UNIVERSIDADE FEDERAL DE LAVRAS

FERNANDO ANTÔNIO SILVA PINTO

EFEITOS ECOLÓGICOS DAS ESTRADAS NA CONSERVAÇÃO DE ESPÉCIES NA AMERICA LATINA:

ESTADO DO CONHECIMENTO, DESAFIOS E OPORTUNIDADES

LAVRAS – MG

2019

FERNANDO ANTÔNIO SILVA PINTO

EFEITOS ECOLÓGICOS DAS ESTRADAS NA CONSERVAÇÃO DE ESPÉCIES NA AMERICA LATINA: ESTADO DO CONHECIMENTO, DESAFIOS E OPORTUNIDADES

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos Naturais em Paisagens Fragmentadas e Agroecossistemas, para a obtenção do título de Doutor.

Dra. Clara Grilo
Orientadora

Dr. Anthony Paul Clevenger
Coorientador

LAVRAS – MG

2019

Ficha catalográfica elaborada pelo Sistema de Geração de Ficha Catalográfica da Biblioteca Universitária da UFLA, com dados informados pelo(a) próprio(a) autor(a).

Pinto, Fernando Antônio Silva.
Efeitos ecológicos das estradas na conservação de espécies na América Latina: Estado do conhecimento, desafios e oportunidades / Fernando Antônio Silva Pinto. - 2019.
85 p.: il.

Orientadora: Clara Grilo.
Coorientador: Anthony Paul Clevenger.
Tese (doutorado) - Universidade Federal de Lavras, 2019.
Bibliografia.

1. Ecologia de estradas. 2. Vertebrados. 3. América Latina. I. Grilo, Clara. II. Clevenger, Anthony Paul. III. Título.

FERNANDO ANTÔNIO SILVA PINTO

EFEITOS ECOLÓGICOS DAS ESTRADAS NA CONSERVAÇÃO DE ESPÉCIES NA AMERICA LATINA: ESTADO DO CONHECIMENTO, DESAFIOS E OPORTUNIDADES

ECOLOGICAL EFFECTS OF ROADS IN SPECIES CONSERVATION IN LATIN AMERICA: CURRENT KNOWLEDGE, CHALLENGES, AND OPPORTUNITIES

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos Naturais em Paisagens Fragmentadas e Agroecossistemas, para a obtenção do título de Doutor.

APROVADA em 19 de fevereiro de 2019

Dr Eduardo van den Berg UFLA

Drª Fernanda Zimmermann Teixeira UFMG

Dr Nelson Henrique de Almeida Curi UNILAVRAS

Drª Simone Rodrigues de Freitas UFABC

Drª Clara Grilo

Orientadora

LAVRAS-MG

2019

Ao biólogo e amigo Angelo Barbosa Monteiro (in memorian).

Dedico

AGRADECIMENTOS

Começo por agradecer a minha família por todo o apoio, incentivo e as condições de estudo que sempre me foram dadas. Agradeço também as boas energias espirituais que me auxiliaram a chegar até aqui, assim como, ao lado sombrio da força, por me fazer conhecer a dor, o medo e conseguir controla-los (±) até então.

À CAPES pela concessão da bolsa de estudos (Código de financiamento nº 001) valorosa para o desenvolvimento desta tese. Agradeço enormemente a oportunidade de ter convivido e trabalhado com pessoas como a Clara e o Tony, e mais ainda, por saber que continuaremos a trabalhar juntos. “Junta-te aos bons e serás como eles, junta-te aos maus e serás pior do que eles”.

Agradeço pela nova oportunidade concedida em poder agradecer aos revisores anônimos do artigo 1, bem como a A. Bertasoni pelas discussões iniciais sobre biologia e ecologia do tamanduá-bandeira no Brasil. Agradeço ainda aos membros da banca (Eduardo, Fernanda, Nelson e Simone) pelas valiosas contribuições, sugestões e discussões para a melhoria da tese. Agradeço tambem a todos os colegas anônimos (alcoólicos ou não), amigos e professores ao qual tive a satisfação de conversar sobre ciência, zoologia e ecologia ao longo da minha trajetória. Um salve para todos os amigos, antigos e novos, que hoje se espalham pelos rincões desse Brasil e saber que sempre poderei contar.

Agradeço por todo o aprendizado obtido ao longo desses anos de doutorado na UFLA além de todos os amigos que auxiliaram no desenvolvimento desta tese, seja por meio de conversas descontraídas ou pelo auxilio técnico com analise e interpretação de dados e escrita científica. Prefiro não citar nomes com receio de esquecer algum, mas tenho certeza que cada um sabe a influência e a importância que tiveram. Agradeço nominalmente a Ellen C. de Carvalho por toda sua competência, eficiência e prestatividade como secretária do programa de pós-graduação em ecologia aplicada da UFLA.

Luke: *Mas eu não consigo.*

Yoda: *Por isso fracassar você irá.*

Guerra nas Estrelas: O Império Contra-Ataca (1980).

RESUMO

Estradas causam efeitos ecológicos adversos em muitas espécies de animais em todo o mundo principalmente pela fragmentação de habitats e pela mortalidade por atropelamento. Muito do conhecimento sobre tais efeitos vem de regiões temperadas, sobretudo em países do hemisfério norte, com realidades socioambientais particulares. Neste estudo, avaliamos os efeitos ecológicos das estradas em vertebrados terrestres na América Latina por meio de abordagens distintas. No primeiro artigo, empreendo um estudo de revisão sistemática de literatura para a América Latina, buscando acessar o atual estado de conhecimento sobre efeitos ecológicos das estradas, identificar a lacunas deste conhecimento, e, ao mesmo tempo propor uma agenda para futuras pesquisas. Após a revisão de aproximadamente 200 artigos, identificamos uma tendência no aumento das publicações na última década concentrada maioriotariamente na América do Sul, com estudos a nível de indivíduos (mortalidade), focados principalmente em mamíferos. Poucos estudos buscaram entender os efeitos das estradas a nível de populações e genes, bem como avaliar medidas de mitigação de impactos. Recomendamos duas estratégias para pesquisas: 1) com foco em quantificar e entender como as espécies (indivíduos) interagem com as estradas bem como as implicações a nível populacional, e, 2) avaliações em escalas regionais e nacionais da vulnerabilidade das espécies auxiliando estrategicamente em tomadas de decisão para conservação. No segundo artigo, analiso os efeitos da fragmentação do habitat e da mortalidade por atropelamentos sobre populações do tamanduá-bandeira (*Myrmecophaga tridactyla*) no Brasil. Aplico um modelo populacional espacialmente-explícito para estimar a área mínima de mancha de habitat abaixo do qual as populações não são viáveis e a densidade máxima de estradas tolerada pela espécie. Os resultados revelaram valores mínimos de tamanho de habitat variando entre 247 e 498 km² e densidade máxima de estradas entre 0.21 e 0.55 km/km². Ademais, revelamos ainda, que entre 32 e 36% do total da área de distribuição do tamanduá-bandeira são inadequadas à sua persistência.

Palavras-chave: Tamanduá-bandeira. Fragmentação. Atropelamento. Persistência populacional. América Latina. Efeito das estradas. Revisão de literatura

ABSTRACT

Roads can cause adverse ecological effects for many animal species worldwide, mainly due to habitat fragmentation and mortality from collision with vehicles. Much of the knowledge about such effects come from temperate regions in countries of the northern hemisphere, with different socioenvironmental realities. In this study, we analyzed the ecological effects of roads on vertebrate species in Latin America over different approaches. In the first article, I carried out a systematic literature review in order to assess the current state of knowledge about the ecological effects of roads on vertebrates in Latin America, to identify gaps of knowledge and, then to propose an agenda for future research. After reviewing nearly 200 articles, we identified a trend in the increase of publications in the last decade concentrated mainly in South America, with studies at the individual level (mortality), focused mainly on mammals. Few studies tried to understand the effects on the population level and gene level, neither evaluation of mitigation measures. We recommended a two-speed approach to research: a first, focused on quantifying how species (individuals) interact with roads as well as their implications at the population level, and a second that assess the vulnerability of the species to the roads at regional or national scales. In the second paper, I analyzed the effects of habitat fragmentation and road-kills over giant-anteater (*Myrmecophaga tridactyla*) populations in Brazil. We use a spatially-explicit population model that reaches outputs approximations on minimum patch size and maximum road density required for giant anteater populations viability. The results showed that minimum patch size estimations varying between 247 and 498 km² and the maximum road densities between 0.21 and 0.55 km/km². Furthermore, we showed that unsuitable areas for the species persistence ranged between 32 to 36% of their range in Brazil.

Keywords: Giant anteater. Fragmentation. Road-kills. Population persistence. Latin America. Road effects. Literature review.

LISTA DE FIGURAS

PRIMEIRA PARTE

SEGUNDA PARTE

ARTIGO 1

ARTIGO 2

SUMÁRIO

PRIMEIRA PARTE

1 INTRODUÇÃO

Infraestruturas de transporte como estradas e ferrovias têm protagonismo histórico na sociedade humana moderna, ao conectar pessoas, serviços e mercados, além de serem estratégicas em contextos geopolíticos e econômicos (VAN DER REE; SMITH; GRILO, 2015). Componentes já integrados à paisagem moderna, as redes de estrada cobrem aproximadamente 21 milhões de quilômetros da superfície da Terra, com projeções para a construção de mais 4 milhões até 2050 (MEIJER et al., 2018) sobretudo em países em desenvolvimento como na Ásia (MAHMOUD et al., 2017), África (ASCENSÃO et al., 2018; SLOAN et al., 2018) e América do Sul (LAURANCE; BALMFORD, 2013; BAGER et al., 2015). Em particular, há um especial empenho por parte dos países da América do Sul em expandir e integrar seus modais de transporte, e fortalecer regionalmente o comercio de mercadorias e exportações (CONSEJO SURAMERICANO DE INFRAESTRUCTURA Y PLANEAMIENTO - COSIPLAN, 2017). Quase metade dos projetos do Conselho (46%) são voltados para ampliação e/ou melhoria de estradas, avançando dentre áreas já densamente povoadas, a áreas naturais remotas e pouco conhecidas e com interesse de conservação a nível mundial (AUBAD; ARAGÓN; RODRÍGUEZ, 2010; CARVALHO; MUSTIN, 2017). Pesquisas em ecologia de estradas mostram que tais infraestruturas trazem consigo efeitos ecológicos diversos, em geral prejudicais à conservação da biodiversidade (LAURANCE, 2015).

De modo geral, os efeitos das estradas estão relacionados aos processos de fragmentação e degradação de habitats, destacados como importantes causadores de declínios e perda de espécies em todo o mundo (GIBBON et al., 2000; CROOKS et al., 2017). A fragmentação do habitat causada pela construção de uma estrada pode gerar efeitos adversos nas bordas de habitats (FUENTES-MONTEMAYOR et al., 2009; HADDAD et al., 2015), subdivisões e isolamento das populações (JAEGER, 2013), alterar o comportamento de animais (CHEN; KOPROWSKI, 2016) e reduzir a diversidade genética (BALKENHOL et al., 2013). Infraestruturas de transporte podem atuar como catalisadoras dos processos indiretos de fragmentação e degradação de habitats, posto que acelera efeitos resultantes da ação humana, dentre eles: desmatamentos, assentamentos ilegais e especulações de terras, (BOTTAZZI; DAO, 2013; BARBER et al., 2014; FEARNSIDE, 2015), além de efeitos diretos provenientes do tráfego de veículos, como a poluição química, sonora e visual (ARÉVALO; NEWHARD, 2011; MAYNARD et al., 2016) e mortalidade por atropelamento (GALINA; MIHART, 2018; MAGIOLI et al., 2018).

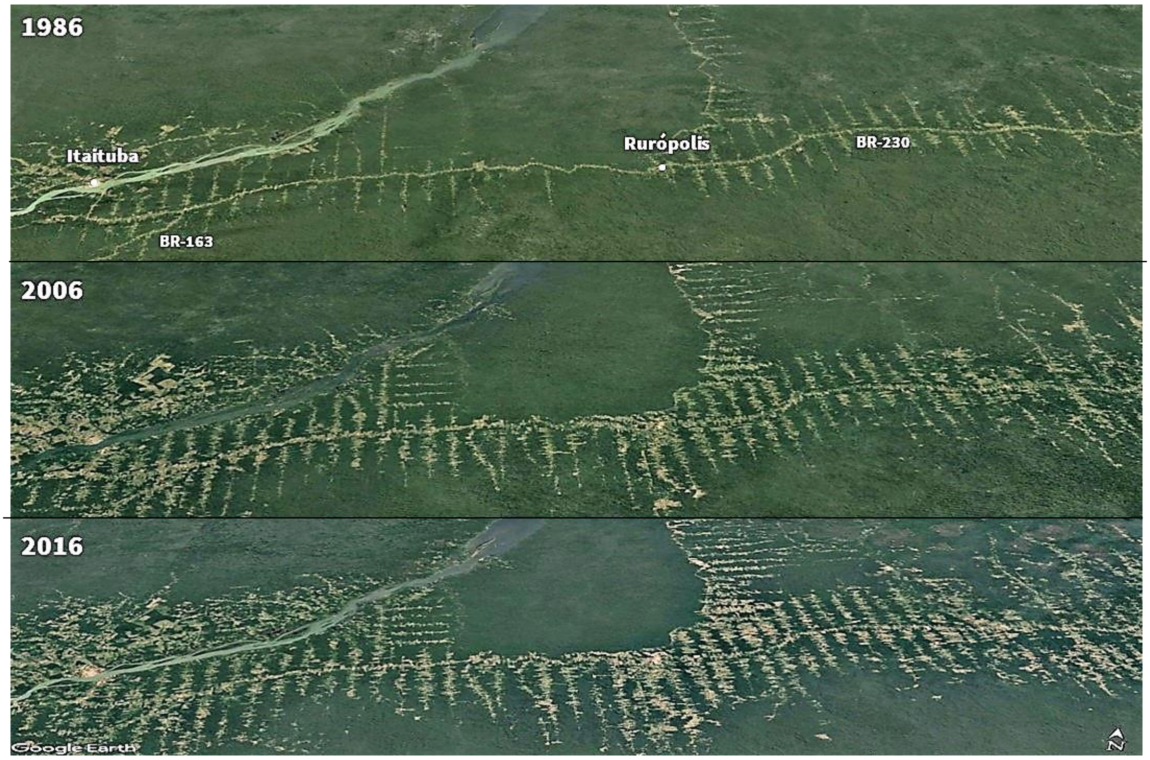
O atropelamento de animais silvestres constitui uma das mais importantes ameaças à conservação de espécies nos dias de hoje (MUMME et al., 2000; FISCHER et al 2018). A perda de indivíduos por atropelamento pode resultar em mudanças na dinâmica e viabilidade de populações (BORDA-DE-ÁGUA; GRILO; PEREIRA, 2014), especialmente para espécies com baixa densidade populacional e potencial reprodutivo como mamíferos de médio e grande porte (RYTWINSKI; FAHRIG, 2015), podendo levar ao declínio dessas populações (BENÍTEZ-LÓPEZ; ALKEMADE; VERWEIJ, 2010). Adicionalmente, os atropelamentos podem causar prejuízos materiais além de sérios riscos a vida humana (HUIJISER et al., 2013), desta forma, é imperioso que se desenvolvam pesquisas no intuito de reduzir ou evitar a mortalidade por atropelamento tanto para garantir a segurança rodoviária quanto proteger as populações silvestres (GUNSON; TEIXEIRA, 2015; RYTWINSK et al., 2015).

Entender como, onde, porque e quais espécies tendem a cruzar as estradas são questões essenciais e importantes nas tomadas de decisões (GRILO et al., 2012; RYTWINSKI; FAHRIG, 2012) e se mostra um campo de pesquisa florescente na América Latina (GONZÁLEZ-SUÁREZ; ZANCHETA; GRILO, 2018; ASSIS; GIACOMINI; RIBEIRO, 2019). Estudos recentes mostram que as espécies respondem de forma diferente a presença das estradas e ao tráfego, podendo causar efeito de repulsa em espécies de primatas, carnívoros, roedores e aves na América Central e do Sul (DEVELEY; STOUFFER, 2001; COLCHERO et al., 2011; ASCENSÃO et al., 2017; ASENSIO et al., 2017), podem ter efeitos mistos (repulsa e atração) na ocorrência de pequenos mamíferos (SALINAS; ARANDA, 2012; ROSA et al 2017) e até favorecer a presença de grandes herbívoros como os guanacos (*Lama guanicoe*) (CAPPA et al., 2017) e espécies invasoras na região sul da América do Sul (GANTCHOFF; BELANT, 2015).

Pesquisas em ecologia aplicada são essenciais para o conhecimento quali-quantitativo bem como para a identificação dos efeitos ecológicos advindos da ação humana (NUÑEZ et al., 2019), e ao mesmo tempo, fundamentais nos processos de tomadas de decisões e implementações de políticas públicas (LAURANCE, 2018). No caso particular da America Latina, há que se considerar o contexto histórico e geográfico da rede de estradas, distribuída de forma heterogênea e onde cada região responde por suas particularidades. Enquanto altas densidades de estradas já existem em regiões específicas nas Américas Central e do Sul (MEIJER et al., 2018), novas redes se formarão em zonas remotas, limítrofes a áreas protegidas e terras indígenas, tendo implicações a nível ecológico, sociocultural e consequentemente levando a tomadas de decisões distintas (BARNI et al., 2012; ESPINOSA; BRANCH; CUEVA, 2014; LAURANCE; ARREA, 2017). Por exemplo, áreas sob influência da estrada transamazônica no estado do Pará (Figura 1), veem suas taxas de desmatamento se elevarem devido a grilagem e ocupação ilegal de terras quando há “rumores” sobre pavimentação da estrada (IMAZON, 2017). Segundo FEARNSIDE (2008), a relação entre estradas e desmatamento na Amazônia envolve uma imbricada trama com diferentes atores (ex. posseiros e grileiros de terras, mineradores e madeireiros, fazendeiros e latifundiários), cada um com seu papel e atuações distintas conforme a época e a região, sendo imprescindível um maior controle, fiscalização e adoção de políticas públicas por parte dos governos. Por outro lado, regiões no centro-sul da América do Sul e da América Central, contam com uma paisagem bastante fragmentada (FREITAS et al., 2013) requerendo ações e planejamentos distintos, focados principalmente na redução dos atropelamentos (CIOCHETI et al 2017; SECCO; ROSA; GONÇALVES, 2018) e na desfragmentação de habitats (GALINA; MIHART; CALVA, 2018).

O objetivo geral desta tese é avaliar os efeitos das estradas sobre espécies de vertebrados na América Latina através de abordagens científicas distintas. Para cumprir este objetivo, compilei toda a informação disponível na literatura científica sobre efeitos das estradas em vertebrados na América Latina por meio de uma revisão sistemática de literatura. O intuito foi caracterizar o atual estado de conhecimento sobre o tema, identificar lacunas de conhecimento e nortear futuras pesquisas (Artigo 1 – Submetido ao periódico *Conservation Biology*). Além disso, aplico um modelo populacional espacialmente-explícito no intuito de entender como os atropelamentos e a fragmentação de habitat afetam populações do tamanduá-bandeira (*Myrmecophaga tridactyla*) no Brasil (Artigo 2 – Publicado no periódico *Biological Conservation*).

Figura 1. Imagens de satélite em três momentos distintos da estrada transamazônica - BR-230 - em seu entroncamento com a BR-163 (Cuiabá – Santarém), região central do estado do Pará e da Amazônia Brasileira.



Fonte: GOOGLE, 2018

2 CONCLUSÃO GERAL

Esta tese traz resultados que vêm a contribuir para o entendimento dos efeitos das estradas na conservação de espécies na América Latina e em especial nas populações de tamanduá-bandeira no Brasil. Apresento o primeiro esforço de revisão sobre o estado de conhecimento dos efeitos ecológicos das estradas em vertebrados terrestres na América Latina. Estudo este, essencial na definição de lacunas de conhecimento, tanto no aspecto geográfico quanto taxonômico, fundamental para o direcionamento de pesquisas, planejamento e priorização de medidas de mitigação dos efeitos negativos das estradas sobre a biodiversidade.

Muitos estudos já existem sobre a quantificação de atropelamentos e identificação de seus padrões espaciais (COELHO et al., 2008; ASCENSÃO et al., 2017; GALLINA; MIHART, 2018), ainda assim, não é suficiente para conhecer o real impacto na viabilidade de populações. Uma vez que nem todas as espécies são vulneráveis à quantidade de atropelamentos (ex. CEIA-

HASSE et al., 2017), o uso de modelos populacionais espacialmente explícitos é uma estratégia valiosa no entendimento dos reais impactos das estradas, quer ao nível da perda e fragmentação do habitat quer ao nível da mortalidade adicional provocada por colisões com veículos. Estratégias para a conservação necessitam de modelos precisos para melhor definir prioridades de mitigação dos efeitos negativos. Desta forma, é necessário melhorar a veracidade dos modelos com parâmetros mais refinados sobre histórias de vida das espécies, além de um melhor conhecimento sobre o comportamento das espécies em relação a estradas. Nos parágrafos seguintes, apresento a conclusão geral desta tese, fragmentada conforme o *Estado do conhecimento, Desafios* e *Oportunidades.*

2.1 Estado do conhecimento

O conhecimento sobre os efeitos ecológicos das estradas na América Latina está distribuído de forma irregular entre os países, concentrado principalmente na América do Sul (89%), com destaque para o Brasil que conta com mais da metade do total de estudos (51%). Dentre as áreas de pesquisa, há um predomínio de estudos relativos a quantificação dos atropelamentos, direcionados principalmente para mamíferos de médio e grande porte. A Ecologia de Estradas apresenta-se como um campo de pesquisa promissor na América Latina, todavia, o conhecimento básico sobre os impactos ecológicos das estradas ainda é uma lacuna em diversos países e regiões do continente. A revisão sistemática de literatura empreendida no Artigo 1, indica uma total ausência de conhecimento em países da região do “Cone Sul” na América do Sul (ex. Paraguai e Uruguai), além de muitos outros na América Central e Caribe (ex. Nicarágua, Honduras, El Salvador, Cuba).

No Artigo 2, os resultados sugerem que as áreas críticas à viabilidade populacional do tamanduá-bandeira no Brasil podem variar entre 32-36% do total de sua área de distribuição. Os modelos indicaram ainda que a fragmentação de habitats tem um impacto importante na conservação do tamanduá e que aproximadamente 21% da quantidade de habitat favorável a presença da espécie está abaixo do tamanho mínimo estimado. Este estudo é a primeira tentativa de se avaliar as implicações da rede de estradas sobre populações do tamanduá-bandeira em escala nacional, e traz ainda informações básicas sobre pressões antrópicas, ao quantificar, por exemplo, classes de cobertura do solo e densidade de estradas em sua área de distribuição. Mostramos que as regiões centro-sul se encontram altamente fragmentadas e com maiores densidades de rodovia, enquanto a região norte conta com importantes remanescentes contínuos de habitats.

2.2 Desafios

Projeções indicam um cenário de expansão da rede mundial de estradas lideradas principalmente por países em desenvolvimento, muitos destes, localizados na América Latina (MEIJER et al., 2018) e em regiões de valor mundial para conservação (LAURANCE; BALMFORD, 2013). Existem vários desafios para prevenir o impacto negativo das estradas dos quais destaco: 1) ampliar o conhecimento sobre os efeitos ecológicos das estradas na América Latina para além do Brasil; 2) investir em projetos de monitoramento antes e após a construção/ampliação das estradas (TAYLOR; GOLDINGWAY, 2014; CIOCHETI et al., 2017); 3) monitorar e controlar os efeitos indiretos associados as estradas (ex. desmatamentos, assentamentos ilegais, queimadas, tráfico e comércio ilegal de animais), principalmente em áreas de floresta contínua como na Bacia Amazônica e 4) analisar as vantagens e desvantagens socioeconômicas da construção de estradas em áreas de conservação e ter a opção de não construir, quando os custos ambientais excedem os ganhos socioeconômicos (LAURANCE, 2018).

Cerca de 25% das espécies de mamíferos encontram-se ameaçadas de extinção em todo o mundo (IUCN, 2019), principalmente devido à perda e fragmentação de seus habitats, além de impactos antrópicos diretos como as mortes por colisão com veículos. Dessa forma, estratégias que busquem acessar e quantificar os efeitos das estradas no declínio de populações são tarefas essenciais, e não menos desafiadoras, para a conservação de espécies. O tamanduá-bandeira é uma espécie classificada como Vulnerável de extinção (IUCN, 2019), endêmica e emblemática da América Latina, e vem sendo registrada há décadas em estudos de monitoramento de fauna atropelada no Brasil (FREITAS; JUSTINO; SETZ, 2014). Entender como populações do tamanduá respondem aos efeitos das estradas é essencial para os esforços de conservação da espécie. Aplico nesta tese, uma abordagem macroecológica como uma ferramenta para a acessar os efeitos da fragmentação e dos atropelamentos na conservação da espécie. Nosso modelo vai além da quantificação de indivíduos atropelados nas estradas e pode ser encarado como um primeiro passo na seleção de áreas de risco para viabilidade do tamanduá-bandeira no Brasil (CEIA-HASSE et al., 2017), e como um direcionamento para futuras investigações a escalas locais e regionais com diferentes cenários de rede de estradas e comportamento das espécies face às estradas (GRILO et al., 2019).

