vehicle collisions, improving either safety and the conservation of biodiversity.

Below, we emphasize the main outcomes of the thesis which can also be used as recommendations for applied actions and scientific development.

6.1. Chapter 1: Reliability of roadkill data collected by no-experts

6.1.1. Outcomes and recommendations

- Common mammals are more easily identified by non-experts than rare, threatened and non-common species;
- Training for road maintenance personnel and other non-experts in species identification is mandatory in order to improve the reliability of species identification of road-killed animals
- Experts need to verify the roadkill records and associated images for species that may be a concern for biological conservation and that are known to be poorly identified by non-experts.

6.1.2. Next steps

- To test the reliability and quality of roadkill records collected by maintenance personnel before and after training.

6.2. Chaper 2: Roadkill estimates for São Paulo state

6.2.1. Outcomes and recommendations

- Roadkills seems to be a chronic and growing impact for wildlife populations what can act as an important driver of defaunation;
- Understanding the causes of population declines and ultimately processes contributing to extinction is particularly important to strategically focus actions on populations most at risk;
- Estimates generated in reginal scales are more accurate than extrapolations in large scales (biomes or nationwide);
- The estimates can be used on conservation planning as National Action Plans from CENAP/ICMBio specifically for Maned wold (*Chrysocyon brachyurus*), Hoary fox (*Lycalopex vetulus*), Ocelot (*Leopardus pardalis*) and Puma (*Puma concolor*).

6.2.2. Next steps

- To conduct analyses with specific species as Population Viability Analysis to calculated and understand the impact of individual losses from different species cause in populations as the extinction risk.
-

6.3. Chapter 3: Roadkill predictive models

6.3.1. Outcomes and recommendations

- Northeast region of São Paulo state is the main critical area for mammal roadkill;
- The critical roadkill areas, for all seven mammals species combined incorporated, in total, 260 municipalities in the State and cover 3.62% of all paved road network;
- The Maned wolf has 3,662 km of critical road section, above 70% of roadkill probability, totalizing 10.03% of all paved road network;

- Toll road sections that were critical to roadkill hotspots of all mammals combined, totalized 485.254 km of roads (7.5% of toll roads in the state);
- The implementation of effective mitigation measures as fences, underpasses, overpasses and animal detection systems should be applied considering the critical road sections pointed by roadkill hotspot analysis and/or critical sections pointed by roadkill predictive models with higher risk.;
- Roadkill predictive models could be required by environmental agencies on environmental licensing for road construction or duplication in local or regional scales during the process of road design and planning of mitigation measures.

6.3.2. Next steps

- Generate more accurate roadkill predictive model to Hoary fox;
- To collect more roadkill data on Northwest area of São Paulo state and run the models again to test the probability of roadkill in this specific area;
- To test other algorithms instead of Maxent to predict roadkill.

6.4. Chapter 4: Human safety, economy and legal perspectives

6.4.1. Outcomes and recommendations

- The number of reported animal-vehicle crashes and associated costs are increasing in São Paulo State;
- On average, the Military Highway Police of São Paulo reported 2,611 animal-vehicle crashes per year (3.3% of total crashes), and 18.5% of these resulted in human injuries or fatalities;
- The total annual cost to society, from animal-vehicle crashes, was estimated at R$ 56,550,642 (US $ 25,144,794);
- The average cost for an animal-vehicle crash, regardless of whether human injuries and fatalities occurred, was R$ 21,656 (US $ 9,629);
- The Brazilian legal system overwhelmingly (91.7 % of the cases) holds the road administrator liable for animal-vehicle collisions, both with wild and domestic species;
- On average, road administrators spent R$ 2,463,380 (US $ 1,005,051) per year compensating victims on court cases.

- An improved coordination between the laws that relate to animal-vehicle collisions and human safety, and the process for environmental licenses that focusses on reducing collisions with wildlife and providing habitat connectivity are strongly recommended.
- Better management practices, raising awareness and social change regarding to abandoned domesticated animals including horses, cattle, and dogs;

6.4.2. Next steps

- To identify the species of wild animals on animal-vehicle crashes records from the Military Highway Police in São Paulo state.
- To conduct more deep analyses on costs to society and cost-benefit analyses on implementation of mitigation measures to reduce mammal-vehicle collisions on a state scale.