2.3 Oportunidades

No artigo 1, vimos que apesar da grande quantidade de estudos em ecologia de estradas, lacunas básicas de conhecimento ainda existem. Dada as dificuldades de financiamento de pesquisa em países em desenvolvimento como os da América Latina, os resultados apresentados nesta tese podem auxiliar no melhor direcionamento, ao focar em áreas específicas de pesquisa (ex. biodiversidade, mitigação) e grupos taxonômicos (ex. anfíbios, répteis). São necessárias pesquisas em biodiversidade que tentem analisar por exemplo como a diversidade e distribuição de espécies variam perto de diferentes tipos de rodovias (TORRES et al., 2016), além de estudos que quantifiquem o comportamento individual das espécies frente as estradas e ao tráfego (GRILO et al., 2012). Estudos que analisem padrões temporais e espaciais de atropelamentos serão essenciais para auxiliar nos esforços de mitigação além de serem importantes para aplicação de modelos de previsão de riscos de atropelamento em diferentes escalas espaciais. A lacuna de conhecimento em pesquisas de mitigação parece ser um reflexo de poucos projetos de mitigação de impactos viários sobre a vida silvestre na América Latina. As pesquisas em mitigação devem ser de longo prazo tornando-se base para o desenvolvimento de melhores práticas de manejo, sensíveis a diferentes contextos ecológicos, socioeconômicos e políticos (VAN DER GRIFT, 2005).

Estudos que busquem entender como as espécies interagem com as estradas, a influência das mesmas na estrutura e persistência de populações, tanto em escalas regionais quanto nacionais, se fazem essenciais para conhecer os mecanismos subjacentes aos impactos das estradas, e desta forma, aplicar as medidas mais adequadas para mitigar os efeitos negativos. Pesquisas que avaliem o comportamento animal, o fluxo gênico, a abundância relativa das espécies em diferentes paisagens fragmentadas por estradas, podem vir a ser uma importante estratégia para a validação dos modelos apresentados no Artigo 2. Mais pesquisas sobre biologia e ecologia populacional do tamanduá-bandeira em diferentes regiões do Brasil são essenciais. Destaca-se neste contexto, o projeto “Bandeiras e Rodovias” (www.tamanduabandeira.org/) que pretende contribuir com informação de base sobre a espécie, auxiliando dessa forma na capacidade de inferência de futuros modelos.

A formação de redes de coordenação de pesquisa ajudaria a desenvolver cooperativamente e disseminar soluções localmente apropriadas para problemas ambientais associados a rede de estradas na América Latina (PORTER, 2012). Para além das redes de pesquisadores, o desafio futuro deverá ser a criação de redes de cooperação com todas as instituições implicadas na construção de estradas com as agencias publicas e privadas de transportes, ONGs, agencias estatais de conservação, universidades e grupos de pesquisa para definir prioridades em termos de ações de forma a promover uma rede de cooperação ambientalmente sustentável. Iniciativas como essas já se iniciaram em países da América do Sul incluindo o Brasil (BAGER, 2017), Uruguai (www.ecobiouruguay.org.uy) e Colômbia (www.recosfa.com/), e que porventura, pode vir a ser o primeiro passo para a estruturação de uma rede eficaz de estudos, monitoramento dos impactos e mitigação dos efeitos negativo das estradas na biodiversidade.

REFERÊNCIAS

ARÉVALO, J. E.; NEWHARD, K. Traffic noise affects forest bird species in a protected tropical forest. **Revista de Biologia Tropical,** San José v. 59, n. 2, p. 969–980, Jun. 2011.

ASCENSÃO, F.; DESBIEZ, A. L. J.; MEDICI, E. P.; BAGER, A. Spatial patterns of road mortality of medium–large mammals in Mato Grosso do Sul, Brazil. Wildlife Research, v. 44, p. 135, Mar. 2017.

ASCENSÃO, F. et al. The effect of roads on edge permeability and movement patterns for small mammals: a case study with Montane Akodont. **Landscape Ecology,** Tempe, v. 32, n. 4, p. 781–790, Jan. 2017.

ASCENSÃO, F. et al. Environmental challenges for the Belt and Road Initiative. **Nature Sustainability,** London, v. 1, p. 206–209, Mai. 2018.

ASENSIO, N. et al. The effect of roads on spider monkeys' home range and mobility in a heterogeneous regenerating forest. **Biotropica**, Washington, v. 49, n. 4, p. 546–554, Abr. 2017.

ASSIS, J. C. et al. Road Permeability Index: Evaluating the heterogeneous permeability of roads for wildlife crossing. **Ecological Indicators,** London**,** v. 99, n. XX, p. 365–374, 2019.

AUBAD, J. et al. Human access and landscape structure effects on Andean forest bird richness. **Acta Oecologica**, v. 36, n. 4, p. 396–402, Ago. 2010.

BAGER, A. et al. The Influence of Economics, Politics and Environment on Road Ecology in South America. Pages 407- 413, in van der Ree, R, Smith DJ, Grilo C, editors. **Handbook of Road Ecology**. Wiley Blackwell, 2015.

BAGER, A. **Sumário executivo da estratégia nacional para a mitigação de impactos da infraestrutura viária na biodiversidade**. Coordenação: Alex Bager - Lavras: UFLA, Mar. 2017.

BALKENHOL, N. et al. Landscape-level comparison of genetic diversity and differentiation in a small mammal inhabiting different fragmented landscapes of the Brazilian Atlantic Forest. **Conserv. Genet**., v. 14, p. 355-367, Fev. 2013.

BARBER, C. P. et al. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. **Biological Conservation,** Washington**,** v. 177, p. 203–209, Ago. 2014.

BARNI, P. E. et al. Desmatamento no sul do estado de Roraima: padrões de distribuição em função de projetos de assentamento do INCRA e da distância das principais rodovias (BR-174 e BR-210). **Acta Amazonica,** Manaus, v. 42, n. 2, p. 195–204. 2012.

BENÍTEZ-LÓPEZ, A. et al. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. **Biological Conservation**, Washington, v. 143, p. 1307-1316, Mar. 2010.

BORDA-DE-ÁGUA, L. et al. Modeling the impact of road mortality on barn owl (Tyto alba) populations using age-structured models. **Ecological Modelling**, v. 276, p. 29-37, Jan. 2014.

BOTTAZZI, P.; DAO, H. On the road through the Bolivian Amazon: A multi-level land governance analysis of deforestation. **Land Use Policy**, v. 30, p. 137–146, Mar. 2013.

CAPPA, F. M. et al. Effects of roads on the behaviour of the largest South American artiodactyl (*Lama guanicoe*) in an Argentine reserve. **Animal Behaviour,** v. 131, p. 131–136, Jun. 2017.

CARVALHO, W. D.; MUSTIN, K. The highly threatened and little known Amazonian savannahs. **Nature Ecology and Evolution,** London**,** v. 1, n. 0100, p. 1–3, Mar. 2017.

CEIA-HASSE, A.; BORDA-DE-ÁGUA, L.; GRILO, C.; PEREIRA, H.M. Global exposure of carnivores to roads. **Glob. Ecol. Biogeogr**, v. 26, p. 592-600, 2017.

CHEN, H. L.; KOPROWSKI, J. L. Barrier effects of roads on an endangered forest obligate: Influences of traffic, road edges, and gaps. **Biological Conservation**, Washington, v. 199, p. 33-40, Mar. 2016.

CIOCHETI, G. et al. Highway widening and underpass effects on vertebrate road mortality. **Biotropica,** Washington, v. 49, n. 6, p.765–769, Mar. 2017.

CROOKS, K. R. et al. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. **Proc. Natl. Acad**., v. 114, n. 29, p. 7635-7640, 2017.

COELHO, I. P.; KINDEL, A.; COELHO, A. V. P. Roadkills of vertebrate species on two highways through the Atlantic Forest Biosphere Reserve, southern Brazil. **European Journal of Wildlife Research**, v. 54, p. 689–699, Jul. 2008.

COLCHERO, F. et al. Jaguars on the move: Modeling movement to mitigate fragmentation from road expansion in the Mayan Forest. **Animal Conservation,** Cambridge**,** v. 14, n. 2, p. 158–166, Set. 2011.

COSIPLAN (Consejo Suramericano de Infraestructura y Planeamiento). Cartera de proyectos 2017. **Foro técnico IISRA, Comité de Coordinación Técnica**. Buenos Aires, Argentina. p. 269, Dez. 2017.

DEVELEY, P. F.; STOUFFER, P. C. Effects of roads on movements by understory birds in mixed-species flocks in Central Amazonian Brazil. **Conservation Biology,** Washington, v. 15, n. 5, p. 1416–1422, Nov. 2001.

ESPINOSA, S. et al. Road development and the geography of hunting by an amazonian indigenous group: Consequences for wildlife conservation**. PLoS ONE,** San Francisco, v. 9, n. 12, p. 1–21, Dez. 2014.

FEARSNIDE, P. M. The roles and movements of actors in the deforestation of Brazilian Amazonia. **Ecology and Society,** v. 13, n. 1, art. n. 23, Jun.2008.

FEARNSIDE, P. M. Highway Construction as a Force in the Destruction of the Amazon Forest. Pages: 414-423, in van der Ree, R, Smith DJ, Grilo C, editors. **Handbook of Road Ecology**. Wiley Blackwell, 2015.

FISCHER, W. et al. Roadkill records of reptiles and birds in Cerrado and Pantanal landscapes. **Check List,** v. 14, n. 5, p. 845–876, Out. 2018.

FREITAS, S. R. et al. How are native vegetation and reserves affected by different road types in a southeastern Brazilian state? **Oecologia Australis,** Rio de Janeiro, v. 17, n. 4, p. 447–458. Dez. 2013.

FREITAS, C. H.; JUSTINO, C. S.; SETZ, E. Z. F. Road-kills of the giant anteater in south-eastern Brazil: 10 years monitoring spatial and temporal determinants. **Wildlife Research**, v. 41, p.673–680, Mar. 2014.

FUENTES-MONTEMAYOR, E. et al. Living on the edge: roads and edge effects on small mammal populations. **Journal of Animal Ecology**, v. 78, p. 857–865. 2009

GALLINA, G. A.; HIDALGO-MIHART, M. G. A Review of Road-killed Felids in Mexico. **Therya,** Ciudad de Mexico**,** v. 9, n. 2, p. 147–159. 2018

GALLINA, G. A. et al. Conservation implications for jaguars and other neotropical mammals using highway underpasses. **PLoS ONE,** San Francisco**,** v. 13, n. 11, p. 1–20, Nov. 2018.

GANTCHOFf, M. G.; BELANT, J. L. Anthropogenic and environmental effects on invasive mammal distribution in northern Patagonia, Argentina. **Mammalian Biology,** v. 80, n. 1, p. 54–58, Out. 2015.

GIBBON, J. W. et al. The Global Decline of Reptiles, Déjà Vu Amphibians. **BioScience,** v. 50, n. 8, p. 653–666, Jan. 2000.

GOOGLE. Google Earth Pro. Versão 7.3. 2018. Imagens históricas. Acesso em: 10/01/2019.

GONZÁLEZ-SUÁREZ, M. et al. Spatial and species-level predictions of road mortality risk using trait data. **Global Ecology and Biogeography,** Tucson**,** v. 27, n. 9, p. 1–12, Mai. 2018.

GRILO, C. et al. Individual Spatial Responses towards Roads: Implications for Mortality Risk. **PLoS ONE**, San Francisco, v. 7, n. 9, p. 1–11, Set. 2012.

GRILO, C.; PINTO, F. A. S.; ANDRÁŠIK, R.; PEREIRA, H. M.; CLEVENGER, A.P. 2019. Reply: Modeling scenarios of population response to roads as a conservation risk assessment strategy. **Biological Conservation,** v. 230, p. 201–202, Jan. 2019.

GUNSON, K.; TEIXEIRA, F. Z. Road-Wildlife Mitigation Planning can be Improved by Identifying the Patterns and Processes Associated with Wildlife-Vehicle Collisions. Pages: 101-109, in van der Ree, R, Smith DJ, Grilo C, editors. **Handbook of Road Ecology**. Wiley Blackwell, 2015.

HADDAD, N. M. et al. Habitat fragmentation and its lasting impact on Earth's ecosystems. **Sci. Adv**., v. 1, n. 2, p. 1-9, Mar. 2015.

HUIJSER, M. P. et al. Mammal road mortality and cost–benefit analyses of mitigation measures aimed at reducing collisions with capybara (*Hydrochoerus hydrochaeris*) in São Paulo State, Brazil. **Oecologia Australis,** Rio de Janeiro**,** v. 17, n. 1, p. 129–146. Mar. 2013.

INSTITUTO DO HOMEM E MEIO AMBIENTE DA AMAZÔNIA - IMAZON, 2017. Relatório de atividades 2017.

IUCN (international Union for Conservation of Nature and Natural Resources) 2019. **The IUCN Red List of Threatened Species**. Version 2018-2. http://www.iucnredlist.org.

JAEGER, J. A. G. Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. **Landscape Ecology**, v. 15, n. 2, p. 115–130, 2000.

LAURANCE, W. F.; BALMFORD, A. 2013. Land use: A global map for road building. **Nature**, v. 495, p**.** 308–309, Mar. 2013.

LAURANCE, W. F. If you can't build well, then build nothing at all. **Nature**, v. 563, p**.** 295, Mar. 2013.

LAURANCE, W. F. Bad Roads, Good Roads. Pages: 10-15, in van der Ree, R, Smith DJ, Grilo C, editors. **Handbook of Road Ecology**. Wiley Blackwell, 2015.

LAURANCE, W. F.; ARREA, I. B. Roads to riches or ruin? **Science,** New York, v. 358, n. 6362, p. 442–444, Out. 2017.

LAURANCE, W. F. Conservation and the Global Infrastructure Tsunami: Disclose, Debate, Delay! **Trends in Ecology & Evolution,** Cambridge, v. 33, n. 8, p. 1–4, Jun. 2018.

MAHMOUD, M. I. et al. Alternative routes for a proposed nigerian superhighway to limit damage to rare ecosystems and wildlife. **Tropical Conservation Science,** v. 10, p. 1-10, Abr. 2017.

MAYNARD, R. J. et al. Road-Edge Effects on Herpetofauna in a Lowland Amazonian Rainforest. **Tropical Conservation Science,** v. 9, n. 1, p. 264–290, Mar. 2016.

MEIJER, J. R. et al. Global patterns of current and future road infrastructure. **Environmental Research Letters,** v. 13, n. 6, p. 1-11, Mai. 2018.

MUMME, R. L. et al. Life and death in the fast lane: Demographic consequences of road mortality in the Florida Scrub-Jay. **Conservation Biology,** v. 14, n. 2, p. 501–512, Ago. 2000.

NUÑEZ, M. A. et al. Assessing the uneven global distribution of readership , submissions and publications in applied ecology : obvious problems without obvious solutions. **Journal of Applied Ecology,** v. 56, p. 4–9. Jan. 2019.

PORTER et al. Research Coordination Networks: Evidence of the relationship between funded interdisciplinary networking and scholarly impact. **BioScience**, v. 62, p. 282-288, 2012.

ROSA, C. A. et al. Edge effects on small mammals: Differences between arboreal and ground-dwelling species living near roads in Brazilian fragmented landscapes. **Austral Ecology,** v. 43, n. 1, p. 117–126, Set. 2017.

RYTWINSKI, T.; FAHRIG, L. Do species life history traits explain population responses to roads? A meta-analysis. **Biological Conservation,** v. 147, n. 1, p. 87-98, Jan. 2012.

RYTWINSKI, T.; FAHRIG, L. The Impacts of Roads and Traffic on Terrestrial Animal Populations. Pages: 237-246, in van der Ree, R, Smith DJ, Grilo C, editors. **Handbook of Road Ecology**. Wiley Blackwell, 2015.

RYTWINSKI, T. et al. How effective is road mitigation at reducing road-kill? A meta-analysis. **PLoS ONE**, v. 11, n. 11, p. 1–25, Nov. 2015.

SALINAS, F. A.; ARANDA, F. L. Las carreteras pueden restringir el movimiento de pequeños mamíferos en bosques Andinos de Colombia Estudio de caso en el Bosque de Yotoco, Valle del Cauca. **Caldasia,** v. 34, n. 2, p. 409–420, Dez. 2012.

SECCO, H. et al. Biodiversity crisis on Brazilian roads. **Biodiversity**, v. 19, n. 3-4, p. 219-220, Ago. 2018.

SLOAN, S. et al. Hidden challenges for conservation and development along the Trans-Papuan economic corridor. **Environmental Science & Policy,** v. 92, p. 98–106. Nov. 2018.

TAYLOR, B. D.; GOLDINGAY, R. L. Use of highway underpasses by bandicoots over a 7-year period that encompassed road widening. **Australian Mammalogy**, v. 36, p. 178–183, Mai. 2014.

TORRES, A.; JAEGER, J. A. G.; ALONSO, J. C. Assessing large-scale wildlife responses to human infrastructure development. **Proceedings of the National Academy of Sciences**, v. 113, p.8472–8477, Jan. 2016.

VAN DER GRIFT, E. A. Defragmentation in the Netherlands: A Success Story? **GAIA**, v. 14, p. 144 –147, 2005.

VAN DER REE, R. et al. The Ecological Effects of Linear Infrastructure and Traffic: Challenges and Opportunities of Rapid Global Growth. Pages: 1–9, in van der Ree, R, Smith DJ, Grilo C, editors. **Handbook of Road Ecology**. Wiley Blackwell, 2015.

SEGUNDA PARTE – ARTIGOS

ARTIGO 1 -*EFFECTS OF ROADS ON VERTEBRATE SPECIES IN LATIN AMERICA*

(*ARTIGO SUBMETIDO AO PERIÓDICO CONSERVATION BIOLOGY*)

Effects of Roads on Vertebrate Species in Latin America

*Fernando A. S. Pinto[1], Anthony P. Clevenger[2], Clara Grilo[1]
*Corresponding author (asp.fernando@gmail.com)

Article Impact Statement: Our paper reviews the state of research and the main findings, identifies science needs and strategies to inform decision making of road projects in Latin America.

Running head: Road effects in Latin America.

Key words: biodiversity, fragmentation, habitat loss, Latin America, literature review, mitigation, road effects.

Word Count: 7,495.

Author's complete mailing addresses:
[1]Programa de Pós-Graduação Ecologia Aplicada, Universidade Federal de Lavras; Campus Universitário, Postal Code 3037, PO Box 37200-000, Lavras, Minas Gerais Brazil.
[2] Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, Montana USA 59717

Acknowledgements
This study was part of the project 'Road macroecology: Analysis tools to assess impacts on biodiversity and landscape structure' funded by CNPq (no. 401171/2014-0). This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001 1502819. C.G. was supported by CNPq (AJT no. 300021/2015-1). APC was supported by CNPq (Nº 454186/2016-9) and the Woodcock Foundation. We would like to thank to Flavio Zanchetta Ferreira for the first review literature on road-kills in Brazil.

Abstract

Biodiversity in Latin America is at risk today due to habitat loss, land conversion into agriculture and urban areas. The developing countries of South and Central America have begun to invest heavily in new road construction, often with the support of international development banks. Managing the environmental and social impacts of new infrastructure in Latin America will be a challenge given the unprecedented scale of planned investments in the next decade. Understanding the impacts of roads on wildlife communities in Latin America will help inform road planning and mitigation measures. We reviewed 199 papers that showed an increased trend in publications in the last decade with a geographic bias for South America; Brazil accounted for more than a half of the studies. Mammals were the most studied group followed by birds, reptiles and amphibians. Most studies focused on road mortality and at the individual level. Despite a prevalence of studies describing the effects of roads on wildlife, there were few studies evaluating road impacts at population and gene levels. We recommend a two-speed approach to research: one that focuses on quantifying the interaction of individuals towards roads and the implications on the population viability; and a second consisting of regional or continental-scale analyses and modelling of road risks to species and populations to inform road planning immediately. We see an urgent need to employ rapid approaches predictive tools for difficult-to-sample or understudied species and areas, and identify areas for connectivity and biodiversity conservation.

1. Introduction

Latin America is one the most biologically diverse regions in the world encompassing eight of 25 world hotspots for biodiversity conservation (Myers et al. 2000). Tropical ecosystems are especially vulnerable to road impacts due to the ecological specialization of species living within the complex, multi-layered architecture of tropical forests; and edge and barrier effects are exceptionally pronounced for tropical species that are more prone to avoid forest edges and clearings (Laurance et al. 2009). Furthermore, the extension of transportation infrastructure, which facilitates human settlement and increased activity in frontier areas has been identified as one of the primary causes of tropical deforestation (Geist & Lambin 2002).

South and Central America have begun to invest heavily in new road construction, often with the support of international development banks (IDB 2017; CAF 2018). The Initiative for Integration of Regional Infrastructure of South America (IIRSA) was initiated in 2004, signed by 12 countries to build a continental-wide transportation system with many projects in remote and roadless areas (COSIPLAN 2017). In 2014, there were 579 projects with an investment of $US 163 Bn. Ninety percent of IIRSA projects are transportation and half of those are road infrastructure (COSIPLAN 2017).

In the Amazon basin like most tropical regions road projects have many indirect effects: illegal colonization, deforestation, mining and illegal hunting (Fearnside & Graça 2006; Laurance & Balmford 2013). The ambitious plans for IIRSA and other road building programs in Latin America needs to be analyzed with caution since the knowledge on the negative effects on wildlife in these areas are lacking. A qualitative and quantitative assessment of the impacts of roads on wildlife in Latin America is critical to define science-based conservation strategies to mitigate road expansion in the next decades.

Reviews of the effects of roads on wildlife have largely been from developed nations and temperate areas (Trombulak & Frissell 2007; Taylor & Goldingay 2010; Kociolek et al. 2011). The impacts of roads are often qualitatively and quantitatively different in tropical regions than in other ecosystem types (Laurance et al. 2009). Therefore, understanding these impacts, or the lack of, will help to guide road planning and mitigation measures more suitable for the Latin America context. We reviewed existing research on the effects of roads on wildlife in Latin America and identified critical research gaps of knowledge and define future directions for research.

2. Methods

2.1 Literature search and research effort on road ecology

Our review is based on peer-reviewed publications obtained from database searches of Web of Science, Google Scholar, Scopus, Science Direct and contacting colleagues in Latin America. Our search covered geography, taxa, and common terms related to roads (paved, unpaved, traffic, transport, motorway, highway, vehicle). We conducted searches in English, Spanish and Portuguese (Supporting Information) .

Publications were then classified by research area and sub-topics (Supporting Information), geography, taxonomic group (amphibians, reptiles, birds and mammals), level of biological organization (gene, individual, population and ecosystem) (Noss 1990), and type of roads (1-2 lanes unpaved, 1-2 lanes paved, and highways >2 lanes). Our search revealed relative and not absolute measures of activity among research areas and sub-topics. The same publication could be assigned to more than one research area and/or sub-topic.

2.2 Effects of roads on habitat and wildlife vertebrates

Road effects were examined among four research areas (habitat, biodiversity, mortality, mitigation) with associated sub-topics (Supporting Information). Habitat consisted of studies on the effects of roads on species habitat, interpreted as habitat loss and fragmentation from road construction, the opening of new areas for human settlements and deforestation rates. Biodiversity consisted of the effect of roads (single roads or road networks) and traffic on species richness, composition, abundance and behaviour. Mortality examined road-kill occurrence, road-kill rates and spatial/temporal patterns. Mitigation comprised studies that evaluated or recommended mitigation measures.

We categorized the main effects of roads, negative, positive, neutral or contrasting effects, for taxonomic group and by species. We identified gaps in research to help identify future research needs by intersecting research areas and sub-topics with taxonomic groups displayed as a heat map/table.

3. Results

We found a total of 199 studies presenting road effects on wildlife vertebrates in Latin America (see Supporting Information). The majority of studies were from South America (89%), of which more than a half of studies (51.5%) were conducted in Brazil (n=103), followed by Argentina (n=23), Colombia (n=17), Bolivia (n=15) and Ecuador (n=12). Only 11% of the studies were from Central America: Mexico (n=10), Costa Rica (n=10) and Panama (n=3; Figure 1). There is only one study that covered all Latin American countries related to a global analysis of carnivore exposure to roads (Ceia-Hasse et al. 2017; Figure 1). The number of studies has grown since 1990, with a peak in 2013 and slight decline to near 20 studies per year (Supporting Information). Over half of the studies for any given year focused on mortality effects of roads.

3.1 Research effort on road ecology

Studies covered a wide range of taxa, including 61 studies on mammals (30%), 23 on birds (11%), 17 on reptiles (8%) and 7 on amphibians (3.5%). The remaining wildlife studies were multi-taxon (n=61; 30%). A total of 30 studies (15%) documented landscape level effects such as habitat loss due roads, deforestations patterns, land use changes and increased in human access. Two-thirds of studies were at the individual level (65%), followed by community/ecosystems (27%), populations (8%) and genes (1%). More than half of the studies were conducted on 2 lane paved roads (64%), 26% on unpaved roads and only 10% on highways.

Of the research areas (sub-topics) exploring road effects on wildlife, 58 studies addressed road effects on biodiversity (20% species richness, 49% abundance, 31% species behavior), 35 the effects on species habitat, and 110 on mortality (79% species composition, 21% spatial and temporal patterns). Mitigation measures were the focus of 15 studies (56% recommendations, 44% evaluating effectiveness).

Brazil was the only country with studies in all research areas (Figure 2a). Habitat studies were concentrated mainly in countries on the Amazon Basin, while biodiversity studies were distributed throughout South American countries (Figure 1). The heat map revealed a preponderance of mortality studies, comprising nearly half (48%) of all studies, especially for medium-large mammals and reptiles (Figure 2b). Few studies evaluated road effects on amphibians in Latin America (Figure 2b)

3.2 Main effects of roads on habitat and wildlife

3.2.1 Habitat

We found 35 papers related to habitat loss and fragmentation due to roads with the great majority of the studies (95%) having negative effects (Supporting Information). Most of the documented effects were related to an increase in deforestation rates and adverse effects due accessibility like an increase in hunting pressure (Espinosa et al. 2014), illegal logging (Freitas et al. 2013), establishment of human settlements (Bilsborrow et al. 2004; Mertens et al. 2004) and land conversions (Soares-Filho et al. 2004; Bottazzi & Dao 2013).

Nearly 95% of all deforestation in Brazilian Amazon occurred within 5.5 km of roads with lower deforestation rates near protected areas (Barber et al. 2014). In fact, Barni et al. (2012) showed that the availability of roads and the presence of human settlements were strongly related to deforestation rates and a subsequent study showed an increase in illegal activities (logging, hunting) due to the increased accessibility on protected areas in Amazon basin (Kauano et al. 2017). Similar relationship between road network and deforestation, fragmentation and land conversions for agriculture was found in Brazilian Atlantic Forest and Cerrado (e.g. Freitas et al. 2010; Casella & Filho 2013) and in Bolivian Amazon (Locklin & Haack 2003; Forrest et al. 2008; Tejada et al. 2016).

In the Ecuadorian Amazon the establishment of roads by oil companies since the 1990s imposed changes in social aspects for traditional people (Franzen 2006). Among these changes, one of the most important was the emergence of a wild meat market and the increase in settlements along roads, that reduced birds and mammals diversity due hunting pressure on Yasuní Biosphere Reserve (Suárez et al. 2009, 2013). Rates of bushmeat extraction and trade were higher closer to markets than further away. Hunters located closer to markets concentrated their effort on large-bodied species (Espinosa et al. 2014). Nevertheless, because oil roads are controlled for public access, deforestation rates were higher on public-access non-oil roads, and a 1% increase in public roads would result in a 22% increase in agricultural conversion (Baynard et al. 2013).

3.2.2 Biodiversity

3.2.2.1 Species richness

Changes in species richness and composition in response to roads were covered in 15 studies of which 56% were related to bird communities, 17% mammals and amphibian communities, and 5% on reptiles. The effects on species richness varied among taxon; half were found to be negative with roughly a quarter positive (28%) or were neutral (22%; Supporting Information).

Forest bird communities in Brazilian Amazon were affected in species composition and richness where roads were present and effects of human access (logging, fire, hunting, traffic disturbance, edge effects) were greater than habitat loss (Ahmed et al. 2014). Forest bird richness in the Colombian Andes decreased in areas with high access and disturbance (Aubad et al. 2010). Similarly in the Ecuadorian Amazon reduced bird and mammal richness resulted from illegal trade and bushmeat market access from industry roads (Suarez et al. 2013).

Roads had mainly negative effects on the species composition for amphibians in Colombia (Vargas-Salinas 2011) and Ecuador (Withworth et al. 2015). Contrasting effects were found for birds. New habitats created on road edges reduced species richness of savannah and understory birds (Silva et al., 2017, Withworth et al. 2015), while there was no effect on community diversity of birds in a range of habitats (Astudillo et al. 2014, Avalos & Bermúdez, 2016, Bager & Rosa 2012; Supporting Information).

Roads had no effect on medium-large mammal community diversity (Di Bitetti et al. 2013). However, new habitats created on road edges and low-volume unpaved roads had positive effects and increased species richness in diverse terrestrial vertebrate communities (Vargas-Salinas et al. 2009, Weyland et al. 2014, Di Bitetti et al. 2014).

3.2.2.2 Species abundance

The effects of roads on species abundance was addressed in 36 studies: 41% on mammals, 28% birds, 14% and 11% reptiles and amphibians, respectively (Figure 2b). Effects varied among taxon and species groups; more than half were negative effects (60%), 24% neutral and 16% positive (Table 1).

Habitat degradation from the creation of coastal roads reduced population densities of sand-dune lizards in Brazil and Argentina (Rocha et al. 2009; Vega et al. 2000). Changes in bird abundance close to roads was best explained by traffic noise (Arévalo & Newhard 2011), and habitat alterations along road edges (Astudillo et al. 2014; Silva et al. 2017).

There was a negative relationship between increases in road density and population density of Morelet’s Crocodile (*Crocodylus moreletii*) in Mexican wetlands (González-Trujillo et al. 2014). Similar decreases in species abundance near roads occurred for bromeliad amphibians in Ecuadorian Amazon (McCracken & Forstner 2014), for amphibians and reptiles in a lowland Amazonian rainforests of Ecuador (Maynard et al. 2016), and for pumas (*Puma concolor*) in the Argentinian Chaco (Quiroga et al. 2016). High hunting pressure, deforestation and others human activities associated with roads and access explained declines in primates numbers in Peruvian Amazon and French Guiana (Aquino & Charpentier 2014; Thoisy et al. 2010) and among Andean bears (*Tremarctos ornatus*) in Ecuador and Venezuela (Peralvo et al. 2005; Sánchez-Mercado et al. 2008). There were contrasting effects of roads on carnivore species abundance in fragmented landscapes in Central Chile. The responses were species-specific as Chilean cats preferred habitats far from roads and close to large habitat patches, while Andean foxes preferred open habitats close to roads and scarcely used forests in a fragmented landscape (Acosta-Jamett & Simonetti 2004).

Mixed responses to roads were reported for wild boar (*Sus scrofa*) in different parts of Argentina. Occurrence was higher close to roads, using roads for travel through forest patches (Gantchoff & Belant 2015), while occurrence was higher with distance from roads (Cuevas et al. 2013). Some species were found more abundant close to roads. Similarly, abundance of European hares (*Lepus europaeus*) benefited from human settlements and associated roads (Gantchoff & Belant 2015).

3.2.2.3 Species behavior

Wildlife may avoid roads and thus restrict access to important habitat patches (Chen & Koprowski 2016). This is especially true for forest-dependent species such as understory birds that are specialized for forest-interior conditions, strongly avoid forest edges and unable to narrow forest clearings (Develey & Stouffer 2001; Laurance et al. 2004). Spider monkeys (*Ateles sp*) crossed roads where canopy gaps were smallest (Asensio et al. 2017). Jaguars (*Panthera onca*) in Mexico's Mayan forest avoided crossing highways and rarely crossed paved roads (Colchero et al. 2011).

Traffic effects on species behavior is mainly negative (Supporting Information). Bromeliad frogs (*Andinobates bombetes*) avoided vocalizing during periods of high traffic noise levels (Vargas-Salinas 2013). Andean condors (*Vultur gryphus*) changed habitat use and feeding behavior due to roads and traffic, feeding in patches distant from roads (Speziale et al. 2008).

Traffic-related effects had significant impacts on an endemic montane toad (*Melanophryniscus* sp.), limiting their ability to cross roads and increasing habitat isolation (Cairo & Zalba 2007).

Negative effects were also found for small mammals (Supporting Information). Montane akodon rodent (*Akodon montensis*) avoided crossing forest edges near dirt or paved roads compared to roadless edges (Ascensão et al. 2017b). Roads were found to limit seed dispersal by small mammal communities (Lambert et al. 2014). Species-specific responses of small mammals to road edges revealed contrasting effects: ground-dwelling species were attracted to road edges, while arboreal species avoided road edges (Rosa et al. 2017). Two endemic rodents from Cozumel Island showed significant and contrasting changes in population parameters (age structure and gender) between forest interior and edge habitats near roads (Fuentes-Montemayor et al. 2009). A neutral effect was found for a rodent species in an agricultural landscape in Argentina, where there was no genetic differentiation, suggesting gene flow was occurring across the road (Chiappero et al. 2016).

Roads can lead to positive or neutral effects for guanacos (*Lama guanicoe*). Apparently, roads had no negative but potentially positive effects on this species. Guanacos perceive the roadside vegetation as safer in landscapes dominated by open areas to decrease the detection by predators (Marino & Johnson 2012; Cappa et al. 2017).

3.2.3 Mortality

Road mortality represented more than half (n=110) of the studies in Latin America. Most (79%) focused on species composition, less on spatial patterns of mortality. Half of the studies (n=52) analysed the composition of multiple vertebrate taxa; the other half a single taxon level. Mammal studies predominated with 77% (n=88), of which 30% (n=32) were for a single mammal species (Figure 2 b).

Nearly 700 species (n=673) were recorded as road-kill on roads in Latin America. Among vertebrates, birds and reptiles showed the highest richness with 235 and 231 species, respectively; followed by mammals (n=155) and amphibians (n=52) (Supporting Information). Estimates of road-kill rates by species were provided in 73% (n=67) of the studies (Supporting Information). Amphibians had high mean road-kill rate (±SD) with 5.03 (±22.5) ind./km/year, followed by reptiles with 0.317 (±1.012) ind./km/year, mammals 0.166 ind./km/year (±0.5) and birds 0.130 (±0.39). Mortality studies (33%) identified 28 species listed as Threatened (IUCN 2018), 16 classified as Near Threatened, 10 as Vulnerable and two as Endangered (Supporting Information). The majority of threatened species were mammals (n=19), followed by birds (n=6), reptiles (n=2) and amphibians (n=1).

Five studies analysed the implications of road mortality on population viability. Long-term persistence of giant anteaters in a protected area surrounded by high-volume roads in central Brazil was threatened when mortality rates surpassed 5% of the population, as in other protected areas in Brazilian Cerrado (Diniz & Brito 2013, 2015). Road mortality was predicted to impact jaguar population persistence in Atlantic forests in southern Brazil, causing an 80% reduction of metapopulation and 45% of extant population within 100 years (Cullen et al. 2016). High mortality rates among juvenile lava lizards (*Microlophus albemarlensis*) in the Galapagos Islands seriously threatened the populations' long term chance of survival (Tanner et al. 2007). In a global analysis of carnivore exposure to roads, long-term population persistence of four felid species and one canid from Latin America were threatened by roads (Ceia-Hasse et al. 2017). The study found critical areas for species persistence, particularly south-central Mexico and southeast Brazil.

3.2.3.1 Spatial and temporal patterns

Twenty-five studies documented spatial and/or temporal patterns of road-related mortality. Amphibian road-kills were related to traffic volume, presence of water bodies near roads and wet seasons in southern Brazil (Coelho et al. 2012). Traffic volume was associated with road-kills incidences among reptiles in Amazon (Maschio et al. 2016), while in southern Brazil mortality was positively associated with proximity to rice plantations (Gonçalves et al. 2017). Reptile road-kills increased during wet seasons in different regions of Brazil (Santos et al. 2011; Costa et al. 2015; Gonçalves et al. 2017; Miranda et al. 2017). Increasing traffic volume explained road-kill occurrence of rufous-legged-owl (*Strix rufipes*) and bats (Ojeda et al. 2015; Secco et al. 2017). The proximity to rivers and riparian habitats were positively associated with road-kills of medium-large mammals in different roads in Brazil (Bueno et al. 2013, 2015;

Freitas et al. 2015; Ascensão et al. 2017a). Road-kills were found to peak in the dry season for vertebrate species (Melo & Santos-Filho 2007; Cuyckens et al. 2016).

3.2.4 Mitigation

Only 7% (n=15) of studies provided recommendations for mitigation (n=11) or evaluated their effectiveness (n=4). Seven specifically focused on mitigation strategies for mammals, two for amphibians, while five included a multi-taxon approach. Recommendations focused on reducing the number of road-kill (Bager & Rosa 2010; Coelho et al. 2012; Araya-Gamboa & Salom-Pérez 2015; Mata et al. 2016; Ascensão et al. 2017a) and increasing road permeability for individual movements (Colchero et al. 2011).

Two studies evaluated mitigation by quantifying road-kill rates before and after underpass and fencing were installed (Bager & Fontoura 2013; Ciocheti et al. 2017), while Costa et al. (2017) used a spatial analysis to evaluate the efficacy of underpasses in promoting connectivity between landscapes. They showed that underpasses failed to mitigate road-kill rates and the barrier effect of roads. In contrast, a rope bridge made for arboreal species showed positive results in restoring movements and connectivity (Teixeira et al. 2013).

4. Research gaps and future directions for research

4.1 Knowledge gaps

Our review is the first we are aware of from tropical regions and developing nations. The road network in Latin America is expected to increase exponentially (Sanchez 2015, Meijer et al. 2018). Although there were a growing number of papers documenting road effects in Latin America our review revealed some striking patterns.

Firstly, there was a clear geographic imbalance in the distribution of papers, the majority of published work from South America and a glaring deficit from Central American countries. It is not clear what might explain the disproportionate number of papers. Brazil is the largest and most populated country in Latin America, with a long history of biodiversity conservation research, including infrastructure impacts (Reid & Souza 2005; Fearnside 2006). Secondly, although we know roads and traffic can fragment and degrade habitats, limiting gene flow within populations, few Latin papers analyzed road effects at gene or population level

(Chiappero et al. 2016; Cullen et al. 2016). The population-level consequences of roads has received little attention elsewhere as the majority of studies up until now have focused at the individual level and single factors, e.g., mortality, population fragmentation (Bennett 2017). Last, we discovered a discrepancy among research areas. Our heat map showed that the number of papers dealing with mortality (primarily among medium and large-sized mammals) greatly exceeds the number of papers in nearly all other research areas. Because road-kills are the most conspicuous effect of roads, mortality studies are the first step into assessing impacts, plus they are low-cost and relatively easy to conduct. Recently, researchers have begun considering how these same impacts can spur evolutionary changes in organisms (Brady & Richardson 2017).

4.2 Future directions for research

Road ecology is an emerging field of research in Latin America and for the most part the basic science regarding road effects on wildlife communities is still lacking. To adequately quantify the environmental trade-offs for transportation infrastructure expansion projects, basic scientific knowledge is needed to quantify impacts at the landscape level and to increase understanding of the multiple and cumulative effects roads have on threatened ecosystems. There are few research efforts in Latin America addressing the ecological effects of roads and developing science-based solutions for mitigation and best management practices (Teixeira et al. 2016). Herein we describe some recommendations per research area:

Habitat. Few studies directly assessed the thresholds of road density with species densities and distributions. At a local scale, some carnivore species establish in areas below a road density threshold of 0.6 km/km^2 (Frair et al. 2008). At a large scale, assessments of the exposure of terrestrial vertebrates to roads using an integrated modelling framework can be applied at different spatial scales (e.g. Row et al. 2007; Ceia-Hasse et al. 2017). This framework can help assess the effects of developing road networks and inform prioritization schemes for road building, identify areas for conservation, and species requiring particular mitigation and restoration measures.

Biodiversity. Studies analysing how species diversity and distribution varies near road types should be conducted in different ecosystems. Future studies should also focus on understanding individual behavior toward road types (e.g. Grilo et al. 2012). Corridors are important conservation tools to keep wildlife populations viable over the long term, however, roads are rarely part of the conservation equation, and only one paper addressed connectivity (Colchero et al. 2011). Quantifying the interactions of species with roads will provide information on demographic and genetic connectivity, research rarely addressed in Latin America (Bischof et al. 2016). In the tropics, plant-animal mutualisms such as seed dispersal are vital for ecosystem functioning (Wright 2002). A huge body of knowledge has been accumulated on the ecology of those interactions at population level (Dennis et al. 2007). It will be important to know how changes in keystone species abundance and distribution from roads affect ecological processes (Corlett 2017).

Mortality. Further studies are needed to understand the spatial and temporal drivers of wildlife-vehicle collisions to make predictions on road-kill risk. A database was recently compiled of geo-referenced road-kill data in Brazil (Grilo et al. 2018) and can serve as example for other Latin American nations to follow. Empirical estimates of road mortality in Latin America show that some species are more likely to be killed than others, but to what extent this variation can be explained and predicted using intrinsic species characteristics coupled with spatial and temporal factors still remains poorly understood (Gonzalez-Suarez et al. 2018). It is also crucial to evaluate the effect of road-kills on population abundance and persistence (e.g. Beaudry et al. 2008). The road-kill rates estimated in the literature combined with the knowledge of population density and the use of population models can provide insights on the viability of populations in roaded landscapes.

Mitigation. Designing potential solutions and mitigation is context-sensitive to different ecological, socioeconomic and policy environments (Van der Ree et al. 2015). Current lack of mitigation research is an artefact of few mitigation projects in Latin America. Mitigation research should be long-term to account for ecological variability (Hughes et al 2017) and will be the basis for developing context-sensitive best management practices (van der Grift 2005). As more roads are mitigated results of research efficacy can be shared among colleagues working with similar taxa in similar environments. Formation of research coordination networks would help cooperatively develop and disseminate locally appropriate solutions to environmental problems caused by roads in Latin America (Porter 2012, Soler 2014).

Conclusions

Study of the impacts of roads is an emerging research field in Latin America. Research on the impact of roads has never been more urgent or pressing. We suggest a two-speed strategy be used to address the science and decision-making needs to keep up with the fast pace of road building in Latin America (Laurance & Arrea 2017). Local scale research should continue to better understand species, population and ecosystem impacts of roads, in concert with larger, continental-scale analyses and modelling road risks to species and populations to inform road planning immediately. There is a glaring need for research into the ecological effects of roads on wildlife vertebrates in Latin America. Given the lack of research funding in developing nations like those of Latin America, our review can serve to help focus limited research funds on specific research areas, taxonomic groups and ecosystems. This is critically important today given transportation infrastructure development is currently outpacing the research and science needed to inform the burgeoning number of projects, so they are designed with minimal impacts to wildlife communities and biodiversity conservation.

Supporting Information

A list of reviewed studies (Appendix S1), documented effects of roads on wildlife communities in Latin America (Appendix S2), summary of road-kill rates for each species and by each study in Latin America (Appendix S3), systematic quantitative literature review and definition of research areas and sub-topics (Appendix S4), temporal patterns of published studies (Appendix S5), top 20 species with the higher mean of road-kill rates separated by amphibians (Appendix S6), reptiles (Appendix S7), birds (Appendix S8), and mammals (Appendix S9) are available on line. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Acosta-Jamett G, Simonetti JA. 2004. Habitat use by *Oncifelis guigna* and *Pseudalopex culpaeus* in a fragmented forest landscape in central Chile. Biodiversity and Conservation **13:**1135–1151.

Ahmed SE, Lees AC, Moura NG, Gardner TA, Barlow J, Ferreira J, Ewers RM. 2014. Road networks predict human influence on Amazonian bird communities. Proceedings of the Royal Society B: Biological Sciences **281**:1742–1742.

Aquino R, Charpentier E. 2014. Primates Diversity and abundance in habitats of the influence area of the Iquitos – Nauta road , Peruvian Amazon. Ciencia Amazónica **4:**3–12.

Araya-Gamboa D, Salom-Pérez R. 2015. Identificación de sitios de cruce de fauna en la ruta 415, en el “Paso del Jaguar”, Costa Rica. Infraestructura Vial **17:**5–12.

Arévalo JE, Newhard K. 2011. Traffic noise affects forest bird species in a protected tropical forest. Revista de Biologia Tropical **59**: 969–980.

Ascensão F, Desbiez ALJ, Medici EP, Bager A. 2017a. Spatial patterns of road mortality of medium–large mammals in Mato Grosso do Sul, Brazil. Wildlife Research **44**:135-146.

Ascensão F, Lucas PS, Costa A, Bager A. 2017b. The effect of roads on edge permeability and movement patterns for small mammals: a case study with Montane Akodont. Landscape Ecology **32:**781–790.

Asensio N, Murillo-Chacon E, Schaffner CM, Aureli F. 2017. The effect of roads on spider monkeys’ home range and mobility in a heterogeneous regenerating forest. Biotropica **49:**546–554.

Astudillo PX, Samaniego GM, Machado PJ, Aguilar JM, Tinoco BA, Graham CH, Latta SC, Farwig N. 2014. The impact of roads on the avifauna of páramo grasslands in Cajas National Park, Ecuador. Studies on Neotropical Fauna and Environment **49:**204–212.

Aubad J, Aragón P, Rodríguez MÁ. 2010. Human access and landscape structure effects on Andean forest bird richness. Acta Oecologica **36:**396–402.

Ávalos G, Bermúdez E. 2016. Effect of a major highway on the spatial and temporal variation in the structure and diversity of the avifauna of a tropical premontane rain forest. Revista de Biología Tropical **64:**1383–1399

Bager A, Rosa CA. 2012. Impacto da rodovias BR-392 sobre comunidades de aves no extremo sul do Brasil. Brazilian Journal of Ornithology **20:** 30–39.

Bager A, Fontoura V. 2013. Evaluation of the effectiveness of a wildlife roadkill mitigation system in wetland habitat. Ecological Engineering **53:**31–38.

Bager A, Rosa CA. 2010. Priority ranking of road sites for mitigating wildlife roadkill. Biota Neotropica **10:**149–153.

Barber CP, Cochrane MA, Souza CM, Laurance WF. 2014. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. Biological Conservation **177:**203–209.

Barni PE, Fearnside PM, Graça PML de A. 2012. Deforestation in the southern portion of the Roraima State: distribution with respect to INCRA settlement projects and distance from major highways (BR-174 and BR-210). Acta Amazonica **42:**195–204.

Baynard CW, Ellis JM, Davis H. 2013. Roads, petroleum and accessibility: The case of eastern Ecuador. GeoJournal **78:** 675–695.

Beaudry F, de Maynadier PG, Hunter MLJ. 2008. Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. Biological Conservation **141:** 2550–2563.

Bennett VJ. 2017. Effects of Road Density and Pattern on the Conservation of Species and Biodiversity. Current Landscape Ecology Reports **2:**1–11.

Bilsborrow RE, Barbieri AF, Pan W. 2004. Changes in population and land use over time in the Ecuadorian Amazon. Acta Amazonica **34:** 635–647.

Bischof R, Brøseth H, Gimenez O. 2016. Wildlife in a Politically Divided World: Insularism Inflates Estimates of Brown Bear Abundance. Conservation Letters **9:**122–130.

Bottazzi P, Dao H. 2013. On the road through the Bolivian Amazon: A multi-level land governance analysis of deforestation. Land Use Policy **30:**137–146.

Brady, S.P., Richardson, J.L., 2017. Road ecology: shifting gears toward evolutionary perspectives. Frontiers in Ecology and the Environment **15:**91–98.

Bueno C, Faustino MT, Freitas SR. 2013. Influence of landscape characteristics on capybara road-kill on highway BR-040, Southeastern Brazil. Oecologia Australis **17:**130–137.

Bueno C, Sousa COM, Freitas SR. 2015. Habitat or matrix: which is more relevant to predict road-kill of vertebrates? Brazilian Journal of Biology **75:**228–238.

CAF (Development Bank of Latin America). 2018. Annual Report 2017. Caracas: CAF. Available from http://scioteca.caf.com/handle/123456789/1191

Cairo SL, Zalba SM. 2007. Effects of a paved road on mortality and mobility of red bellied toads (*Melanophryniscus* sp.) in Argentinean grasslands. Amphibia Reptilia **28:**377–385.

Cappa FM, Giannoni SM, Borghi CE. 2017. Effects of roads on the behaviour of the largest South American artiodactyl (*Lama guanicoe*) in an Argentine reserve. Animal Behaviour **131:**131–136.

Casella J, Filho ACP. 2013. the Influence of Highway Br262 on the Loss of Cerrado Vegetation Cover in Southwestern Brazil. Oecologia Australis **17:**77–85.

Ceia-Hasse A, Borda-de-Água L, Grilo C, Pereira HM. 2017. Global exposure of carnivores to roads. Global Ecology and Biogeography **26:**592–600.

Chen HL, Koprowski JL. 2016. Barrier effects of roads on an endangered forest obligate: Influences of traffic, road edges, and gaps. Biological Conservation **199**:33-40.

Chiappero MB, Sommaro L V., Priotto JW, Wiernes MP, Steinmann AR, Gardenal CN. 2016. Spatio-temporal genetic structure of the rodent *Calomys venustus* in linear, fragmented habitats. Journal of Mammalogy **97:**424–435.

Ciocheti G, de Assis JC, Ribeiro JW, Ribeiro MC. 2017. Highway widening and underpass effects on vertebrate road mortality. Biotropica **49:**765–769.

Coelho IP, Teixeira FZ, Colombo P, Coelho AVP, Kindel A. 2012. Anuran road-kills neighbouring a peri-urban reserve in the Atlantic Forest, Brazil. Journal of Environmental Management **112:**17–26.

Colchero F, Conde DA, Manterola C, Chávez C, Rivera A, Ceballos G. 2011. Jaguars on the move: Modeling movement to mitigate fragmentation from road expansion in the Mayan Forest. Animal Conservation **14:**158–166.

Corlett RT. 2017. A bigger toolbox: Biotechnology in biodiversity conservation. Trends in Biotechnology **35:** 55-65.

COSIPLAN (Consejo Suramericano de Infraestructura y Planeamiento). 2017. Cartera de proyectos 2017. Foro técnico IISRA, Comité de Coordinación Técnica. Buenos Aires, Argentina. p. 269.

Costa AS, Ascensão F, Bager A. 2015. Mixed sampling protocols improve the cost-effectiveness of roadkill surveys. Biodiversity and Conservation **24:**2953–2965.

Costa MS, Lisbôa JM, Silva MD. 2017. Distribuição e características das passagens de fauna na BR 392, trecho entre Rio Grande e Pelotas/RS - Brasil. Geographia Meridionalis **03:**60–85.

Cuevas FM, Ojeda RA, Jaksic FM. 2013. Multi-scale patterns of habitat use by wild boar in the Monte Desert of Argentina. Basic and Applied Ecology **14:**320–328.

Cullen L, Stanton JC, Lima F, Uezu A, Perilli MLL, Resit Akcakaya H. 2016. Implications of fine-grained habitat fragmentation and road mortality for jaguar conservation in the atlantic forest, Brazil. PLoS ONE **11:**1–17.

Cuyckens GAE, Mochi LS, Vallejos M, Perovic PG, Biganzoli F. 2016. Patterns and Composition of Road-Killed Wildlife in Northwest Argentina. Environmental Management **58:**810–820.

Develey PF, Stouffer PC. 2001. Effects of roads on movements by understory birds in mixed-species flocks in Central Amazonian Brazil. Conservation Biology **15:**1416–1422.

Dennis AJ, Green RJ, Schupp EW, Westcott DA. 2007. Seed dispersal: theory and its application in a changing world. Wallingford: CABI Publishing. 720 p.