6.5. Next steps in a whole

- To reduce wildlife road mortality on paved roads in São Paulo state, the environmental agencies (Environmental Secretary of São Paulo state (SMA) and CETESB)) and transportation agencies (DER, ARTESP, DERSA) should dialogue constantly aiming to provide practical ground solutions during road planning and environmental licensing of roads;
- The São Paulo state needs a long-term planning to reconnect the fragmented landscape, in a structural and functional level, using mitigation measures as underpasses, overpasses, canopy crossings and bridges on priority areas for conservation cut by roads, mainly protected areas;
- From a human safety point of view, the civil engineers in São Paulo should start to include wildlife presence, movement and hazard to traffic to elevate safety standards on road planning – including new roads or the upgrade of existent roads;
- From a Biological point of view, the loss of mammal individual´s, mainly threatened species, by roadkill should be considered as a priority in order to reduce unnatural mortality;

6.6. My next steps

- The outcomes from this thesis will be presented on Environmental and Transportation agencies in São Paulo state on the second semester of 2019 as well as I´m going to make available all data, analyses and maps that could be useful for these agencies;
- The chapter 2 and 3 will be submitted to publication on the second semester of 2019;
- I´m going to continue my research on road ecology, but mostly focused on understanding the real impact of individual losses by roadkill on wild mammal populations in São Paulo state and how to provide practical solutions on the reduction of road mortality.

7. CONSIDERAÇÕES FINAIS

Compreender os impactos das rodovias e do tráfego em níveis superiores é necessário por diversas boas razões. As agências ambientais têm como principal objetivo conservar a biodiversidade e os recursos naturais, e as agências de transporte têm como objetivo fornecer tráfego seguro para pessoas e produtos, construindo rodovias cada vez melhores. Quando ocorre uma colisão envolvendo animal na rodovia, ambas as agências falharam, e os custos econômicos são gerados e compartilhados pela sociedade.

Reduzir os efeitos negativos das rodovias e do tráfego só será possível se houver mais diálogo entre a comunidade científica, profissionais que atuam no planejamento de agências ambientais e de transporte e tomadores de decisões políticas. A sociedade também tem um papel nesse processo, moldando normas e valores.

O objetivo desta tese foi apresentar dados de mamíferos de médio e grande porte atropelados em rodovias do Estado de São Paulo com diferentes abordagens: demonstrando impactos para a conservação da biodiversidade, segurança humana, aspectos legais e econômicos das colisões envolvendo mamíferos silvestres. Com os resultados da tese, órgãos ambientais e de transportes do estado de São Paulo, podem se articular conjuntamente para reduzir as colisões com animais, melhorando a segurança e a conservação da biodiversidade.

A seguir, destacamos os principais resultados da tese, que também podem ser utilizados como recomendações para ações aplicadas e desenvolvimento científico.

7.1. Capítulo1: Confiabilidade de dados de atropelamento coletados por não-especialistas

7.1.1. Resultados e recomendações

- Os mamíferos comuns são mais facilmente identificados por não-especialistas do que espécies raras, ameaçadas e não comuns;
- O treinamento para inspetores de tráfego e outros não especialistas na identificação de espécies é obrigatório, a fim de melhorar a confiabilidade da identificação de espécies de animais mortos na rodovia.
- Os especialistas precisam verificar os registros de atropelamentos e imagens associadas para espécies que podem ser uma preocupação para a conservação biológica e que são reconhecidamente mal identificadas por não especialistas.

7.1.2. Próximos passos

- Testar a confiabilidade e a qualidade dos registros de atropelamentos coletados pelo pessoal de manutenção antes e depois do treinamento.

7.2. Capítulo 2: Estimativas de atropelamento para o Estado de São Paulo

7.2.1. Resultados e recomendações

- Os atropelamentos parecem ser um impacto crônico e crescente para as populações de animais silvestres, o que pode ser um importante fator de defaunação;
- Compreender as causas dos declínios populacionais e, em última análise, os processos que contribuem para a extinção é particularmente importante para focar estrategicamente as ações nas populações silvestres em maior risco;
- As estimativas geradas com dados de referência locais e regionais são mais precisas do que as extrapolações em grandes escalas (biomas ou nível nacional);
- As estimativas podem ser usadas no planejamento de conservação como Planos de Ação Nacionais do CENAP / ICMBio, especificamente para lobo guará (*Chrysocyon brachyurus*), raposinha do campo (*Lycalopex vetulus*), jaguatirica (*Leopardus pardalis*) e onça parda (*Puma concolor*).

7.2.2. Próximos passos

- Conduzir análises com espécies específicas como Análise de Viabilidade Populacional para calcular e compreender o impacto de perdas individuais de diferentes espécies causam nas populações o risco de extinção.