Di Bitetti MS, Albanesi SA, Foguet MJ, De Angelo C, Brown AD. 2013. The effect of anthropic pressures and elevation on the large and medium-sized terrestrial mammals of the subtropical mountain forests (Yungas) of NW Argentina. Mammalian Biology **78:** 21–27.

Di Bitetti MS Di, Paviolo A, Angelo C De. 2014. Camera trap photographic rates on roads vs. off roads: location does matter. Mastozoología Neotropical **21:** 37–46.

Diniz MF, Brito D. 2013. Threats to and viability of the giant anteater, *Myrmecophaga tridactyla* (Pilosa: Myrmecophagidae), in a protected Cerrado remnant encroached by urban expansion in central Brazil. Zoologia **30:**151-156.

Diniz MF, Brito D. 2015. Protected areas effectiveness in maintaining viable giant anteater (*Myrmecophaga tridactyla*) populations in an agricultural frontier. Natureza e Conservação **13:**145–151.

Espinosa S, Branch LC, Cueva R. 2014. Road development and the geography of hunting by an Amazonian indigenous group: Consequences for wildlife conservation. PLoS ONE **9**:1–21.

Fearnside PM. 2006. Dams in the Amazon: Belo Monte and Brazil's Hydroelectric Development of the Xingu River Basin. Environmental Management **38**: 16.

Fearnside PM, Graça PMLA. 2006. BR-319: Brazil's Manaus-Porto Velho Highway and the potential impact of linking the Arc of Deforestation to Central Amazonia. Environmental Management **38**:705-706.

Forrest JL, Sanderson EW, Wallace R, Marcelo T, Lazzo S, G LH. 2008. Patterns of Land Cover Change in and Around Madidi National Park , Bolivia. Biotropica **40:**285–294.

Frair JL, Merrill EH, Beyer HL, Morales JM. 2008. Thresholds in landscape connectivity and mortality risks in response to growing road networks. Journal of Applied Ecology **45:** 1504–1513.

Franzen MA. 2006. Evaluating the sustainability of hunting: a comparison of harvest profiles across three Huaorani communities. Environmental Conservation**. 33:** 1–10.

Freitas SR, Hawbaker TJ, Metzger JP. 2010. Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. Forest Ecology and Management **259:**410–417.

Freitas SR, Sousa COM, Boscolo D, Metzger JP. 2013. How are native vegetation and reserves affected by different road types in a southeastern Brazilian state? Oecologia Australis **17:**447–458.

Freitas SR, de Oliveira AN, Ciocheti G, Vieira MV, Matos DM da S. 2015. How landscape features influence road-kill of three species of mammals in the Brazilian savanna? Oecologia Australis **18:**35–45.

Fuentes-Montemayor E, Cuarón AD, Vásquez-Dominguez E, Benítez-Malvido J, Valenzuela-Galván D, Andresen E. 2009. Living on the edge: roads and edge effects on small mammal populations. Journal of Animal Ecology, **78:**857–865.

Gantchoff MG, Belant JL. 2015. Anthropogenic and environmental effects on invasive mammal distribution in northern Patagonia, Argentina. Mammalian Biology **80:**54–58.

Geist HJ, Lambin EF. 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience **52:**143-150.

Gonçalves LO, Alvares DJ, Teixeira FZ, Schuck G, Coelho IP, Esperandio IB, Anza J, Beduschi J, Bastazini VAG, Kindel A. 2017. Reptile road-kills in Southern Brazil: Composition, hot moments and hotspots. Science of the Total Environment **615:**1438–1445.

Gonzáles-Suárez M, Ferreira FZ, Grilo C. 2018. Spatial and species-level predictions of road mortality risk using trait data. Global Ecology and Biogeography DOI.wiley.com/10.1111/geb.12769.

González-Trujillo R, Méndez-Alonzo R, Arroyo-Rodríguez V, Vega E, González-Romero A, Reynoso VH. 2014. Vegetation Cover and Road Density as Indicators of Habitat Suitability for the Morelet’s Crocodile. Journal of Herpetology **48:**188–194.

Grilo C, et al. 2012. Individual Spatial Responses towards Roads: Implications for Mortality Risk. PLoS ONE **7:**1–11.

Grilo C, et al. 2018. Brazil road-kill: a dataset of wildlife terrestrial vertebrate road-kills. Ecology **0 (0**): doi:10.1002/ecy.2464.

Hughes BB, et al. 2017. Long-Term Studies Contribute Disproportionately to Ecology and Policy. BioScience **67:** 271-281.

IDB (Inter-American Development Bank). 2017. Annual Report 2017: The year in review. Available from https://publications.iadb.org/handle/11319/8824.

IUCN 2018. The IUCN Red List of Threatened Species. *Version 2018-1*. <http://www.iucnredlist.org>. Downloaded on 05 July 2018.

Kauano ÉE, Silva JMC, Michalski F. 2017. Illegal use of natural resources in federal protected areas of the Brazilian Amazon. PeerJ **5**: e3902; DOI 10.7717/peerj.3902

Kociolek AV, Clevenger AP, ST. Clair CC, Proppe, DS. 2010. Effects of road networks on bird populations. Conservation Biology **25**: 241-249.

Lambert TD, Sumpter KL, Dittel JW, Dupre S, Casanova K, Winker A, Adler GH. 2014. Roads as barriers to seed dispersal by small mammals in a neotropical forest. Tropical Ecology **55:**263–269.

Laurance WF, Goosem M, Laurance SGW. 2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology and Evolution **24** (12):659-669.

Laurance SGW, Stouffer PC, Laurance WF. 2004. Effects of road clearings on movement patterns of understory rainforest birds in central Amazonia. Conservation Biology **18:**1099–1109.

Laurance WF, Balmford A. 2013. Land use: A global map for road building. Nature **495**:308-309.

Laurance WF, Arrea IB. 2017. Roads to reaches or ruin? Science **358:** 442-444.

Locklin CC, Haack B. 2003. Roadside measurements of deforestation in the Amazon area of Bolivia. Environmental Management **31:**774–783.

Marino A, Johnson A. 2012. Behavioural response of free-ranging guanacos (*Lama guanicoe*) to land-use change: Habituation to motorised vehicles in a recently created reserve. Wildlife Research **39:**503–511.

Maschio GF, Santos-Costa MC, Prudente ALC. 2016. Road-Kills of Snakes in a Tropical Rainforest in the Central Amazon Basin, Brazil. South American Journal of Herpetology **11:**66–80.

Mata C, Malo JE, Galaz JL, Cadorzo C, Lagunas H. 2016. A three-step approach to minimise the impact of a mining site on vicuña (*Vicugna vicugna*) and to restore landscape connectivity. Environmental Science and Pollution Research **23:**13626–13636.

Maynard RJ, Aall NC, Saenz D, Hamilton PS, Kwiatkowski MA. 2016. Road-Edge Effects on Herpetofauna in a Lowland Amazonian Rainforest. Tropical Conservation Science **9:**264–290.

McCracken SF, Forstner MRJ. 2014. Oil road effects on the anuran community of a high canopy tank bromeliad (*Aechmea zebrina*) in the upper Amazon Basin, Ecuador. PLoS ONE **9:** e85470. doi:10.1371/journal.pone.0085470

Meijer JR, Huijbregts MAJ, Schotten KCGJ, Schipper AM. 2018. Global patterns of current and future road infrastructure. Environmental Research Letters **13** 064006.

Melo ES, Santos-Filho M. 2007. Efeitos da BR-070 na Província Serrana de Cáceres, Mato Grosso, sobre a comunidade de vertebrados silvestres. Revista Brasileira de Zoociências **9:**185–192.

Mertens B, Kaimowitz D, Puntodewo A, Vanclay J, Mendez P. 2004. Modeling deforestation at distinct geographic scales and time periods in Santa Cruz, Bolivia. International Regional Science Review **27:**271–296.

Miranda JES, Umetsu RK, de Melo FR, Melo FCSA, Pereira KF, Oliveira SR. 2017. Roadkill in the Brazilian cerrado savanna: Comparing five highways in southwestern Goiás. Oecologia Australis **21:**337–349.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. 2000. Biodiversity hotspots for conservation priorities. Nature **406**: 853-858.

Noss, RF. 1990. Indicators of monitoring biodiversity: a hierarchical approach. Conservation Biology **4:**355-364.

Ojeda VS, Trejo AR, Seijas S, Chazarreta L. 2015. Highway Network Expansion in Andean Patagonia: a Warning Notice From Rufous-Legged Owls. Journal of Raptor Research **49:**201–209.

Peralvo, MF, Cuesta F, van Manen F. Delineating priority habitat areas for the conservation of Andean bears in northern Ecuador. Ursus **16:** 222-233.

Porter et al. 2012 Research Coordination Networks: Evidence of the relationship between funded interdisciplinary networking and scholarly impact. BioScience **62**: 282-288

Quiroga VA, Noss AJ, Paviolo A, Boaglio GI, Di Bitetti MS. 2016. Puma density, habitat use and conflict with humans in the Argentine Chaco. Journal for Nature Conservation **31**:9–15.

Reid J, Souza Jr. WC. 2005. Infrastructure and conservation policy in Brazil. Conservation Biology **19**: 740-746.

Rocha CFD, Siqueira C da C, Ariani C V. 2009. The endemic and threatened lizard *Liolaemus lutzae* (Squamata: Liolaemidae): current geographic distribution and areas of occurrence with estimated population densities. Zoologia **26:**454–460.

Rosa CA, Secco H, Carvalho N, Maia AC, Bager A. 2017. Edge effects on small mammals: Differences between arboreal and ground-dwelling species living near roads in Brazilian fragmented landscapes. Austral Ecology **43:**117–126.

Row JR, Blouin-Demers G, Weatherhead PJ. 2007. Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*). Biological Conservation **137:**117-124.

Rytwinski T, Soanes K, Jaeger JAG, Fahrig L, Findlay CS, Houlahan J, Van Ree R Der, Van Der Grift EA. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE **11:**1–25.

Sánchez, L. 2015. The impact of the IIRSA Road Infrastructure Programme on Amazonia, Impact Assessment and Project Appraisal, **33**:234-235.

Sánchez-Mercado A, Ferrer-Paris JR, Yerena E, García-Rangel S, Rodríguez-Clark KM. 2008. Factors affecting poaching risk to Vulnerable Andean bears *Tremarctos ornatus* in the Cordillera de Mérida, Venezuela: Space, parks and people. Oryx **42:**437–447.

Santos ALP, da Rosa CA, Bager A. 2011. Variação sazonal da fauna selvagem atropelada na rodovia MG 354, Sul de Minas Gerais – Brasil. Biotemas **25:**73–79.

Secco H, Gomes LA, Lemos H, Mayer F, Machado T, Guerreiro M, Gregorin R. 2017. Road and landscape features that affect bat roadkills in southeastern Brazil. Oecologia Australis **21:**323–336.

Silva VP, Deffaci AC, Hartmann MT, Hartmann PA. 2017. Birds Around the Road: Effects of a Road on a Savannah Bird Community in Southern Brazil. Ornitologia Neotropical **28:**119–128.

Soares-Filho B, Alencar A, Nepstad D, Cerqueira G, Del Carmen Vera Diaz M, Rivero S, Solórzano L, Voll E. 2004. Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: The Santarém-Cuiabá corridor. Global Change Biology **10:**745–764.

Soler MG. 2014. Intergovernmental Scientific Networks in Latin America: Supporting Broader Regional Relationships and Integration. Science & Diplomacy **3 (4).**

Speziale KL, Lambertucci SA, Olsson O. 2008. Disturbance from roads negatively affects Andean condor habitat use. Biological Conservation **141:**1765–1772.

Suárez E, Morales M, Cueva R, Bucheli U V., Zapata-Ríos G, Toral E, Torres J, Prado W, Olalla VJ. 2009. Oil industry, wild meat trade and roads: Indirect effects of oil extraction activities in a protected area in north-eastern Ecuador. Animal Conservation **12:**364–373.

Suárez E, Zapata-Ríos G, Utreras V, Strindberg S, Vargas J. 2013. Controlling access to oil roads protects forest cover, but not wildlife communities: A case study from the rainforest of Yasuní Biosphere Reserve (Ecuador). Animal Conservation **16:**265–274.

Tanner D, Lehman C, Perry J. 2007. On the Road to Nowhere: Galápagos Lava Lizard Populations. Bulletin of the Chicago Herpetological Society **42:**125–132.

Taylor BD, Goldingay RL. 2010. Roads and wildlife: Impacts, mitigation and implications for wildlife management in Australia. Wildlife Research **37:**320–331.

Teixeira FZ, Printes RC, Fagundes JCG, Alonso AC, Kindel A. 2013. Canopy bridges as road overpasses for wildlife in urban fragmented landscapes. Biota Neotropica **13:**117–123.

Teixeira FZ, Coelho IP, Lauxen M, Esperandio IB, Hartz SM, Kindel A. 2016. The need to improve and integrate science and environmental licensing to mitigate wildlife mortality on roads in Brazil. Tropical Conservation Science **9**:34-42.

Tejada G, Dalla-Nora E, Cordoba D, Lafortezza R, Ovando A, Assis T, Aguiar AP. 2016. Deforestation scenarios for the Bolivian lowlands. Environmental Research **144:** 49–63.

Thoisy B, Richard-Hansen C, Goguillon B, Joubert P, Obstancias J, Winterton P, Brosse S. 2010. Rapid evaluation of threats to biodiversity: Human footprint score and large vertebrate species responses in French Guiana. Biodiversity and Conservation **19:**1567–1584.

Trombulak SC, Frissell CA. 2007. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology **14:**18–30.

van der Grift EA. 2005. Defragmentation in the Netherlands: A Success Story? GAIA **14**: 144 – 147.

Vargas-Salinas F, Berrío-Baca H. 2009. Herpetofauna asociada a la vegetación de borde de carretera em la región de Anchicayá, Valle del Cauca, pacífico de Colombia. Novedades Colombianas **9**:28-37.

Vargas-Salinas F, Delgado-Ospina I, López-Aranda F. 2011. Amphibians and reptiles killed by motor vehicles in a Sub-Andean forest in western Colombia. Caldasia **33:**121–138.

Vargas-Salinas F. 2013. Traffic noise correlates with calling time but not spatial distribution in the threatened poison frog *Andinobates bombetes*. Behaviour **150:**569–584.

Vega LE, Bellagamba PJ, Fitzgerald LA. 2000. Long-term effects of anthropogenic habitat disturbance on a lizard assemblage inhabiting coastal dunes in Argentina. Canadian Journal of Zoology **78:** 1653–1660.

Weyland F, Baudry J, Ghersa CM. 2014. Rolling Pampas agroecosystem: which landscape attributes are relevant for determining bird distributions? Revista Chilena de Historia Natural **87:**1-12.

Whitworth A, Beirne C, Rowe J, Ross F, Acton C, Burdekin O, Brown P. 2015. The response of faunal biodiversity to an unmarked road in the Western Amazon. Biodiversity and Conservation **24:**1657–1670.

Wright SJ. 2002. Plant diversity in tropical forests: a review of mechanisms of species coexistence. Oecologia **130:** 1–14.

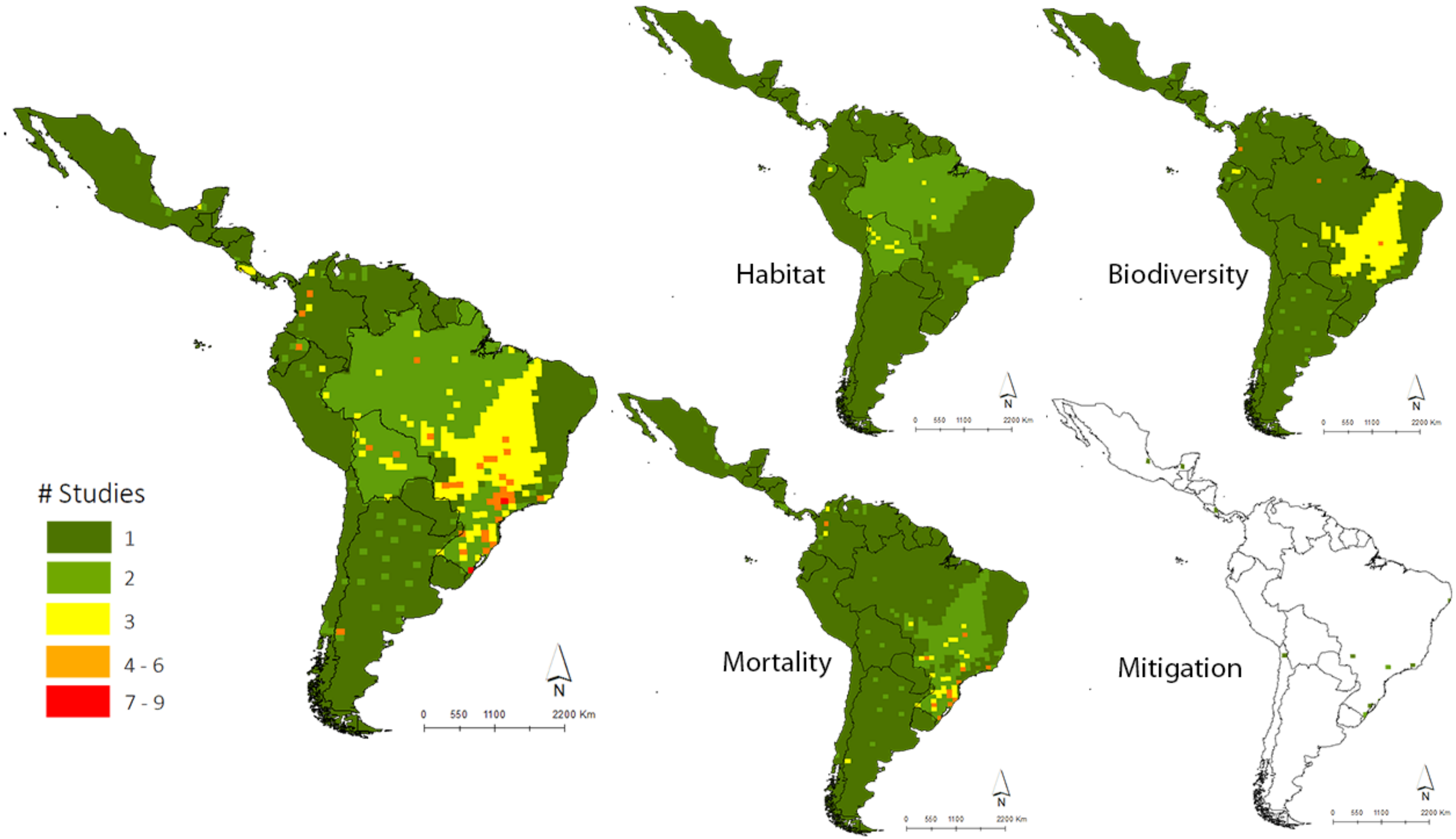


Figure 1. Number of studies reporting road effects on wildlife vertebrates in Latin America per 100 x 100 km grid cell. Maps show the geographic distribution of all studies (left) and by research areas.

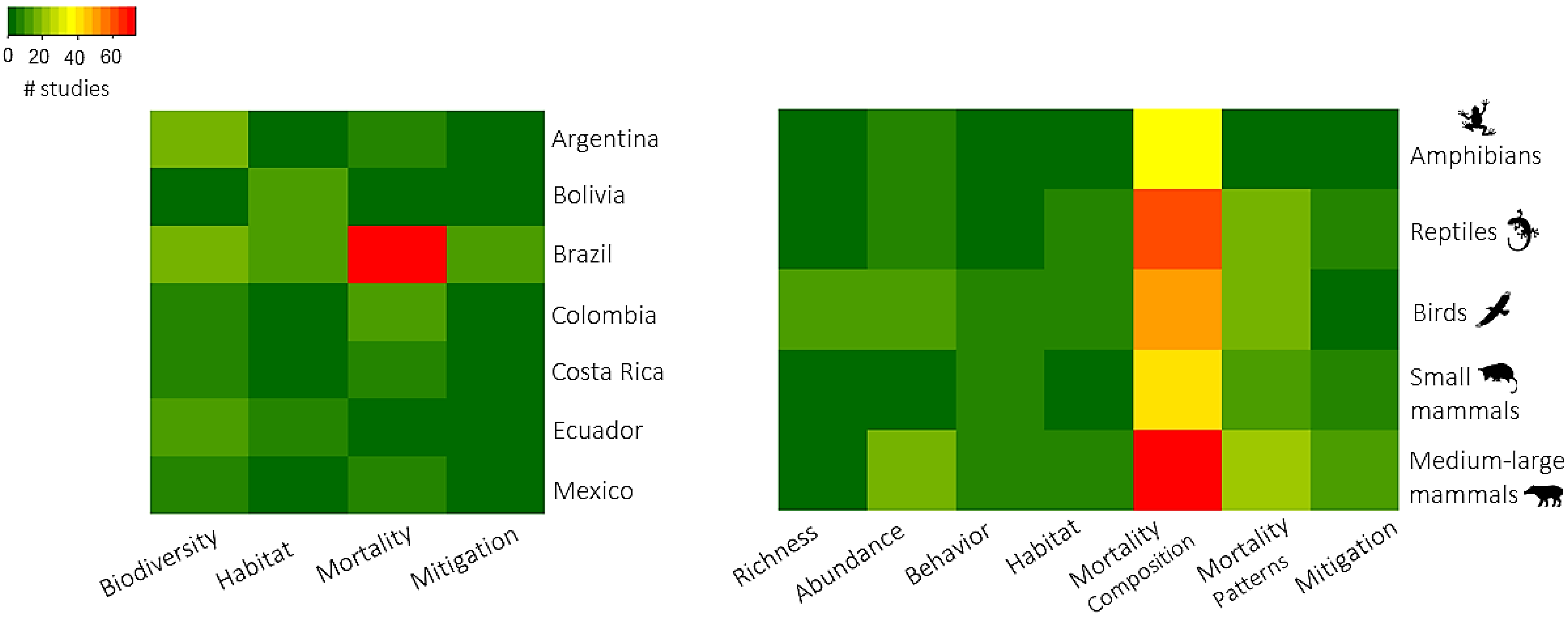


Figure 2 – a) Number of studies regarding research areas and Latin American countries (countries that account for > 10 studies). b) Number of studies regarding research areas (sub-topics) and taxon. Color scale indicates the number of studies, hotter colors represent large number of studies.

Appendix S1 - A list of reviewed studies:

Acosta-Jamett G, Simonetti JA. 2004. Habitat use by *Oncifelis guigna* and *Pseudalopex culpaeus* in a fragmented forest landscape in central Chile. Biodiversity and Conservation **13:**1135–1151.

Ahmed SE, Lees AC, Moura NG, Gardner TA, Barlow J, Ferreira J, Ewers RM. 2014. Road networks predict human influence on Amazonian bird communities. Proceedings of the Royal Society B: Biological Sciences **281**:1742–1742.

Alfaro VC, Quesada FD. 2016. Registro de mamíferos silvestres atropellados y hábitat asociados en el cantón de la fortuna, San Carlos, Costa Rica. Biocenosis **30:** 49-58.

Andrade EVE, Moura GJB. 2011. Proposta de manejo das rodovias da REBIO Saltinho para mitigação do impacto sobre a anurofauna de solo. Revista Ibero-Americana de Ciências Ambientais **2:**24-38.

Aquino R, Charpentier E. 2014. Primates Diversity and abundance in habitats of the influence area of the Iquitos – Nauta road , Peruvian Amazon. Ciencia Amazónica **4**:3–12.

Araya-Gamboa D, Salom-Pérez R. 2015. Identificación de sitios de cruce de fauna en la ruta 415, en el “Paso del Jaguar”, Costa Rica. Infraestructura Vial **17:**5–12.

Arévalo JE, Newhard K. 2011. Traffic noise affects forest bird species in a protected tropical forest. Revista de Biologia Tropical **59:**969–980.

Arriagada RA, Echeverria CM, De Moya. 2016. Creating Protected Areas on Public Lands: Is There Room for Additional Conservation? PLoS ONE 11:e0148094. doi:10.1371/journal.pone.0148094

Artavia A, Jiménez M, Martínez-Salinas A, Pomareda E, Araya-Gamboa D, Arévalo-Huezo E. 2015. Registro de mamíferos silvestres en la sección de la ampliación de la Ruta 32, Limón, Costa Rica. Brenesia **8384**:37–46.

Ascensão F, Desbiez ALJ, Medici EP, Bager A. 2017. Spatial patterns of road mortality of medium–large mammals in Mato Grosso do Sul, Brazil. Wildlife Research **44**:135.

Ascensão F, Lucas PS, Costa A, Bager A. 2017. The effect of roads on edge permeability and movement patterns for small mammals: a case study with Montane Akodont. Landscape Ecology **32:**781–790.

Asensio N, Murillo-Chacon E, Schaffner CM, Aureli F. 2017. The effect of roads on spider monkeys’ home range and mobility in a heterogeneous regenerating forest. Biotropica **49:**546–554.

Astudillo PX, Samaniego GM, Machado PJ, Aguilar JM, Tinoco BA, Graham CH, Latta SC, Farwig N. 2014. The impact of roads on the avifauna of páramo grasslands in Cajas National Park, Ecuador. Studies on Neotropical Fauna and Environment **49:**204–212.

Attademo AM, Peltzer PM, Lajmanovich RC, Elberg G, Junges C, Sanchez LC, Bassó A. 2011. Wildlife vertebrate mortality in roads from Santa Fe Province, Argentina. Revista Mexicana de Biodiversidad **82:**915–925.

Aubad J, Aragón P, Rodríguez MÁ. 2010. Human access and landscape structure effects on Andean forest bird richness. Acta Oecologica **36**:396–402.

Ávalos G, Bermúdez E. 2016. Effect of a major highway on the spatial and temporal variation in the structure and diversity of the avifauna of a tropical premontane rain forest. Revista de Biología Tropical **64:**1383–1399.

Bager A, Rosa CA. 2010. Priority ranking of road sites for mitigating wildlife roadkill. Biota Neotropica **10:**149–153.

Bager A, Da Rosa CA. 2011. Influence of sampling effort on the estimated richness of road-killed vertebrate wildlife. Environmental Management **47**:851–858.

Bager A, Rosa CA. 2012. Impacts of the BR-392 highway on bird communities in extreme southern Brazil. Brazilian Journal of Ornithology **20:** 30–39.

Bager A, Fontoura V. 2013. Evaluation of the effectiveness of a wildlife roadkill mitigation system in wetland habitat. Ecological Engineering **53:**31–38.

Barber CP, Cochrane MA, Souza CM, Laurance WF. 2014. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. Biological Conservation **177:**203–209.

Barbosa NPU, Fernandes WW, Carneiro MAA, Júnior LAC. 2010. Distribution of non-native invasive species and soil properties in proximity to paved roads and unpaved roads in a quartzitic mountainous grassland of southeastern Brazil (rupestrian fields). Biological Invasions **12**:3745–3755.

Barri, FR. 2010. Preliminary evaluation of native mastofauna mortality due to collision with vehicles in three Argentinian routes. Ecología Aplicada **9**: 161-165.

Barni PE, Fearnside PM, Graça PML de A. 2012. Deforestation in the southern portion of the Roraima State: distribution with respect to INCRA settlement projects and distance from major highways (BR-174 and BR-210). Acta Amazonica **42:**195–204.

Baynard CW, Ellis JM, Davis H. 2013. Roads, petroleum and accessibility: The case of eastern Ecuador. GeoJournal **78:** 675–695.

Belão M, Bóçon R, Christo SW, Souza MAM, Souza Jr. JL. 2014. Incidentes De Mamíferos Na Rodovia Br-277, Paraná – Brasil. Publicatio UEPG: Ciencias Biologicas e da Saude **20**:37–41.

Bencke GA, Bencke CSC. 1999. The potential importance of roads deaths as a cause of mortality for largest forest owls in southern Brazil. Cotinga **11:** 17-18.

Bilsborrow RE, Barbieri AF, Pan W. 2004. Changes in population and land use over time in the Ecuadorian Amazon. Acta Amazonica **34:** 635–647.

Bottazzi P, Dao H. 2013. On the road through the Bolivian Amazon: A multi-level land governance analysis of deforestation. Land Use Policy **30:**137–146.

Braz V da S, França FGR. 2016. Wild vertebrate roadkill in the Chapada dos Veadeiros National Park, Central Brazil. Biota Neotropica **16**:1–11.

Brum TR, Santos-Filho M, Canale GR, Ignácio ARA, Brum TR, Santos-Filho M, Canale GR, Ignácio ARA. 2017. Effects of roads on the vertebrates diversity of the Indigenous Territory Paresi and its surrounding. Brazilian Journal of Biology:0–0. http://dx.doi.org/10.1590/1519-6984.08116

Bueno C, Almeida PJAL. 2010. Sazonalidade de atropelamentos e os padrões de movimentos em mamíferos na BR-040 (Rio de Janeiro-Juiz de Fora). Revista Brasileira de Zoociências **12**:219–226.

Bueno C, Faustino MT, Freitas SR. 2013. Influence of landscape characteristics on capybara road-kill on highway BR-040, Southeastern Brazil. Oecologia Australis **17:**130–137.

Bueno C, Sousa COM, Freitas SR. 2015. Habitat or matrix: which is more relevant to predict road-kill of vertebrates? Brazilian Journal of Biology **75**:228–238.

Cáceres NC, Hannibal W, Freitas DR, Silva EL, Roman C, Casella J. 2010. Mammal occurrence and roadkill in two adjacent ecoregions (Atlantic Forest and Cerrado) in south-western Brazil. Zoologia (Curitiba) **27**:709–717.

Caceres NC. 2011. Biological characteristics influence mammal road kill in an Atlantic Forest-Cerrado interface in south-western Brazil. Italian Journal of Zoology **78:**379–389.

Cairo SL, Zalba SM. 2007. Effects of a paved road on mortality and mobility of red bellied toads (*Melanophryniscus* sp.) in Argentinean grasslands. Amphibia Reptilia **28:**377–385.

Cappa FM, Giannoni SM, Borghi CE. 2017. Effects of roads on the behaviour of the largest South American artiodactyl (*Lama guanicoe*) in an Argentine reserve. Animal Behaviour **131:**131–136.

Carvalho CF, Custódio AEI, Junior OM. 2015. Wild vertebrates roadkill aggregations on the BR-050 highway, state of Minas Gerais, Brazil. Bioscience Journal **31**:951–959.

Carvalho NC de, Bordignon MO, Shapiro JT. 2014. Fast and furious: a look at the death of animals on the highway MS-080, Southwestern Brazil. Iheringia. Série Zoologia **104:**43–49.

Caruso N, Lucherini M, Fortin D, Casanave EB. 2016. Species-specific responses of carnivores to human-induced landscape changes in central Argentina. PLoS ONE **11:**1–16.

Casella J, Filho ACP. 2013. the Influence of Highway Br262 on the Loss of Cerrado Vegetation Cover in Southwestern Brazil. Oecologia Australis **17:**77–85.

Castillo JC, Urmendez-M D, Zambrano-G G. 2015. Mortalidad de fauna por atropello Vehicular en un sector de la Vía Panamericana entre Popayán y Patía. Boletín Científico Centro De Museos Museode Historia Natural **19:**207–219.

Ceia-Hasse A, Borda-de-Água L, Grilo C, Pereira HM. 2017. Global exposure of carnivores to roads. Global Ecology and Biogeography **26:**592–600.

Ceron K, Bôlla DAS, De Mattia DL, Carvalho F, Zocche JJ. 2017. Roadkilled bats (mammalia: Chiroptera) in two highways of santa catarina state, Southern Brazil. Oecologia Australis **21:**207–212.

Cherem JJ, Kammers M, Ghizoni-Jr IR, Martins A. 2007. Mamíferos de médio e grande porte atropelados em rodovias do Estado de Santa Catarina, sul do Brasil. Biotemas **20**:81–96.

Chiappero MB, Sommaro L V., Priotto JW, Wiernes MP, Steinmann AR, Gardenal CN. 2016. Spatio-temporal genetic structure of the rodent *Calomys venustus* in linear, fragmented habitats. Journal of Mammalogy **97:**424–435.

Ciocheti G, de Assis JC, Ribeiro JW, Ribeiro MC. 2017. Highway widening and underpass effects on vertebrate road mortality. Biotropica **49:**765–769.

Coelho IP, Kindel A, Coelho AVP. 2008. Roadkills of vertebrate species on two highways through the Atlantic Forest Biosphere Reserve, southern Brazil. European Journal of Wildlife Research **54:**689–699.

Coelho IP, Teixeira FZ, Colombo P, Coelho AVP, Kindel A. 2012. Anuran road-kills neighboring a peri-urban reserve in the Atlantic Forest, Brazil. Journal of Environmental Management **112**:17–26.

Colchero F, Conde DA, Manterola C, Chávez C, Rivera A, Ceballos G. 2011. Jaguars on the move: Modeling movement to mitigate fragmentation from road expansion in the Mayan Forest. Animal Conservation **14:**158–166.

Contreras-Moreno FM, Hidalgo-Mihart MG, Pérez-Solano LA, Vázquez-Maldonado YAV. 2013. Nuevo registro de Tapir centroamericano (*Tapirus bairdii*) atropellado en el Noroeste del estado de Campeche, México**.** Tapir Conservation **22:** 22-25.

Corrêa LLC, Silva DE, Oliveira SV de, Finger JVG, Santos CR dos, Petry MV. 2017. Vertebrate road kill survey on a highway in southern Brazil. Acta Scientiarum. Biological Sciences **39:**219.

Costa LS. 2011. Survey of wild mammals small and medium-size run over in BR 101, stretch between the municipalities of Joinville and Piçarras, state of Santa Catarina. Bioscience Journal **27:**666–672.

Costa RRGF, Dias LA. 2013. Mortality of vertebrate by running over in a stretch of the Highway GO- 164 in the Southwest of Goias. Revista de Biotecnologia e Ciência **2:** 58-74.

Costa AS, Ascensão F, Bager A. 2015. Mixed sampling protocols improve the cost-effectiveness of roadkill surveys. Biodiversity and Conservation **24:**2953–2965.

Costa MS, Lisbôa JM, Silva MD. 2017. Distribuição e características das passagens de fauna na BR 392, trecho entre Rio Grande e Pelotas/RS - Brasil. Geographia Meridionalis **03:**60–85.

Cuevas FM, Ojeda RA, Jaksic FM. 2013. Multi-scale patterns of habitat use by wild boar in the Monte Desert of Argentina. Basic and Applied Ecology **14:**320–328.

Cullen L, Stanton JC, Lima F, Uezu A, Perilli MLL, Resit Akcakaya H. 2016. Implications of fine-grained habitat fragmentation and road mortality for jaguar conservation in the atlantic forest, Brazil. PLoS ONE **11:**1–17.

Cunha HF da, Moreira FGA, Silva SDS. 2010. Roadkill of wild vertebrates along the GO-060 road between Goiânia and Iporá, Goiás State, Brazil. Acta Scientiarum. Biological Sciences **32.**

Cuyckens GAE, Mochi LS, Vallejos M, Perovic PG, Biganzoli F. 2016. Patterns and Composition of Road-Killed Wildlife in Northwest Argentina. Environmental Management **58:**810–820.

De La Ossa-Nadjar O, De La Ossa VJ. 2015. Vehicle Collisions With Wild Fauna on the Two Roads That Pass Through the Montes De María , Sucre , Colombia. Revista U.D.C.A Actualidad & Divulgación Científica **18**:503–511.

De La Ossa J, Galván-Guevara S. 2015. Registro de mortalidad de fauna silvestre por colisión vehicular en la carretera Toluviejo – ciénaga La Caimanera, Sucre, Colombia. Biota Colombiana **16:**68-76.

Delgado-Vélez, CA. 2007. Muerte de mamíferos por vehículos en La Vía Del Escobero, Envigado, (Antioquia), Colombia. Actual Biologica **29**:235–239.

Delgado-Vélez, CA. 2014. Adiciones al atropellamiento vehicular de mamíferos en la Vía del Escobero, Envigado (Antioquia), Colombia. Revista EIA 11: 147-153.

Develey PF, Stouffer PC. 2001. Effects of roads on movements by understory birds in mixed-species flocks in Central Amazonian Brazil. Conservation Biology **15:**1416–1422.

Di Bitetti MS, Albanesi SA, Foguet MJ, De Angelo C, Brown AD. 2013. The effect of anthropic pressures and elevation on the large and medium-sized terrestrial mammals of the subtropical mountain forests (Yungas) of NW Argentina. Mammalian Biology **78:** 21–27.

Di Bitetti MS Di, Paviolo A, Angelo C De. 2014. Camera trap photographic rates on roads vs. off roads: location does matter. Mastozoología Neotropical **21:** 37–46.

Diniz MF, Brito D. 2013. Threats to and viability of the giant anteater, *Myrmecophaga tridactyla* (Pilosa: Myrmecophagidae), in a protected Cerrado remnant encroached by urban expansion in central Brazil. Zoologia **30:**151-156.

Diniz MF, Brito D. 2015. Protected areas effectiveness in maintaining viable giant anteater (*Myrmecophaga tridactyla*) populations in an agricultural frontier. Natureza e Conservação **13:**145–151.

Espinosa S, Branch LC, Cueva R. 2014. Road development and the geography of hunting by an Amazonian indigenous group: Consequences for wildlife conservation. PLoS ONE **9**:1–21.

Fearnside PM, Graça PMLA. 2006. BR-319: Brazil's Manaus-Porto Velho Highway and the potential impact of linking the Arc of Deforestation to Central Amazonia. Environmental Management **38**:705-706.

Felton A, Wood J, Felton AM, Hennessey B, Lindenmayer DB. 2008. Bird community responses to reduced-impact logging in a certified forestry concession in lowland Bolivia. Biological Conservation **141**:545–555.

Ferreira RB, Soares TS. 2012. Road Mortality of Snakes at the Parque Estadual da Fonte Grande , an Urban Forest of Southeastern Brazil **29**:5–15.

Ferreira CMM, De Aquino Ribas AC, Casella J, Mendes SL. 2014. Variação espacial de atropelamentos de mamíferos em área de restinga no estado do Espírito Santo, Brasil. Neotropical Biology and Conservation **9:** 125-133.

Figueiredo AP, Lima RAS, Soares CM. 2013. Variation of the road-kill rates between highways with different types of paving and number of lanes. Heringeriana **7:** 143-151.

Figueroa PG, Monge-Nájera J. 2000. Fauna silvestre víctima de las carreteras: el caso de Costa Rica. Repertório Científico **6:** 47-50.

Forrest JL, Sanderson EW, Wallace R, Marcelo T, Lazzo S, G LH. 2008. Patterns of Land Cover Change in and Around Madidi National Park , Bolivia. Biotropica **40:**285–294.

Fredericksen NJ, Fredericksen TS. 2004. Impacts of selective logging on amphibians in a Bolivian tropical humid forest. Forest Ecology and Management **191:**275–282.

Freitas SR, Hawbaker TJ, Metzger JP. 2010. Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. Forest Ecology and Management **259:**410–417.

Freitas SR, Sousa COM, Boscolo D, Metzger JP. 2013. How are native vegetation and reserves affected by different road types in a southeastern Brazilian state? Oecologia Australis **17:**447–458.

Freitas SR, de Oliveira AN, Ciocheti G, Vieira MV, Matos DM da S. 2015. How landscape features influence road-kill of three species of mammals in the Brazilian savanna? Oecologia Australis **18:**35–45.

Freitas CH, Justino CS, Setz EZF. 2014. Road-kills of the giant anteater in south-eastern Brazil: 10 years monitoring spatial and temporal determinants. Wildlife Research **41:**673–680.

Freitas SR, de Oliveira AN, Ciocheti G, Vieira MV, Matos DM da S. 2015. How landscape features influence road-kill of three species of mammals in the Brazilian savanna? Oecologia Australis **18:**35–45.

Freitas MA, Printes RC, Motoyama EK, Fucks AE, Veríssimo D, Veríssimo D. 2017. Roadkill records of Lowland Tapir Tapirus terrestris (Mammalia: Perissodactyla: Tapiridae) between kilometers 06 and 76 of highway BR-163, state of Pará, Brazil. Journal of Threatened Taxa **9**:10948.

Fuentes-Montemayor E, Cuarón AD, Vásquez-Dominguez E, Benítez-Malvido J, Valenzuela-Galván D, Andresen E. 2009. Living on the edge: roads and edge effects on small mammal populations. Journal of Animal Ecology, **78:**857–865.

Gantchoff MG, Belant JL. 2015. Anthropogenic and environmental effects on invasive mammal distribution in northern Patagonia, Argentina. Mammalian Biology **80:**54–58.

Gottdenker N, Wallace RB. 2001. La importancia de los atropellos para la ecología y conservación : Dinomys branickii un ejemplo de Bolivia. Ecología en Bolivia **35**:61–67.

Gonçalves LO, Alvares DJ, Teixeira FZ, Schuck G, Coelho IP, Esperandio IB, Anza J, Beduschi J, Bastazini VAG, Kindel A. 2017. Reptile road-kills in Southern Brazil: Composition, hot moments and hotspots. Science of the Total Environment **615:**1438–1445.

González-Gallina A, Benítez-Badillo G, Rojas-Soto OR, Hidalgo-Mihart MG. 2013. The small, the forgotten and the dead: Highway impact on vertebrates and its implications for mitigation strategies. Biodiversity and Conservation **22**:325–342.

González-Trujillo R, Méndez-Alonzo R, Arroyo-Rodríguez V, Vega E, González-Romero A, Reynoso VH. 2014. Vegetation Cover and Road Density as Indicators of Habitat Suitability for the Morelet’s Crocodile. Journal of Herpetology **48:**188–194.

Grilo C, de Resende Cardoso T, Solar R, Bager A. 2016. Do the size and shape of spatial units jeopardize the road mortality-risk factors estimates? Natureza e Conservacao **14**:8–13. Associação Brasileira de Ciência Ecológica e Conservação.

Gullison RE, Hardner JJ. 1994. The effects of road design and harvest intensity on forest damage caused by selective logging: empirical results and a simulation model from the Bosque Chimanes, Bolivia: R. E. Gullison & J. J. Hardner, Forest Ecology & Management, 59: 1–14.

Gumier-Costa F, Sperber CF. 2009. Roadkills of vertebrates in Carajas National Forest, Para, Brazil. Acta Amazonica **39:**459–466.

Gutiérrez-Cifuentes DF, Brand-Alape A, Matilla-Meluk H. 2013. First specimen of the Mammal Collection of The Universidad del Quindío (CMUQ): record of *Eptesicus chiriquinus* (Chiroptera: Vespertillionidae) hit by a car at the Autopista del Café, Quindío, Colombia. Revista Biodiversidade Neotropical **3:**131-136.

Hartmann MT, Martins M. 2011. Snake Road Mortality in a Protected Area in the Atlantic Forest of Southeastern Brazil. South American Journal of Herpetology*,* **6:** 35-42.

Hegel CGZ. 2012. Mamíferos Silvestres Atropelados Na Rodovia Rs-135 E Entorno. Biotemas **25:**165–170.

Hengemühle a, Cademartori C V. 2008. Levantamento de mortes de vertebrados silvestres devido a atropelamento em um trecho da Estrada do Mar (RS-389). Biodiversidade Pampeana **6:**4–10.

Huijser MP, Delborgo Abra F, Duffield JW. 2013. Mammal road mortality and cost–benefit analyses of mitigation measures aimed at reducing collisions with capybara (*Hydrochoerus hydrochaeris*) in São Paulo state, Brazil. Oecologia Australis **17**:129–146.

Inostroza L, Zasada I, König HJ. 2016. Last of the wild revisited: assessing spatial patterns of human impact on landscapes in Southern Patagonia, Chile. Regional Environmental Change **16**:2071–2085.

Kauano ÉE, Silva JMC, Michalski F. 2017. Illegal use of natural resources in federal protected areas of the Brazilian Amazon. PeerJ **5**: e3902; DOI 10.7717/peerj.3902

Klippel AH, Oliveira P V., Britto KB, Freire BF, Moreno MR, Dos Santos AR, Banhos A, Paneto GG. 2015. Using DNA barcodes to identify road-killed animals in two atlantic forest nature reserves, Brazil. PLoS ONE **10**:1–15.

Köhler G, Cedeño-Vázquez JR, Spaeth M, Beutelspacher-Garcia PM. 2016. The Chetumal Snake Census: generating biological data from road-killed snakes. Part 3. Leptodeira frenata, Ninia sebae, and Micrurus diastema. Mesoamerican Herpetology **3:**929–947.

Kunz TS, Ghizoni-JR IR. 2008. Snakes killed on the roads in the state of Santa Catarina, southern Brazil. Biotemas **22:**91-103.

Lambert TD, Sumpter KL, Dittel JW, Dupre S, Casanova K, Winker A, Adler GH. 2014. Roads as barriers to seed dispersal by small mammals in a neotropical forest. Tropical Ecology **55:**263–269.

Laurance SGW, Stouffer PC, Laurance WF. 2004. Effects of road clearings on movement patterns of understory rainforest birds in central Amazonia. Conservation Biology **18:**1099–1109.

Lazcano D, Salinas-Camarena MA, Contreras-Lozano JA. 2009. Notes on Mexican herpetofauna 12: are roads in Nuevo Leon, Mexico, taking their toll on snake populations? Bulletin of the Chicago Herpetological Society **44**:69–75.

Locklin CC, Haack B. 2003. Roadside measurements of deforestation in the Amazon area of Bolivia. Environmental Management **31**:774–783.

López-Herrera DF, León-Yusti M, Guevara-Molina SC, Vargas-Salinas F. 2016. Reptiles en corredores biológicos y mortalidad por atropellamiento vehicular en Barbas-Bremen, departamento del

Quindío, Colombia. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales **40:**484.

Mäki S, Kalliola R, Vuorinen K. 2001. Road construction in the Peruvian Amazon: process, causes and consequences. Environmental Conservation **28**:199–214.

Malizia LR, Aragón R, Chacoff NP, Monmany AC. 1998. ¿Son las rutas una barrera para el desplazamiento de las aves? El caso de la Reserva Provincial La Florida (Tucumán, Argentina). Hornero **15:**10–16.

Marino A, Johnson A. 2012. Behavioural response of free-ranging guanacos (*Lama guanicoe*) to land-use change: Habituation to motorised vehicles in a recently created reserve. Wildlife Research **39:**503–511.

Martinelli MM, Volpi TA. 2011. Mamíferos atropelados na Rodovia Armando Martinelli (ES-080), Espírito Santo, Brasil. Natureza on line **9:**113–116.

Maschio GF, Santos-Costa MC, Prudente ALC. 2016. Road-Kills of Snakes in a Tropical Rainforest in the Central Amazon Basin, Brazil. South American Journal of Herpetology **11**:66–80.

Mata C, Malo JE, Galaz JL, Cadorzo C, Lagunas H. 2016. A three-step approach to minimise the impact of a mining site on vicuña (*Vicugna vicugna*) and to restore landscape connectivity. Environmental Science and Pollution Research **23:**13626–13636.

Maynard RJ, Aall NC, Saenz D, Hamilton PS, Kwiatkowski MA. 2016. Road-Edge Effects on Herpetofauna in a Lowland Amazonian Rainforest. Tropical Conservation Science **9:**264–290.

McCracken SF, Forstner MRJ. 2014. Oil road effects on the anuran community of a high canopy tank bromeliad (*Aechmea zebrina*) in the upper Amazon Basin, Ecuador. PLoS ONE **9:** e85470. doi:10.1371/journal.pone.0085470

Melo ES, Santos-Filho M. 2007. Efeitos da BR-070 na Província Serrana de Cáceres, Mato Grosso, sobre a comunidade de vertebrados silvestres. Revista Brasileira de Zoociências **9:**185–192.

Meneguetti DUO, Meneguetti NFSP, Trevisan O. 2010. Georreferenciamento e avaliação da mortalidade por atropelamento de animais silvestres na linha 200 entre os municipios de Ouro Preto do Oeste e Vale do Paraíso – RO. Revista Científica da Faculdade de Educação e Meio Ambiente **1:**58-64.

Mertens B, Kaimowitz D, Puntodewo A, Vanclay J, Mendez P. 2004. Modeling deforestation at distinct geographic scales and time periods in Santa Cruz, Bolivia. International Regional Science Review **27:**271–296.

Mesquita PCMD, Lipinski VM, Polidoro GLS. 2014. Less charismatic animals are more likely to be “road killed”: human attitudes towards small animals in Brazilian roads. Biotemas **28**:85.

Mili MS, Passamani M. 2006. The impact of the Josil Espíndula Agostini Road (ES-249) on the mortality of wild animals (Vertebrata) by running over. Natureza on line **4:** 40-46.

Millington AC, Velez-Liendo XM, Bradley A V. 2003. Scale dependence in multitemporal mapping of forest fragmentation in Bolivia: Implications for explaining temporal trends in landscape ecology and applications to biodiversity conservation. ISPRS Journal of Photogrammetry and Remote Sensing **57**:289–299.

Miranda JES, Umetsu RK, de Melo FR, Melo FCSA, Pereira KF, Oliveira SR. 2017. Roadkill in the Brazilian cerrado savanna: Comparing five highways in southwestern Goiás. Oecologia Australis **21**:337–349.

Monge-Najera J. 1996. Vertebrate mortality on tropical highways: the Costa Rican case. Vida Silvestre Neotropical 5: 1-3.

Monroy MC, Lacayo ADLO, De La Ossa J. 2015. Runover rate of wildlife in the way San Onofre Maria La Baja, Colombian Caribbean. Revista de la Asociación Colombiana de Ciencias Biologicas **27:** 88-95.

Morales-Mávil JE, Villa-Cañedo JT, Rodríguez SHA, Morales LB. 1997. Mortalidad de vertebrados silvestres en una carretera asfaltada de la region de los tuxtlas, Veracruz, México. Ciencia y el Hombre **27**: 7–23.

Muñoz-Avila JA, Bedoya-Cañon MA, Díaz-Pérez CN, Vargas-Salinas F. 2014. Roadkills give us information about the reproductive biology of the snake Boa constrictor (Linnaeus 1758). Herpetology **7**:761–762.

Muñoz-Sáez A, Perez-Quezada JF, Estades CF. 2017. Agricultural landscapes as habitat for birds in central Chile. Revista Chilena de Historia Natural **90**:1–12. Revista Chilena de Historia Natural.

Ojeda VS, Trejo AR, Seijas S, Chazarreta L. 2015. Highway Network Expansion in Andean Patagonia: a Warning Notice From Rufous-Legged Owls. Journal of Raptor Research **49:**201–209.

Oliveira Jr. PRR, Alberts CC, Francisco MR. 2011. Impact of road clearings on the movements of three understory insectivorous bird species in the Brazilian Atlantic Forest. Biotropica **43:**628–632.

Oliveira Jr., Luis Wendt A, Augusto Aguiar G, Henrique Rocha P. 2012. Characterization of the vertebrate fauna hit on roadway BR 174, Amazonas, Brazil. Rev. Colombiana cienc. Anim **4:**291–307.

Oliveira DS, Martins V, Silva D. 2012. Vertebrados silvestres atropelados na BR 158, RS, Brasil. Revista Biotemas **25**:229-235.

Ossa-Nadjar D LA, Ossa V Jaime D LA. 2013. Fauna Silvestre Atropellada en dos Vías Principales que Rodean los Montes María, Sucre, Colombia. Rev. Colombiana cienc. Anim **5:**158–164.