7.3. Capítulo 3: Modelos de predição de atropelamento

7.3.1. Resultados e recomendações

- A região nordeste do estado de São Paulo é a principal área crítica para atropelamentos de mamíferos;

- As áreas críticas de atropelamento, para todas as sete espécies de mamíferos combinadas, incorporaram, no total, 260 municípios no Estado e cobrem 3,62% de toda a malha viária pavimentada;
- O lobo-guará apresenta 3.662 km de rodovias com trechos críticos, acima de 70% de probabilidade de atropelamento, totalizando 10,03% de toda a malha viária pavimentada;
- Os trechos críticos de atropelamentos de rodovias sob concessão, para todos os mamíferos combinados, totalizaram 485,254 km de rodovias (7,5% das rodovias concedidas no estado);
- A implementação de medidas de mitigação eficazes como cercas, passagens inferiores, viadutos e sistemas de detecção de animais deve ser aplicada, em caráter prioritário, considerando os trechos rodoviários críticos apontados pela análise de *hotspots* de atropelamentos e / ou trechos críticos apontados pelos modelos preditivos de atropelamentos de maior risco.
- Modelos preditivos de atropelamentos podem ser exigidos pelos órgãos ambientais em licenciamento ambiental para construção de rodovias ou duplicação em escalas locais ou regionais durante o processo de planejamento de rodovias e planejamento de medidas de mitigação.

7.3.2. Próximos passos

- Gerar um modelo preditivo de atropelamento mais preciso para raposinha do campo;
- Coletar mais dados de atropelamentos na região noroeste do estado de São Paulo e executar os modelos novamente para testar a probabilidade de atropelamentos nesta área específica;
- Para testar outros algoritmos para prever atropelamentos.

7.4. Capítulo 4: Segurança humana, perspectivas legais e aspectos econômicos

7.4.1. Resultados e recomendações

- O número de acidentes com animais e os custos associados relatados estão aumentando no Estado de São Paulo;
- Em média, a Polícia Rodoviária Militar de São Paulo registrou 2.611 colisões envolvendo animais por ano (3,3% do total de colisões) e 18,5% delas resultaram em ferimentos ou fatalidades humanas;
- O custo anual total para a sociedade, de acidentes envolvendo animais, foi estimado em R $ 56.550.642 (US $ 25.144.794);
- O custo médio de um acidente envolvendo um animal, independentemente de terem ocorrido ferimentos e mortes humanas, foi de R $ 21.656 (US $ 9.629);
- O sistema legal brasileiro responsabiliza o administrador rodoviário por colisões envolvendo animais (91,7% dos casos), tanto com espécies silvestres quanto domésticas;
- Em média, os administradores de rodovias gastaram R $ 2.463.380 (US $ 1.005.051) por ano compensando as vítimas em processos judiciais.
- Uma coordenação aprimorada entre as leis que se relacionam com segurança humana, e o processo de licenciamento ambiental que focam na redução de colisões com animais são altamente recomendados.
- Melhores práticas de manejo, conscientização e mudança social em relação a animais domesticados abandonados, incluindo cavalos, gado e cães;

7.4.2. Próximos passos

- Identificar as espécies de animais silvestres em registros de acidentes envolvendo animais da Polícia Rodoviária Militar no estado de São Paulo.
- Realizar análises mais profundas sobre os custos para a sociedade e análises de custo-benefício na implementação de medidas de mitigação para reduzir as colisões envolvendo mamíferos em escala estadual.

7.5. Próximos passos como um todo

- Para reduzir a mortalidade rodoviária de animais silvestres em rodovias pavimentadas no estado de São Paulo, os órgãos ambientais (Secretaria de Meio Ambiente do Estado de São Paulo (SMA) e CETESB) e agências de transporte (DER, ARTESP, DERSA) devem dialogar constantemente para oferecer soluções práticas durante o planejamento de rodovias e licenciamento ambiental de rodovias;
- O estado de São Paulo precisa de um planejamento de longo prazo para reconectar a paisagem fragmentada, em um nível estrutural e funcional, usando medidas de mitigação como passagens inferiores, viadutos, passagem superiores para animais arborícolas e pontes em áreas prioritárias para conservação cortadas por rodovias, principalmente em Unidades de Conservação de Proteção Integral;
- Do ponto de vista da segurança humana, os engenheiros civis em São Paulo devem começar a incluir a presença, movimento e risco de animais silvestres ao tráfego para elevar os padrões de segurança no planejamento de rodovias - incluindo as novas rodovias ou a duplicação de rodovias existentes;
- De um ponto de vista biológico, a perda de indivíduos de mamíferos, principalmente espécies ameaçadas, por atropelamento deve ser considerada como uma prioridade para reduzir a mortalidade não natural;

7.6. Meus próximos passos

- Os resultados desta tese serão apresentados nas agências de Meio Ambiente e Transporte do estado de São Paulo no segundo semestre de 2019, assim como disponibilizarei todos os dados, análises e mapas que possam ser úteis para essas agências;
- Os capítulos 2 e 3 serão submetidos à publicação no segundo semestre de 2019;
- Vou continuar minha pesquisa sobre ecologia de estradas, mas principalmente focada em entender o impacto real das perdas individuais por animais atropelados em populações de mamíferos silvestres no estado de São

Paulo e como fornecer soluções práticas sobre a redução da mortalidade nas rodovias.