Paes CM, Povaluk M. 2012. Atropelamento de animais silvestres na rodovia federal BR-116, trecho administrado pela concessionária autopista planalto sul 1. Saúde e Meio Ambiente **1:** 26-40.

Peralvo, MF, Cuesta F, van Manen F. 2005. Delineating priority habitat areas for the conservation of Andean bears in northern Ecuador. Ursus **16:** 222-233.

Pereira APFG, Andrade FAG, Fernandes MEB. 2006. Two-year monitoring of mammal roadkill on the PA-458 highway in Bragança, Pará. Boletim Museu Paraense Emílio Goeldi, Ciências Naturais, Belém **1:**77-83.

Pereira JA, Fracassi NG, Rago V, Ferreyra H, Marull CA, McAloose D, Uhart MM. 2010. Causes of mortality in a Geoffroy's cat population-a long-term survey using diverse recording methods. European Journal of Wildlife Research **56**:939–942.

Pinheiro BF, Turci LCB. 2013. Roadkilled vertebrate on Variante highway (BR-307), Cruzeiro do Sul, Acre, Brazil. Natureza on line **11:** 68-78.

Pinowski J. 2005. Roadkills of vertebrates in Venezuela. Revista Brasileira de Zoologia **22:**191-196.

Prado TR, Ferreira AA, Guimarães ZFS. 2006. Effect of the implantation of roads in the Brazilian Cerrado on the fauna of vertebrates. Acta Scientiarum Biological Sciences **28:** 237-241.

Quintero-Ángel A, Osorio-Dominguez D, Vargas-Salinas F, Saavedra-Rodríguez CA. 2012. Roadkill rate of snakes in a disturbed landscape of Central Andes of Colombia. Herpetology Notes **5:**99–105.

Quiroga VA, Noss AJ, Paviolo A, Boaglio GI, Di Bitetti MS. 2016. Puma density, habitat use and conflict with humans in the Argentine Chaco. Journal for Nature Conservation **31**:9–15.

Ramos CCO, Benedito E, Zawadski CA. 2011. Diet and caloric content of roadkill birds in the central region of Paraná State, Brazil. Biotemas **24:**153-170.

Rezzadori T, Hartmann MT, Hartmann PA. 2016. Can proximity to roads influence forest fragmentation? A case study in northern Rio Grande do Sul, Brazil. Biotemas **29:**21-28.

Richard E, Zapata DIC. 2011. Mortalidad de rapaces en carreteras del centro y norte de argentina: análisis preliminar de la problemática. Spizaetus: el Boletín de la Red de Rapaces Neotropicales **11:** 6-15.

Rocha CFD, Siqueira C da C, Ariani C V. 2009. The endemic and threatened lizard *Liolaemus lutzae* (Squamata: Liolaemidae): current geographic distribution and areas of occurrence with estimated population densities. Zoologia **26:**454–460.

Rodda GH. 1990. Highway Madness Revisited: Roadkilled Iguana iguana in the Llanos of Venezuela. Journal of Herpetology **24**: 209-211.

Rodríguez-Castro KG, Ciocheti G, Ribeiro JW, Ribeiro MC, Galetti Jr. PM. 2017. Using DNA barcode to relate landscape attributes to small vertebrate roadkill. Biodiversity Conservation DOI 10.1007/s10531-017-1291-2.

Rojas Chacón E. 2010. Atropello de vertebrados en una carretera secundaria en Costa Rica **3:**1659–441.

Rompré G, Robinson WD, Desrochers A. 2008. Causes of habitat loss in a Neotropical landscape: The Panama Canal corridor. Landscape and Urban Planning **87**:129–139.

Rosa CA, Bager A. 2012. Seasonality and habitat types affect roadkill of neotropical birds. Journal of Environmental Management 97: 1-5.

Rosa CA, Secco H, Carvalho N, Maia AC, Bager A. 2017. Edge effects on small mammals: Differences between arboreal and ground-dwelling species living near roads in Brazilian fragmented landscapes. Austral Ecology **43:**117–126.

Sánchez-Mercado A, Ferrer-Paris JR, Yerena E, García-Rangel S, Rodríguez-Clark KM. 2008. Factors affecting poaching risk to Vulnerable Andean bears *Tremarctos ornatus* in the Cordillera de Mérida, Venezuela: Space, parks and people. Oryx **42:**437–447.

Santiago-Plata VM, Valdez-Leal JD, Pacheco-Figueroa CJ, Cruz-Burelo F, Moguel-Ordóñez EJ. 2013. Ecological aspects of neotropical otter *(Lontra longicaudis annectens)* on the La Veleta road in Laguna de Terminos, Campeche, Mexico. Therya **4:**265-280.

Santos REF. 2009. Ampliação da distribuição de coleta por atropelamento de *Aegolius harrisii* a partir de coleta por atropelamento. Atualidade Ornitológicas **147**:46-47.

Santos ALP, da Rosa CA, Bager A. 2011. Variação sazonal da fauna selvagem atropelada na rodovia MG 354, Sul de Minas Gerais – Brasil. Biotemas **25:**73–79.

Sangermano F, Toledano J, Eastman R. 2012. Land cover change in the Bolivian Amazon and its implications for REDD+ and endemic biodiversity. Landscape Ecology **27**:571–584.

Saranholi BH, Bergel MM, Ruffino PHP, Rodriguez-C KG, Ramazzotto LA, de Freitas PD, Galetti Jr. PM. 2016. Roadkill hotspots in a protected area of Cerrado in Brazil: planning actions to conservation. Revista MVZ Córdoba **21:**5441-5448.

Sássi CM, Nascimento AAT, Miranda RFP, Carvalho GD. 2013. Survey of road-killed wild animals in stretch of the highway BR482. Arquivo Brasileiro de Medicina Veterinária e Zootecnia **65:** 1883-1886.

Schweikert A, Chinowsky P, Espinet X, Tarbert M. 2014. Climate change and infrastructure impacts: Comparing the impact on roads in ten countries through 2100. Procedia Engineering **78**:306–316.

Secco H, Ratton P, Castro E, da Silva Lucas P, Bager A. 2014. Intentional snake road-kill: A case study using fake snakes on a Brazilian road. Tropical Conservation Science **7**:561–571.

Secco H, Gomes LA, Lemos H, Mayer F, Machado T, Guerreiro M, Gregorin R. 2017. Road and landscape features that affect bat roadkills in southeastern Brazil. Oecologia Australis **21**:323–336.

Seijas AE, Araujo-Quintero A, Velásquez N. 2013. Mortalidad de vertebrados en la carretera Guanare-Guanarito, estado Portuguesa, Venezuela. Revista de Biologia Tropical **61:**1619–1636.

Silva RDJ, Cardoso L, Vieira G, Pinto MP. 2006. Malha rodoviária e conflitos de conservação no cerrado Um estudo para a preservação de anfíbios. Maringá **28:**373–378.

Silva MO, Oliveira IS, Cardoso MW, Graf V. 2007. Road kills impact over the herpetofauna of Atlantic Forest (PR-340, Antonina, Paraná). Acta Biológica Paranaense **36**: 103-112.

Silva-Rodríguez EA, Verdugo C, Aleuy OA, Sanderson JG, Ortega-Solís GR, Osorio-Zúñiga F, González-Acuña D. 2010. Evaluating mortality sources for the Vulnerable pudu Pudu puda in Chile: Implications for the conservation of a threatened deer. Oryx **44**:97–103.

Silva DE, Corrêa LLC, Oliveira SV, Cappellari LH. 2013. Monitoring of road-killed vertebrates in two highway sections in the central region of Rio Grande do Sul, Brazil. Revista de Ciências Ambientais **7:** 27-36.

Silva LG, Cherem JJ, Kasper CB, Trigo TC, Eizirik E. 2014. Mapping wild cat roadkills in southern Brazil: baseline data for species conservation. CATnews **61:**4-7.

Silva VP, Deffaci AC, Hartmann MT, Hartmann PA. 2017. Birds Around the Road: Effects of a Road on a Savannah Bird Community in Southern Brazil. Ornitologia Neotropical **28:**119–128.

Soares-Filho B, Alencar A, Nepstad D, Cerqueira G, Del Carmen Vera Diaz M, Rivero S, Solórzano L, Voll E. 2004. Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: The Santarém-Cuiabá corridor. Global Change Biology **10:**745–764.

Sosa R, Schalk CM. 2016. Seasonal activity and species habitat guilds influence road-kill patterns of neotropical snakes. Tropical Conservation Science **9**.

Southworth J, Marsik M, Qiu Y, Perz S, Cumming G, Stevens F, Rocha K, Duchelle A, Barnes G. 2011. Roads as drivers of change: Trajectories across the tri-national frontier in MAP, the southwestern Amazon. Remote Sensing **3**:1047–1066.

Souza MAN, Miranda PC. 2010. Terrestrial mammals found road kills in br-230/PB between Campina Grande and João Pessoa**.** Revista de Biologia e Farmacia **4:** 72-82**.**

Souza RA, de Marco Jr. P. 2014. The use of species distribution models to predict the spatial distribution of deforestation in the western Brazilian Amazon. Ecological Modelling **291:** 250-259.

Souza JC, da Cunha VP, Markwith SH. 2015. Spatiotemporal variation in human-wildlife conflicts along highway BR-262 in the Brazilian Pantanal. Wetlands Ecology and Management **23**:227–239.

Speziale KL, Lambertucci SA, Olsson O. 2008. Disturbance from roads negatively affects Andean condor habitat use. Biological Conservation **141:**1765–1772.

Suárez E, Morales M, Cueva R, Bucheli U V., Zapata-Ríos G, Toral E, Torres J, Prado W, Olalla VJ. 2009. Oil industry, wild meat trade and roads: Indirect effects of oil extraction activities in a protected area in north-eastern Ecuador. Animal Conservation **12:**364–373.

Suárez E, Zapata-Ríos G, Utreras V, Strindberg S, Vargas J. 2013. Controlling access to oil roads protects forest cover, but not wildlife communities: A case study from the rainforest of Yasuní Biosphere Reserve (Ecuador). Animal Conservation **16:**265–274.

Tanner D, Lehman C, Perry J. 2007. On the Road to Nowhere: Galápagos Lava Lizard Populations. Bulletin of the Chicago Herpetological Society **42:**125–132.

Teixeira FZ, Printes RC, Fagundes JCG, Alonso AC, Kindel A. 2013. Canopy bridges as road overpasses for wildlife in urban fragmented landscapes. Biota Neotropica **13:**117–123.

Teixeira FZ, Coelho AVP, Esperandio IB, Kindel A. 2013. Vertebrate road mortality estimates: Effects of sampling methods and carcass removal. Biological Conservation **157**:317–323

Teixeira FZ et al. 2013. Are road-kill hotspots coincident among different vertebrate groups? Oecologia Australis **17**:36-47.

Teixeira FZ, Coelho IP, Lauxen M, Esperandio IB, Hartz SM, Kindel A. 2016. The need to improve and integrate science and environmental licensing to mitigate wildlife mortality on roads in Brazil. Tropical Conservation Science **9**:34-42.

Tejada G, Dalla-Nora E, Cordoba D, Lafortezza R, Ovando A, Assis T, Aguiar AP. 2016. Deforestation scenarios for the Bolivian lowlands. Environmental Research **144:** 49–63.

Thiollay JM. 1999. Responses of an avian community to rain forest degradation. Biodiversity and Conservation **8:**513–534.

Thoisy B, Richard-Hansen C, Goguillon B, Joubert P, Obstancias J, Winterton P, Brosse S. 2010. Rapid evaluation of threats to biodiversity: Human footprint score and large vertebrate species responses in French Guiana. Biodiversity and Conservation **19:**1567–1584.

Trejo A, Seijas S. 2003. Una Estimación De Aves Muertas En Ruta En El Parque Nacional Nahuel Huapi , Noroeste De La Patagonia Argentina. Hornero **18**:97–101.

Tumeleiro LK, Koenemann J, Ávila MCN, Pandolfo FR, Oliveira EV. 2006. Notas sobre mamíferos da região de Uruguaiana: estudo de indivíduos atropelados com informações sobre a dieta e Conservação. Biodiversidade Pampeana **4:**38-41.

Turci LCB, Bernarde PS. 2009. Vertebrate roadkills on State Highway 383, Rondônia, Brazil. Biotemas **22:** 121-127.

Vargas-Salinas F, Berrío-Baca H. 2009. Herpetofauna asociada a la vegetación de borde de carretera em la región de Anchicayá, Valle del Cauca, pacífico de Colombia. Novedades Colombianas **9**:28-37.

Vargas-Salinas F, Delgado-Ospina I, López-Aranda F. 2011. Amphibians and reptiles killed by motor vehicles in a Sub-Andean forest in western Colombia. Caldasia **33:**121–138.

Vargas Salinas F, López Aranda F. 2012. Could roads restraint the movement of small mammals in Andean forests of Colombia? Study case in the bosque de Yotoco, Valle del Cauca. Caldasia **34:**409–420.

Vargas-Salinas F. 2013. Traffic noise correlates with calling time but not spatial distribution in the threatened poison frog *Andinobates bombetes*. Behaviour **150:**569–584.

Vega LE, Bellagamba PJ, Fitzgerald LA. 2000. Long-term effects of anthropogenic habitat disturbance on a lizard assemblage inhabiting coastal dunes in Argentina. Canadian Journal of Zoology **78:** 1653–1660.

Weiss LP, Vianna VO. 2012. A study of the impact of federal roads BR-376, BR-373 and BR- 277 roads, Apucarana and Curitiba, Paraná stretch on the run over of wild animals. Ciência Biologia e Saúde **18:** 121-133.

Weyland F, Baudry J, Ghersa CM. 2014. Rolling Pampas agroecosystem: which landscape attributes are relevant for determining bird distributions? Revista Chilena de Historia Natural **87:**1-12.

Whitworth A, Beirne C, Rowe J, Ross F, Acton C, Burdekin O, Brown P. 2015. The response of faunal biodiversity to an unmarked road in the Western Amazon. Biodiversity and Conservation **24:**1657–1670.

Xavier MS, Lemos HM, Caccavo A, Bezerra E, Secco H, Gonçalves PR. 2017. Noteworthy coastal records of the maned wolf, *Chrysocyon brachyurus* (Illiger, 1815), in Southeastern Brazil. Boletim da Sociedade Brasileira de Mastozoologia **78**:9-13.

Appendix S2. Documented effects of roads on wildlife by group of species or by species in Latin America on habitat loss and fragmentation and also biodiversity (richness, abundance and behavior). Negative effects (red), neutral effects (yellow), contrasting effects (blue) and positive effects (green), no information (white).

Species group or species	Habitat	Biodiversity			Reference
	Loss/Frag	Richness	Abundance	Behavior	
Amphibians					
Amphibian community					Vargas-Salinas et al. (2011), Witworth et al. (2015)
					Silva et al. (2006), Vargas-Salinas & Baca (2009)
Anura					
*Andinobates bombetes***					Vargas-Salinas & Amézquita (2013)
Melanophryniscus sp					Cairo & Zalba (2007)
Bromeliad species					McCracken & Forstner (2014)
Forest species					Maynard et al. (2016)
					Fredericksen (2004)
Reptiles					
Snakes and lizards community					Vargas-Salinas et al. (2011), Vargas-Salinas et al (2009)
					Maynard et al. (2016)
Testudines					
*Chelonoidis denticulate***					Espinosa et al. (2014), Suárez et al. (2009)
*Podocnemis unifilis***					Suárez et al. (2009)
Squamata					
*Liolaemus lutzae***					Rocha et al. (2009)
*Liolaemus multimaculatus****					Vega et al. (2000)
Liolaemus gracilis					Vega et al. (2000)
Crocodylia					
Crocodylus moreletii					González-Trujillo et al. (2014)
Caiman crocodilus,					Suárez et al. (2009)
Melanosuchus niger					Suárez et al. (2009)
Birds					
Birds community					Silva et al. (2017)
					Bager & Rosa (2012)
					Malizia et al. (1998)
					Weyland et al. (2014), Whitworth et al. (2015)
Cathartiformes					
*Vultur gryphus**					Speziale et al. (2008)
Galliformes					

Species group or species	Habitat	Biodiversity			Reference
	Loss/Frag	Richness	Abundance	Behavior	
*Crax alector***					Thoisy et al. (2010)
Mitu salvini					Espinosa et al. (2014), Suárez et al. (2009)
Ortalis guttata					Suárez et al. (2009)
Penelope jacquacu					Espinosa et al. (2014), Suárez et al. (2009)
Penelope marail					Thoisy et al. (2010)
Pipile cumanensis					Espinosa et al. (2014)
*Pipile pipile*****					Suárez et al. (2009)
Gruiformes					
Psophia crepitans					Thoisy et al. (2010)
Struthioniformes					
Crypturellus sp					Suárez et al. (2009)
*Tinamus major**					Suárez et al. (2009), Thoisy et al. (2010)
Passeriformes					
Chamaeza campanisona					Oliveira Jr et al. (2011)
Conopophaga lineata					Oliveira Jr et al. (2011)
Corydospiza alaudina					Muñoz-Sáez et al. (2017)
Curaeus curaeus					Muñoz-Sáez et al. (2017)
Pyriglena leucoptera					Oliveira Jr et al. (2011)
Spinus barbatus					Muñoz-Sáez et al. (2017)
Tachycineta meyeni					Muñoz-Sáez et al. (2017)
Piciformes					
Pteroglossus castanotis					Suárez et al. (2009)
Psittaciformes					
Ara ararauna					Suárez et al. (2009)
Forest birds					Ahmed et al. (2014), Aubad et al. (2010),
					Arévalo & Newhard (2011)
					Felton et al. (2008), Suárez et al. (2013), Thiollay (1999)
					Avalos & Bermúdez (2016)
Grasslands birds					Astudillo et al. (2014)
Understory mixed-species flocks					Develey & Stouffer (2001)
Understory birds					Laurance et al. (2004)
Mammals					
Mammals community					Suarez et al. (2013)
					Di Bitetti et al. (2013)

Species group or species	Habitat	Biodiversity			Reference
	Loss/Frag	Richness	Abundance	Behavior	
					Di Bitetti et al. (2014)
Primates community					Aquino et al. (2014)
Small mammals community					Lambert et al. (2014)
Carnivora					
Conepatus chinga					Caruso et al. (2016)
Leopardus geoffroyi					Caruso et al. (2016)
Lycalopex gymnocercus					Caruso et al. (2016)
Oncifelis guigna					Acosta-Jamet & Simonetti (2004)
Pseudalopex culpaeus					Acosta-Jamet & Simonetti (2004)
Puma concolor					Caruso et al. (2016), Quiroga et al. (2016)
*Panthera onca**					Colchero et al. (2011)
Tremarctos ornatus					Peralvo et al. (2005), Sánchez-Mercado et al. (2008)
Cetartiodactyla					
Lama guanicoe					Cappa et al. (2017)
Lama guanicoe					Marino et al. (2012)
Mazama americana					Thoisy et al. (2010),Suárez et al. (2009),Espinosa et al. (2014)
Mazama gouazoubira					Thoisy et al. (2010)
Mazama nemorivaga					Espinosa et al. (2014)
Pecari tajacu					Suárez et al. (2009), Espinosa et al. (2014)
Pecari tajacu					Thoisy et al. (2010)
Sus scrofa					Gantchoff & Belant (2015)
Sus scrofa					Cuevas et al (2013)
*Tayassu pecari***					Suárez et al. (2009), Espinosa et al. (2014)
Cingulata					
Dasypus novemcinctus					Suárez et al. (2009)
Didelphimorphia					
Marmosa robinsoni					Vargas-Salinas & Aranda (2012)
Marmosops incanus					Rosa et al (2017)
Lagomorpha					
Lepus europaeus					Gantchoff & Belant (2015)
Perissodactyla					
*Tapirus terrestris***					Suárez et al. (2009), Espinosa et al. (2014)
Primates					
Alouatta seniculus					Espinosa et al. (2014)

Species group or species	Habitat		Biodiversity		Reference
	Loss/Frag	Richness	Abundance	Behavior	
Alouatta seniculus					Thoisy et al. (2010)
*Ateles belzebuth****					Suárez et al. (2009), Espinosa et al. (2014)
*Ateles geoffroyi****					Ascensio et al. (2017)
*Ateles paniscus***					Thoisy et al. (2010)
Cebus apella					Thoisy et al. (2010)
Cebus olivaceus					Thoisy et al. (2010)
*Lagothrix poeppigii***					Suárez et al. (2009), Espinosa et al. (2014)
Pithecia pithecia					Thoisy et al. (2010)
Saguinus midas					Thoisy et al. (2010)
Rodentia					
Akodon montensis					Ascensão et al. (2017)
Akodon sp,					Rosa et al (2017)
Calomys venustus					Chiappero et al. (2016)
Cerradomys subflavus					Rosa et al (2017)
Cuniculus paca					Suárez et al. (2009), Espinosa et al. (2014)
Dasyprocta agouti					Thoisy et al. (2010)
Dasyprocta fuliginosa					Suárez et al. (2009), Espinosa et al. (2014)
Handleyomys alfaroi					Vargas-Salinas & Aranda (2012)
Hydrochaerus hydrochaeris					Suárez et al. (2009)
Melanomys caliginosus					Vargas-Salinas & Aranda (2012)
Oryzomys couesi,					Fuentes-Montemayor et al. (2009)
Reithrodontomys spectabilis					Fuentes-Montemayor et al. (2009)
Rhipidomys latimanus					Vargas-Salinas & Aranda (2012)
Rhipidomys sp,					Rosa et al (2017)

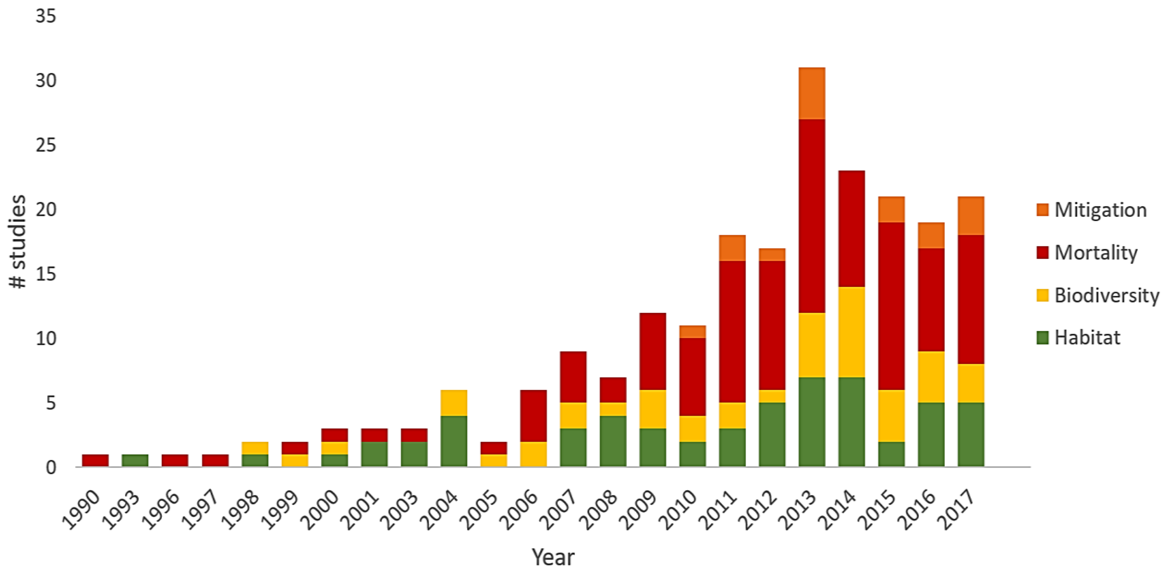
Legend: Threatened species according to IUCN Status: *Near Threatened, **Vulnerable, ***Endangered, ****Critically Endangered.

Appendix S4 – Systematic quantitative literature review and definition of research areas and sub-topics.

We searched published research through the following search engines and databases: Web of Science, Scopus and Science Direct. Our search comprised three groups of information: geographic (on the 21 countries in Latin America, from northern Mexico to southern Patagonia), wildlife vertebrates (amphibians, reptiles, birds and mammals), and common terms related to roads. We made the searches for each Latin America country using the following key search words in English, Spanish and Portuguese: (Latin America country) AND (wildlife* OR vertebrates* OR amphibians* OR reptiles* OR birds* OR aves OR mammals) AND (roads* OR vehicle* OR traffic* OR highways* OR motorway* OR unpaved* OR roadkill* OR transport* OR mitigation*). We restricted our search to these categories because preliminary searches showed that adding other journal categories greatly increased the number of irrelevant papers. We also searched the grey literature through Google Scholar and by contacting road ecology researchers in Latin America using the references found in publications (Plataforma Lattes a database of researchers in Brazil http://lattes.cnpq.br). To limit the studies to those assessing the ecological effects of roads on wildlife, we first screened studies by reading titles and abstracts and excluded studies that did not match these criteria. Each research study was classified according to their research area and sub-topic, according to the following table:

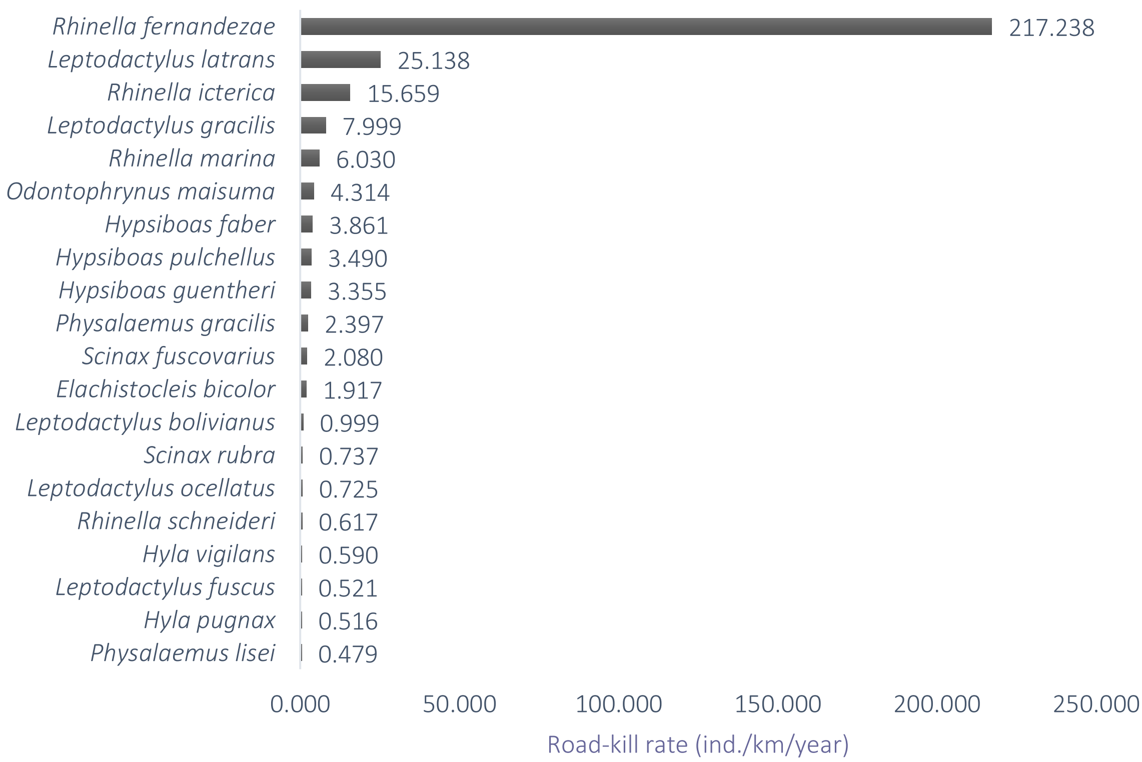
Research area	**Sub-topic**	**Definition**
Habitat	Loss and fragmentation	The effects of road construction, implications of roads on urban sprawl and landscape fragmentation.
Biodiversity	Richness	The effects of road networks on species composition and diversity
	Abundance	The effects of roads on species abundance and density,
	Species behaviour	The effect of traffic, noise and light on species behavior, individual movements (barrier effect).
Mortality	Composition	Number of species and road-kill rates by species
	Spatial/temporal patterns	Evaluation of distribution and aggregation of road-kills and factors that promote road-kill risk
Mitigation	Recommendations	Proposed types of mitigation measures
	Effectiveness	Analysis of efficacy of mitigation measures

Appendix S5. Temporal patterns of published studies



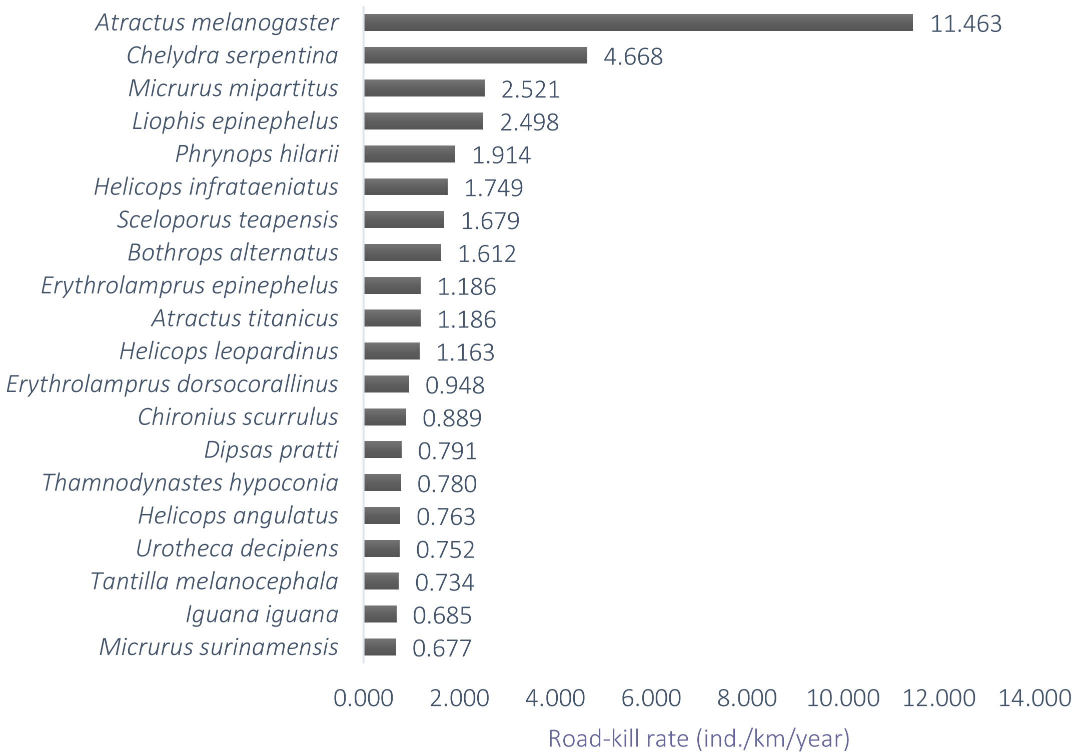
Appendix S5. Number of published studies per year regarding research topics from 1990 until 2017 in Latin America countries.

Appendix S6. Summary of amphibians road-kill rates in Latin America



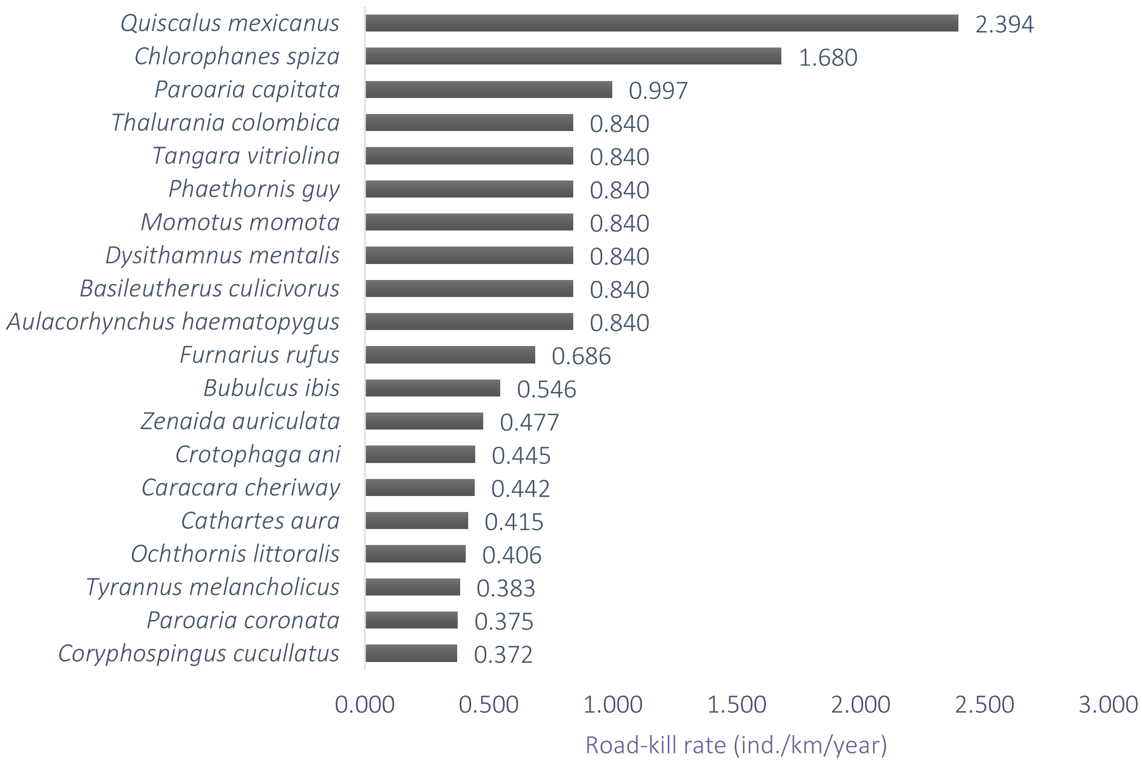
Appendix S6. Top 20 amphibians species with the higher mean of road-kill rates

Appendix S7. Summary of reptiles road-kill rates in Latin America.



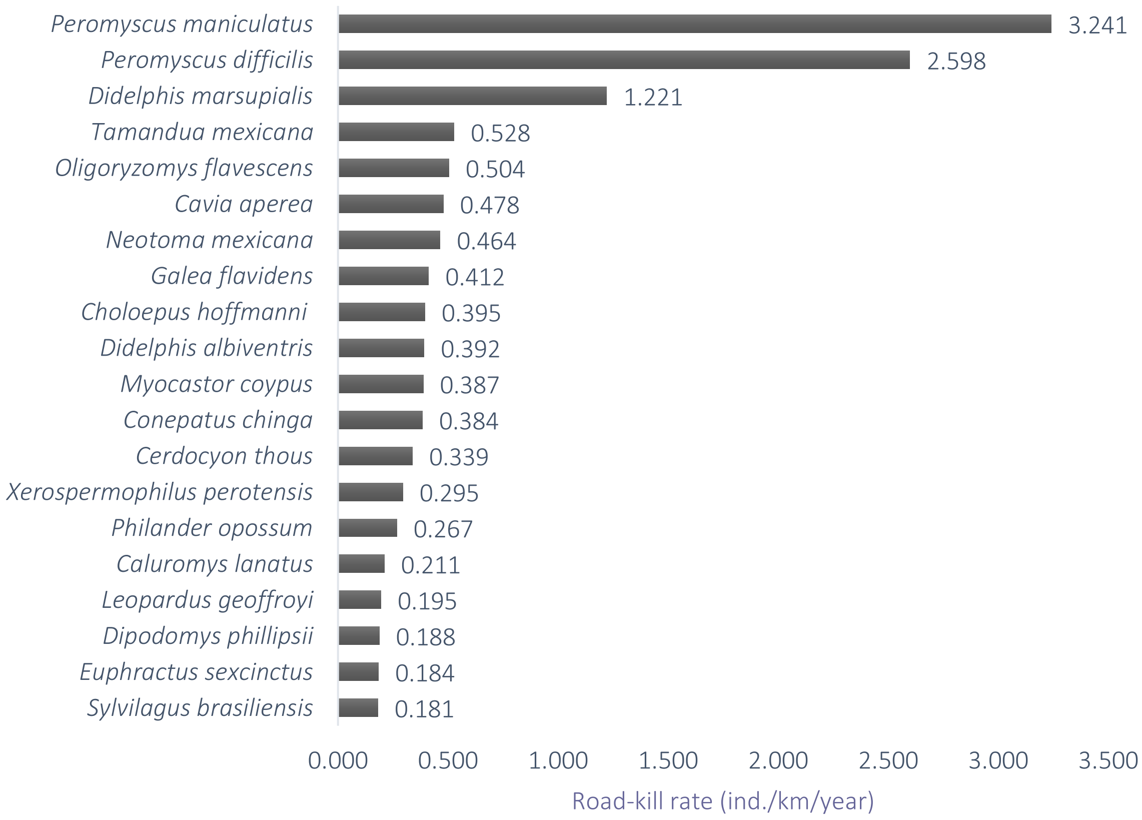
Appendix S7. Top 20 reptiles species with the higher mean of road-kill rates

Appendix S8. Summary of birds road-kill rates in Latin America.



Appendix S8. Top 20 birds species with the higher mean of road-kill rates

Appendix S9. Summary of mammals road-kill rates.



Appendix S9. Top 20 birds species with the higher mean of road-kill rates

ARTIGO 2– GIANT ANTEATER (*Myrmecophaga tridactyla*) CONSERVATION IN BRAZIL: ANALYSING THE RELATIVE EFFECTS OF FRAGMENTATION AND MORTALITY DUE TO ROADS.

Biological Conservation 228 (2018) 148–157

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Giant anteater (*Myrmecophaga tridactyla*) conservation in Brazil: Analysing the relative effects of fragmentation and mortality due to roads

Fernando A.S. Pinto[a,b,*], Alex Bager[a,c], Anthony P. Clevenger[d], Clara Grilo[b]

[a] *Centro Brasileiro de Estudos em Ecologia de Estradas, Universidade Federal de Lavras, Campus Universitário, PO Box 3037, CEP 37200-000 Lavras, Minas Gerais, Brazil*
[b] *Setor de Ecologia e Conservação, Departamento de Biologia, Universidade Federal de Lavras, PO Box 3037, CEP 37200-000 Lavras, Minas Gerais, Brazil*
[c] *Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil*
[d] *Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, MT, USA*

ARTICLE INFO

Keywords:
Giant anteater
Myrmecophaga tridactyla
Patch size
Population persistence
Road density
Spatial explicit population model

ABSTRACT

Road networks can have serious ecological consequences for many species, mainly through habitat fragmentation and mortality due to collisions with vehicles. One example of a species impacted by roads is the giant anteater (*Myrmecophaga tridactyla*), currently listed as Vulnerable by IUCN. Here we analysed the relative effect of fragmentation and mortality due to roads on giant anteater populations and show the critical areas for their persistence in Brazil. We estimated minimum patch size and maximum road density to evaluate the impact of the road network and observed road-kills on this species. We explored different scenarios by varying values of dispersal capacity to estimate the minimum patch size, and also of population densities to estimate maximum road density for giant anteater persistence. Our findings indicated that the minimum patch size can be from 498 to 247 km^2 and the maximum road density can vary between 0.21 and 0.55 km/km^2 in pessimist and optimistic scenarios, respectively. In Brazil, habitat fragmentation seemed to have a major impact over giant anteater populations. Habitat fragmentation due to roads seemed to have a more negative effect than mortality due to collisions with vehicles. Critical areas for the species persistence can represent 32% of its range in the optimistic scenario with 18% of suitable patches below the minimum size and 0.1% above the maximum road density. This study provides insights and implications for road networks on giant anteater populations in Brazil and guidance on road density and patch size thresholds for land managers and road agencies charged with planning ecologically sustainable roads in Brazil.

1. Introduction

Habitat fragmentation constitutes a serious threat for mammals worldwide (Crooks et al., 2017) as 27% of mammals are at risk of extinction, and 40% of those at risk due to habitat loss (Schipper et al., 2008). Road networks are one of the primary anthropogenic contributors to habitat loss and fragmentation, and have been highlighted as primary drivers of biodiversity decline and species extinction (Rands et al., 2010; Crooks et al., 2017). Fragmentation can create adverse edge effects on the boundaries of habitat patches (Haddad et al., 2015), decrease landscape connectivity (Cushman, 2006; Jackson and Fahrig, 2011), act as a barrier for animal movement and gene flow (Chen and Koprowski, 2016), and reduce genetic diversity (Balkenhol et al., 2013), all of which can lead to local declines of populations (Bender et al., 1998; Gibbon et al., 2000).

Mortality from collisions with vehicles is a major negative effect of roads on wildlife (Mumme et al., 2000; Gibbs and Shriver, 2002). In general, high mobility species have higher chances of encountering roads compared to less mobile species, and thus, are more affected by road-related mortality (Rytwinski and Fahrig, 2012). The loss of individuals by road mortality can have a strong effect on population viability especially for species with low reproductive rates (Ferreras et al., 2001; Haines et al., 2006; Medici and Desbiez, 2012; Diniz and Brito, 2013).

The importance of road networks to species ecology (e.g. reproduction, behaviour, habitat use) has motivated work on minimum road density estimation. For example, wolves (*Canis lupus*) and pumas (*Puma concolor*) do not maintain breeding groups in areas with road densities > 0.6 km/km^2 (Thiel, 1985; Van Dyke et al., 1986). Basille et al. (2013) observed that Eurasian lynx (*Lynx lynx*) in southern Norway avoided using areas with a road density > 0.41 km/km^2. While these studies provided a road density threshold that can influence the

* Corresponding author at: Centro Brasileiro de Estudos em Ecologia de Estradas, Universidade Federal de Lavras, Campus Universitário, PO Box 3037, CEP 37200-000 Lavras, Minas Gerais, Brazil.
E-mail address: fernando.pinto@ecoestradas.org (F.A.S. Pinto).

https://doi.org/10.1016/j.biocon.2018.10.023
Received 20 January 2018; Received in revised form 26 September 2018; Accepted 19 October 2018

species ecology, they did not evaluate the impact of road density on population viability. In fact, few studies have taken this next step. A Canadian study found a positive relation between risk of extinction of birds and mammals and a road density > 0.3 km/km^2 (Anderson et al., 2011). Further, Ceia-Hasse et al. (2017) identified road density thresholds above which carnivore species cannot persist, for example: puma (0.77 km/km^2), jaguar (*Panthera onca*, 0.14 km/km^2), Darwin's fox (*Lycalopex fulvipes*, 0.11 km/km^2).

Population viability analysis has been commonly used to evaluate the impact of human activities on wildlife populations (Beaudry et al., 2008; Brook et al., 2000; Row et al., 2007). Understanding the causes of population declines and ultimately processes contributing to extinction is particularly important to strategically focus actions on populations most at risk (Cardillo et al., 2005; Pereira et al., 2010). Spatially-explicit population models have been extensively used in conservation planning as they combine population dynamic with the spatial structure of landscapes (Ceia-Hasse et al., 2017; Schumaker et al., 2014). Assessing the relative role of habitat fragmentation and additional mortality due to collision with vehicles on population viability is crucial to provide guidance to road managers and help implement more effective mitigation measures.

One species considered particularly vulnerable to roads is the giant anteater, *Myrmecophaga tridactyla* (Miranda et al., 2014). Classified as a Vulnerable species, giant anteater populations show a current decrease trend with records of extinctions in Central America and in the southern parts of its range (IUCN, 2018). According to Freitas et al. (2014), the species exhibits road avoidance when traffic is > 2600 vehicles/day, potentially increasing habitat fragmentation effects and population isolation. Furthermore, road-kill studies regularly detect this species, with road-kill rates up to 0.19 ind/km/year (Fischer, 1997). Although road mortality events are well documented in the literature (de Carvalho et al., 2014; de Souza et al., 2015; Ascensão et al., 2017), little is known about how road networks affect the viability of giant anteater populations (Diniz and Brito, 2013, 2015). Assessing road network effects on persistence of giant anteater populations will inform transportation planning decisions by the Brazilian government as they expand national road networks over the next 20 years (DNIT, 2013; Bager et al., 2015).

In this study, we analysed the effects of habitat fragmentation and mortality due to roads on giant anteater populations in Brazil. We estimated the minimum habitat patch size and maximum road density required for giant anteater persistence under six scenarios. Four scenarios to estimate minimum patch size using all combinations between low and high dispersal capacity with roads as barriers and without roads, and two scenarios to estimate maximum road density thresholds using the minimum and maximum giant anteater population densities. Our findings will identify which of the two road effects are more important for giant anteater persistence, thereby providing road density and patch size thresholds for land managers and road agencies responsible for planning ecologically sustainable road networks in Brazil.

2. Material and methods

2.1. Study area

Our study area comprises the giant anteater range in Brazil (IUCN, 2014), which represents almost 90% (7.5 million km^2) of the entire Brazilian territory (Fig. 1). Forested areas encompass almost 65% (4.8 million km^2) of the study area, followed by open and sparse vegetated areas (shrubs and grasslands) with 17% (1.3 million km^2), croplands 14% (1.1 million km^2), water bodies 1.5% (109,000 km^2), herbaceous vegetation (aquatic or regularly flooded) with 1% (77,000 km^2), and urban areas with 0.5% (30,000 km^2) (GLC (Global Land Cover Share) et al., 2014). The study area covers all of the Brazilian biomes except Pampas in the extreme south. The Amazon, Pantanal and Cerrado biomes are totally represented, while the Caatinga and Atlantic forest are partially represented where the species is considered possibly extinct in southern portions of the latter biome (Miranda et al., 2014).

The study area encompasses nearly 35% (~70 million inhabitants) of the Brazilian human population, where the most populated region is the southeast (IBGE, 2017). The mean paved road density ± SD in the giant anteater range is 0.02 ± 0.07 km/km^2, with the highest value in the south-southeast portions (0.05 ± 0.07 km/km^2) and the lowest in the northern region (0.004 ± 0.03 km/km^2).

2.2. Model parameterization

To model the impact of road networks on giant anteater population persistence we followed the approach of Borda-de-Água et al. (2011). The authors used the reaction-diffusion equation proposed by Skellam (1951) (Appendix information A) to derive two simple formulas (Eqs. (1) and (2)) where the main forces driving population dynamics are dispersal and population growth. The Borda-de-Água et al. (2011) approach assumes that a population occurs in a landscape composed of suitable habitat surrounded by unsuitable areas (e.g. roads) acting as a "sink-habitat" and will not persist when it reaches to 1/e (0.36) of its original size in a time given by the relaxation time equation (Appendix information B). The model is parameterized with the following population features: growth rate in suitable habitat (r_1), dispersal variance (σ^2), and survival on roads specified by a (negative) growth rate (r_0). Model output includes predicted minimum patch size below which populations cannot persist (P_{min}) and maximum road density above which populations cannot persist (D_{max}).

$$P_{min} = \pi^2(\sigma^2/r_1) \quad (1)$$

$$D_{max} = r_1/(r_1+|r_0|) \quad (2)$$

We estimated the three anteater population parameters using data from the literature (Table 1). We calculated intrinsic population growth rate (r_1) with a simplified version of the Euler equation (Pereira and Daily, 2006; Appendix information C), using the following parameters obtained from Miranda (2004): fecundity (*b*), the interval between litters (years), age at the first birth (years), and a constant mortality rate (μ). To estimate dispersal variance (i.e. dispersal capacity; σ^2), we used the following equation provided by Pereira and Daily (2006):

$$\sigma^2 = (\sigma m/1.18)^2 * \mu,$$

where (μ) is a constant mortality rate assumed as the inverse of lifespan (Table 1), and (σm) the median dispersal distance derived from the equation suggested by Bissonette and Adair (2008): $\sigma m = 7 * (\sqrt{HR})$, where HR is the median of home-ranges (Table 1).

Population growth rate on roads (r_0) is an approximation of the proportion of the population killed on roads and is always expressed as a negative rate. It was obtained using data on giant anteater population density and estimates of road-kill rates using the following equation:

$$r_0 = (N_{killed}/D) * year^{-1},$$

where N_{killed} is the number of individuals road-killed/km/year, D is the giant anteater population density expressed by the number of individuals/km^2 (Table 1) divided by the road width (we assumed all roads were 10 m wide). Only the highest road-kill rate was used to run the model (Table 1).

2.2.1. Minimum patch size estimation

Calculation of P_{min} requires estimation of population growth rate in suitable habitat. Studies on giant anteater habitat use revealed that four land cover types are suitable habitat for the species for foraging, resting and/or reproduction behaviours (Fig. 1): 1) Grasslands; 2) shrubland areas; 3) herbaceous vegetation, aquatic or regularly flooded and 4) forested areas (Bertassoni et al., 2017; Braga, 2010; Camilo-Alves and Mourão, 2006; Medri and Mourão, 2005). We then identified those land

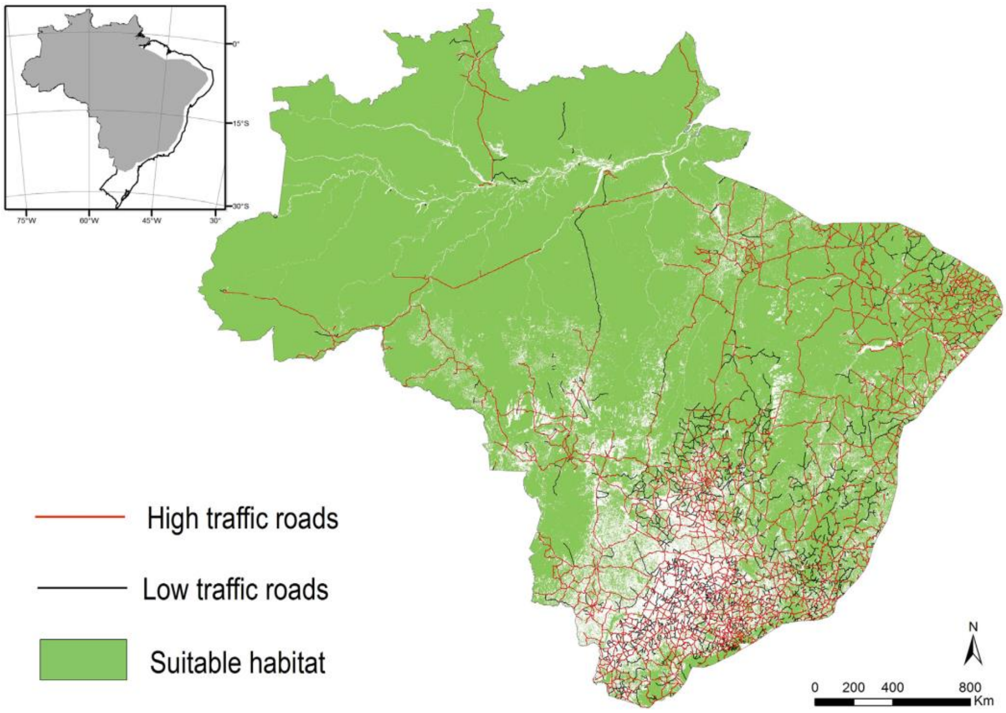


Fig. 1. Extent of suitable Giant anteater habitat in Brazil overlaid with high- and low-traffic volume roads.

cover types at the Global Land Cover spatial data with a resolution of 1 × 1 km (GLC (Global Land Cover Share) et al., 2014).

We used the Equation 1 (Eq. (1)) to estimate the minimum suitable habitat patch size (Pmin) assuming: 1) an infinite carrying capacity ($k = \infty$), 2) considering explicitly the location of the roads, 3) exponential growth in suitable habitats and 4) that all individuals die when crossing a road ($r0 = -\infty$) (Borda-de-Água et al., 2011; Appendix information A). The last assumption is supported by the fact that animals move at slow speed and by the observation of high road-kill rates (Fischer, 1997; Freitas et al., 2014).

2.2.2. Maximum road density estimation

The Equation 2 (Eq. (2)) was used to estimate maximum road density (D_{max}) above which populations cannot persist, assuming 1) exponential population growth, 2) large dispersal ($\sigma^2 = \infty$), 3) ignoring the spatial location of the roads and considering only the road density, and 4) a large carrying capacity ($k = \infty$, so the term $1 - N(x, y, t) / K$ in the reaction-diffusion equation is not considered; Appendix information A) (Borda-de-Água et al., 2011).

For maximum road density, we created a grid square of $10 \times 10\,km^2$ over the Brazilian giant anteater range and estimated the paved road density (km/km^2) for each square (Open Street Map, Geofabrik, 2016). We then mapped the D_{max} values in each square of $10 \times 10\,km^2$.

Table 1
Giant-anteater life history variables used for parameterization of minimum patch size (P_{min}) and maximum road density (D_{max}) models.

Parameters used to compute P_{min} and D_{max}	Life-history parameters[a]	Values	References
Population growth rate (r_1)	Fecundity (b)	0.5	Miranda (2004)
	Interval between litters (years)	0.7	Miranda (2004)
	Age at the first birth (years)	3	Miranda (2004)
	Constant mortality (μ)	0.04 (1/25)	Miranda (2004)
Dispersal variance (σ^2)[b]	Median home range size (km^2; Min; Max)[b]	4.7; 9.5	Braga (2010), Medri (2002), Miranda (2004), Shaw et al. (1987) and Medri and Mourão (2005)
Population growth rate on roads (r_0)	Maximum road-kill rate (ind/km/yr)	0.19	Fischer (1997)
	Population density (ind/km^2; Min; Max)	0.15; 0.4	Desbiez and Medri (2010) and Miranda (2004)

[a] Fecundity: the ratio of the number of female offspring regarding to the mean litter size (50% of mean litter size); litter interval: mean interval between litters; age at first birth: age at first reproductive event; mortality: constant mortality rate (inverse of mean lifespan (25 years)).

[b] We estimated minimum and maximum dispersal variances (σ^2) for scenarios P1, P3 and P2, P4, respectively. We used the median of minimum and maximum home-range sizes found in the literature (varied between 2.7 and 11.9 km^2). First, we calculated the median of all values found for giant anteater (8.11 km^2) and then for the values below the median (2.74; 3.67; 5.7; 7.3 km^2) we calculate the median of the minimum home range and for the values above the 8.11 km^2 (8.92; 9.1; 9.83; 11.9 km^2) we calculated the median of the maximum home range.

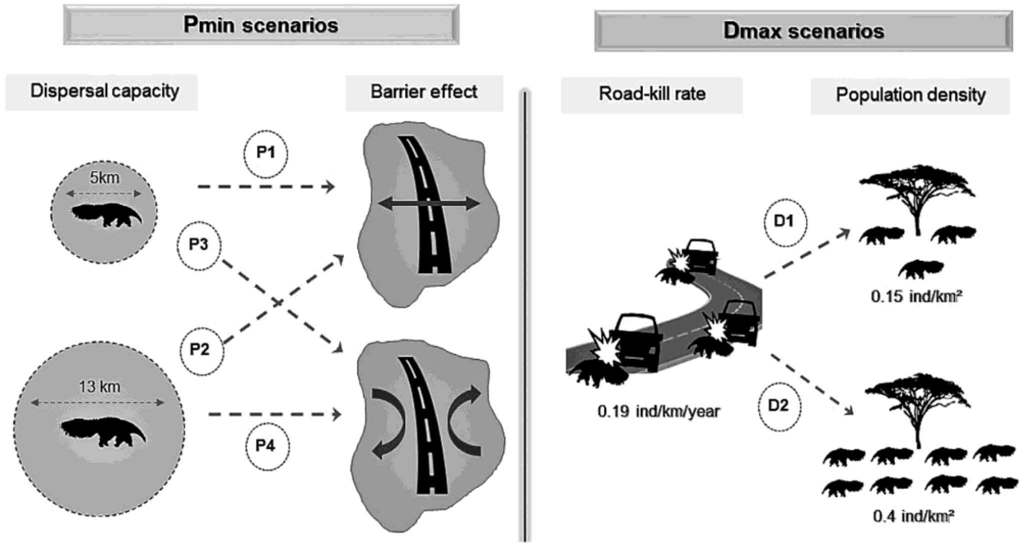


Fig. 2. Four scenarios to estimate minimum patch size (P_{min}) (P_1, P_2, P_3, P_4) and two scenarios to estimate Maximum Road Density (D_{max}) (D_1 and D_2) for giant anteater.

2.3. Scenario development and critical areas

We examined the sensitivity of P_{min} and D_{max} to giant anteater life histories, behaviour, and model assumptions. To assess sensitivity of P_{min}, we varied dispersal variance (σ^2) and barrier effect to create four scenarios: (P_1) limited dispersal capacity (4.7 km^2) and roads do not act as barriers, (P_2) high dispersal capacity (9.5 km^2) and roads are not barriers, (P_3) limited dispersal and roads are barriers, and (P_4) high dispersal and roads are barriers (Fig. 2). To simulate the no-barrier effect of roads (P_1 and P_2), we overlaid our estimated patch sizes with the giant anteater range, ignoring the presence of roads. To simulate roads as a barrier (P_3 and P_4), we intersected estimated patch size with high traffic roads (> 2600 vehicle/day, Freitas et al., 2014) and recalculated the area of each resulting patch in ArcGis. In the absence of official estimates of traffic intensity, we used Open Street Map (Geofabrik, 2016) and reclassified the "motorway", "trunk" and "primary" roads as high traffic roads, and the "secondary" as low traffic roads (Fig. 1). To assess D_{max}, we created two scenarios by combining the maximum road-kill rate (N_{killed}; 0.19 ind./km/yr) with a low and high giant anteater population density estimate (D - 0.15 ind/km^2 and 0.4 ind/km^2, respectively) (D_1 and D_2 scenarios, respectively) (Fig. 2).

We identified areas of low predicted population persistence (critical areas) by overlaying regions with values below the estimated minimum patch sizes (P_{min}) and regions above the maximum road density (D_{max}). We were specifically interested in two contrasting scenarios for critical areas: 1) an optimistic scenario that combines the better P_{min} and D_{max} scenarios (P_1 + D_2), and 2) a pessimistic scenario that combines the worst P_{min} and D_{max} (P_4 + D_1). We added unsuitable habitats at the sum of critical areas. Most of these areas are composed of anthropogenic landscapes representing poor quality habitats for species persistence (i.e. croplands, water bodies, and urban areas; see Section 2.1).

3. Results

3.1. Minimum patch size

Minimum patch size (P_{min}) for giant anteater population persistence was 247 km^2 with minimum dispersal capacity and 498 km^2 with maximum dispersal capacity. Approximately 18% (1.15 million km^2) and 20% (1.3 million km^2) of suitable habitat was below the minimum patch size considering the scenarios without road barrier (P_1 and P_2, respectively; Fig. A1). When we added roads as a barrier by splitting the patches (scenarios P_3 and P_4), 19% of suitable habitat (1.2 million km^2) and 21% (1.35 million km^2) of the suitable habitats were below the minimum estimated patch size, respectively (Fig. A1). The fragmentation process due to roads as a barrier decreased the amount of suitable patches by 3% (~200 thousand km^2), considering the differences between P1 and P4 scenarios.

3.2. Maximum road density

Our results indicate that the maximum road density (D_{max}) for giant anteater population persistence was 0.21 km/km^2 considering the lowest population density scenario (D_1), that represents 0.95% (71,756 km^2) of the giant anteater range in Brazil. Considering the highest population density scenario (D_2), the maximum road density value was 0.55 km/km^2, that represents 0.09% (6798 km^2) of the species range (Fig. A2). Most of the grid cells with D_{max} are concentrated in southeast portion of the range (Fig. A2) with 5% of the cells having road density estimates above 0.21 km/km^2 followed by the South region with 3.5% with a road density above 0.21 km/km^2.

3.3. Critical areas

The optimistic scenario (P_1 + D_2) showed that 32% of the giant anteater range in Brazil (2.4 million km^2) is under critical threats to their population's persistence, while 36% (2.7 millionkm2) was critical considering the pessimistic scenario (P_4 + D_1) (Fig. 3). Other two combinations of critical areas (P_3 and D_2; P_2 and D_1 scenarios), showed that 33% (2.5 million km^2) and 34% (2.6 million km^2) of the species range is critical for persistence respectively (Figs. A3, A4). For all combinations, the central and southern species range was the most affected areas. This coincides with the highest human population density and predominantly agricultural areas on the Brazilian landscape. In particular, the southern region of the Cerrado biome is massively fragmented and scattered in small relatively undisturbed areas, unlike the northern region that contains extensive contiguous natural areas of Amazon and Cerrado biomes.

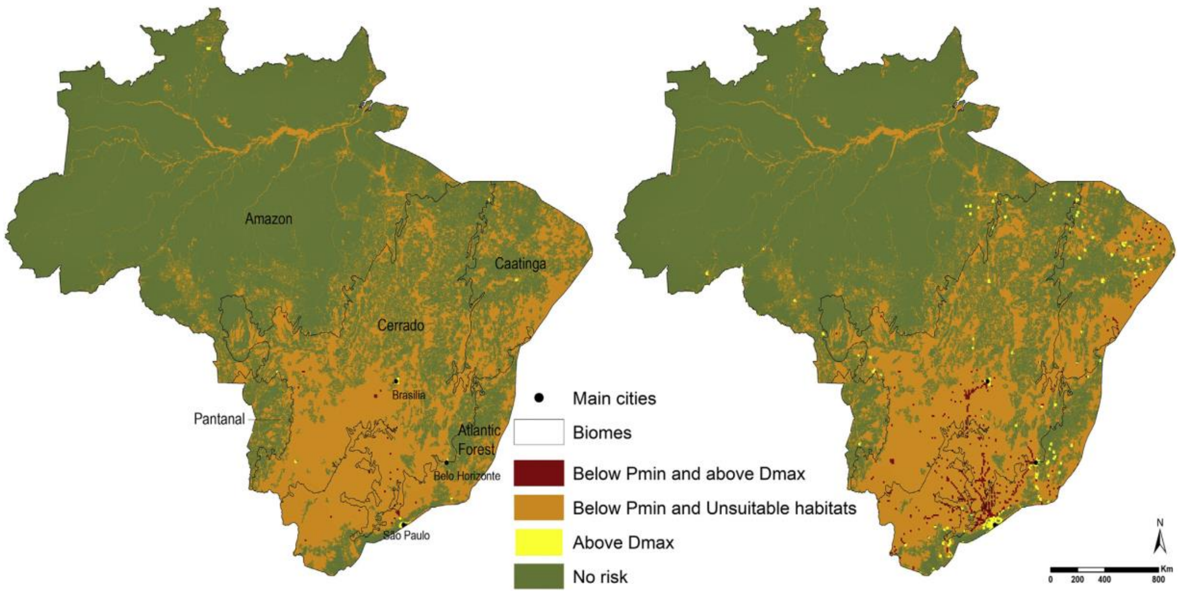


Fig. 3. Critical areas for giant anteater persistence considering the optimistic (left) and pessimistic scenario (right): P_{min} - minimum patch size; D_{max} - maximum road density; No risk - Suitable habitats above P_{min} and below D_{max}.

4. Discussion

Our findings show that habitat fragmentation has a greater impact on persistence of the giant anteater population in Brazil than the observed mortality due to vehicle collisions. Moreover, the effect of roads as a barrier to giant anteater movement, as shown by the modest change in P_{min} (200,000 km^2), seems to be minimal compared to the actual habitat fragmentation due to other human activities. The large area requirements of giant anteaters and current low road density, which does not cause a high proportion of mortality may explain this finding. Our results show that there are few natural patches over 498 km^2 bisected by roads, suggesting that areas covered by the Brazilian road network are already strongly fragmented.

Giant anteaters are flagship species in the Cerrado. This biome harbours most of the giant anteater populations (Miranda et al., 2015) and is currently under serious threat due to habitat fragmentation. Around 46% of the native Cerrado vegetation was lost in the last 60 years (88 million ha), reaching a deforestation rate of 1% per year between 2002 and 2011 and is 2.5 times higher than in the Amazon (Strassburg et al., 2017). Studies showed that maintaining native closed vegetation is crucial for giant anteater habitat use and thermoregulation (Camilo-Alves and Mourão, 2006; Mourão and Medri, 2007) and females reduce their home ranges by avoiding using altered landscapes (e.g. roads and timber plantations) (Bertassoni et al., 2017). Although we did not find a high impact of roads on populations persistence, road network expansion in tropical regions is commonly associated with an increase in others human-related impacts, e.g. urban sprawl and settlements, deforestation, land conversions, hunting (Laurance and Arrea, 2017) that can exacerbate fragmentation effects of giant anteater populations, particularly in the Cerrado biome.

Habitat fragmentation due to anthropogenic impacts affects animal movements worldwide (Cosgrove et al., 2018), reducing one-third to one-half the extent of large-bodied mammals' movement in areas with higher human footprint (Tucker et al., 2018). The establishment of undisturbed natural areas (e.g. protected areas) are important for the conservation of threatened species (Rodrigues et al., 2004), and measures of habitat patch size, shape and connectivity are needed by decision makers. Our study showed two values for the minimum patch size (247 and 498 km^2) directly related to the species dispersal capacity according to the model of Borda-de-Água et al. (2011), which appears to be in line with other predicted values for large-bodied mammals in South America. For example, 116 km^2 for minimum patch size for northern muriqui (*Brachyteles hypoxanthus*) (Brito and De Viveiros Grelle, 2004), 230 km^2 for jaguars (Zanin et al., 2015), and 400 km^2 for carnivore species like the crab-eating fox, maned wolves (*Chrysocyon brachyurus*) and pumas (Ceia-Hasse et al., 2017). Despite the differences in the methods to estimate the minimum patch size, those species have similar demographic attributes such as late sexual maturity (e.g. nine years for northern muriqui females and three years for jaguars females) and small litter size (e.g. two cubs per brood for maned wolf and 2.7 for pumas).

The observed road-kills, per se, did not appear to impose serious risks for giant anteater persistence as only 1% of the Brazilian giant anteater range is above the maximum road density (0.21 km/km^2). This fact may be explained by the low density of paved roads in the study area (0.02 ± 0.07 km/km^2). However, the southeast region with its high road density may threaten the species persistence over the long-term. For example, São Paulo is the most populated and economically developed Brazilian state. Here, 13% of the giant anteater range has an average road density above 0.21 km/km^2. The species is classified regionally as Endangered in São Paulo state (Chiquito and Percequillo, 2009) where remnant Cerrado habitat represents only 1% of the original area and is currently surrounded by pastures, sugarcane fields and road networks (Durigan et al., 2007). Since the Brazilian government intends to increase the road network by adding 129,000 km in the next 20 years (DNIT, 2013; Teixeira et al., 2016) the new areas that exceed the maximum road density could seriously jeopardize giant anteaters persistence in the short or medium term.

Conservation opportunities occur mostly in the central-northern area that encompasses the Amazon Biome and some portions of Cerrado, and the western Pantanal. Most of these regions are roadless or undisturbed areas and still have a considerable amount of suitable patches for giant anteaters persistence according to our model. Undisturbed areas are important to maintain or increase the genetic diversity (Miraldo et al., 2016), that has been observed more diverse to giant anteaters populations living in large protected areas (e.g. Canastra and Emas National Parks and Pantanal biome) when compared to fragmented areas (Clozato et al., 2017). The central and southern portion of the species range, that encompass mainly the Cerrado Biome and some portions of Atlantic Forest, is in more urgent need of conservation efforts as only 2% of the Cerrado is under legal protection (Klink and Machado, 2005). Conservation actions consist of increasing habitat connectivity (Diniz and Brito, 2015; Paviolo et al., 2016), protection of the remnant natural Cerrado habitats (Durigan et al., 2007) and creation of new protected areas.

This study is a first attempt to assess the implications of road networks on giant anteater populations at national scale. A similar approach has been used to assess global exposure of carnivores to roads using a spatially-explicit model and life-history traits (Ceia-Hasse et al., 2017). Demographic parameters were obtained exclusively from giant anteater studies avoiding generalizations using allometric relations (Pereira and Daily, 2006). Similarly, we classified suitable habitats based on the scientific literature rather than using just the species range. The effect of roads as barriers and road-related mortality on this species were analysed by exploring different scenarios of road-kill rates, population densities, dispersal capacity and road avoidance (Diniz and Brito, 2015, 2013). With this approach, we were able to make more precise and informed inferences regarding the limitations of the model.

Our results, however, should be interpreted with caution. For example, giant anteaters do not avoid low traffic volume roads (Freitas et al., 2014) and can use unpaved roads for dispersal (Vynne et al., 2011; Braga, 2010); we considered only paved roads in the model. Paved roads represent about 12% of the Brazilian road network (DNIT, 2013). With this model we may be underestimating the impact of roads on this species. On the other hand, we assumed the highest observed road-kill was constant over the entire study area and giant anteaters used the most suitable habitat. In this case, we may be overestimating the impact of roads on giant anteaters. Due to lack of information on population densities near roads, we used values from undisturbed areas (Desbiez and Medri, 2010; Miranda, 2004). Population densities can decrease near roads (e.g. Benítez-López et al., 2010; Torres et al., 2016), which can be another reason the impact of road networks in our study may be underestimated. Further, the demographic parameters used were the same over the species range, although studies indicated these can vary regionally (Medri, 2002; Miranda, 2004; Shaw et al., 1987) depending on the amount of suitable habitat available and level of fragmentation (Bertassoni et al., 2017; Desbiez and Medri, 2010; Braga, 2010).

The critical values for patch size and road density presented here can be useful for land managers and road planners charged with protected area conservation and minimizing transportation impacts. The minimum patch size presented in our model can be interpreted as a minimum reserve size to serve as a basis for creation of protected areas or increasing their size for giant anteater conservation. The location of critical areas can provide guidance for land managers to target efforts to promote wildlife corridors or stepping stones. Corridors and stepping stones can be a key strategy to maintain continuity between small habitat patches for giant anteater populations (Carvalho et al., 2009; Vynne et al., 2011). This is important because currently protected areas, particularly on Cerrado biome, may not be large enough or effective in conserving and maintaining populations of large-bodied terrestrial mammals (Diniz and Brito, 2015; Eduardo et al., 2012). Moreover, the results presented here for the giant anteater are broadly informative about the risk for other threatened mammals that share similar life histories and high exposure to roads, such as maned wolf, puma (Ceia-Hasse et al., 2017), and Brazilian tapir (*Tapirus terrestris*) (Medici and Desbiez, 2012). Using critical road density threshold areas, transportation practitioners are then able identify where populations of giant anteaters would be impacted by future transportation infrastructure projects in Brazil, including the clearing of habitat for new roads and also prioritizing road segments for mitigation (Teixeira et al., 2016; Ciocheti et al., 2017). Future research on giant anteater life history parameters such as demography, habitat use, dispersal capacities and even road-kill rates will be valuable for refining and improving the model. This will be important for applying the model at a smaller, regional scale for informing transportation project planning and design. Studies that evaluate the genetic differentiation or gene flow (Balkenhol and Waits, 2009; Herrmann et al., 2017) on giant anteaters populations in roaded landscapes could also be an important means of validating the efficacy of our model.

5. Conclusions

Our results contribute to understanding the effects of the Brazilian road network on populations of giant anteater. We highlighted the negative effect of habitat fragmentation showing that large portions of giant anteater habitats are below the minimum patch size for sustaining viable populations. The proportion of areas above the maximum road density is low and concentrated on central-southern areas, which may increase given Brazil's ambitious plan to expand their transportation infrastructure network. The critical values for minimum patch size and maximum road density shown here can be important for transportation practitioners, land managers and decision makers responsible for mitigating transportation impacts and giant anteater conservation. It will also be useful for conservation non-governmental organizations to hold agencies accountable for using the best science available in planning transportation projects and protected areas in giant anteater range. Our framework can be applied at different spatial scales, e.g., examining regional differences in the role of road networks on giant anteater populations. We also encourage further research on the ecology and population biology of giant anteaters, which will help strengthen model inference capability.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 1502819, doctorate scholarship. CG was supported by CNPq (AJT No. 300021/2015-1). We thank Priscila Lucas for help on spatial population analysis. AB was supported by FAPEMIG (APQ-00604-17). APC was supported by CNPq (No. 454186/2016-9) and the Woodcock Foundation.

Appendix A. Reaction-diffusion equation

The population dynamics and dispersal given by (Skellam, 1951; Borda-de-Água et al., 2011):

$$\frac{\partial N(x,y,t)}{\partial t} = \begin{cases} \frac{\partial 2}{2}\nabla 2\ \mathrm{N}\,(\mathrm{x},\mathrm{y},\mathrm{t}) + \mathrm{r1N}(\mathrm{x},\mathrm{y},\mathrm{t})\left(1 - \frac{N(x,y,t)}{K}\right) & \text{if } (\mathrm{x},\mathrm{y}) \notin \text{road} \\ \frac{\partial 2}{2}\nabla 2\ \mathrm{N}\,(\mathrm{x},\mathrm{y},\mathrm{t}) + \mathrm{r0N}\,(\mathrm{x},\mathrm{y},\mathrm{t}) & \text{if } (\mathrm{x},\mathrm{y}) \in \text{roa} \end{cases}$$

where $N(x,y,t)$ is the population density on location (x,y) at time t, and K the carrying capacity; the symbol Δ^2 stands for $(\partial^2/\partial\ x^2 + \partial^2/\partial^2\ y^2)$. The first term on the right-hand side of the equation describes the changes in time and space of the density of a population on the basis of its dispersal distance, assuming a Gaussian distribution. The second term on the top branch corresponds to logistic growth (outside roads) and n the bottom branch corresponds to population decay on roads (assumed by a negative growth rate where $r_0 < 0$) (Borda-de-Água et al., 2011). r_0 is interpreted here as an instantaneous mortality rate when an individual cross a road, measuring the loss of individuals from a specific population.

Appendix B. Relaxation time equation

We can determine the time to extinction of a population in a nonviable patch, that is, one with area, A, smaller than that of the minimum patch size, P_{min} (Borda-de-Água et al., 2011). The relaxation time, t_{rel}, defined as the time a population takes to reach 1/e of its original size, because it obviates the need to define the density threshold below which the population is extinct, which can be different for different populations. Counting from the moment roads were built, t = 0, the time the population takes to reach 1/e of its original abundance is:

$$\text{trel} = \frac{1}{\frac{\partial 2}{2}k2 - r1},$$

where $k^2 = \pi^2 / L^2 + \pi^2 / (\alpha L)^2$.

Appendix C. Intrinsic population growth equation

The intrinsic population growth rate (r_1) follows the methodological approach made by Pereira and Daily (2006), that used a simplified version of Euler equation based on life history species-specific parameters that includes: Age at first breeding (β) (year); Inter-litter interval, (Δ) (year); Fecundity (b); and Constant mortality rate (μ). So, the implicit equation for (r_1) is then:

$$\text{b X} \int_0^\infty \sum_{y=0}^{\infty} \delta(x - y\Delta - \beta) e^{-(r1+\mu)x}\, dx = 1,$$

where δ(x) is the birth pulse function, which has a value of 1/T for x between 0 and T and 0 elsewhere. This equation can be solved numerically to determine r_1.

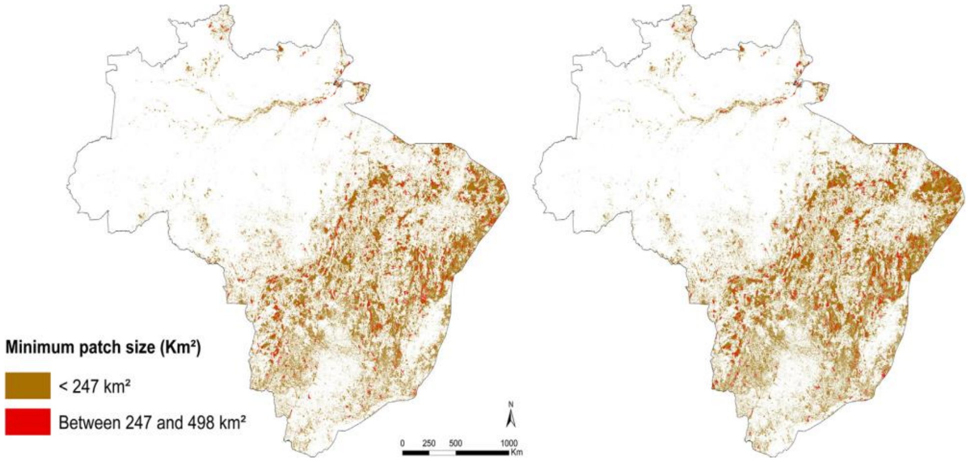


Fig. A1. Maps showing areas below the minimum patch size (P_{min}) for each of the four scenarios. P_1 and P_2 scenarios (left) - Areas below 247 km^2 and areas between 247 and 498 km^2 (that represents the amount of area below the P_{min} added by P_2 scenario) considering the low and high dispersal capacity respectively. P_3 and P_4 scenarios (right) - Areas below 247 km^2 and areas between 247 and 498 km^2 (that represents the amount of area below the P_{min} added by P_4 scenario) considering the limited and high dispersal capacity when roads acting as a barrier.

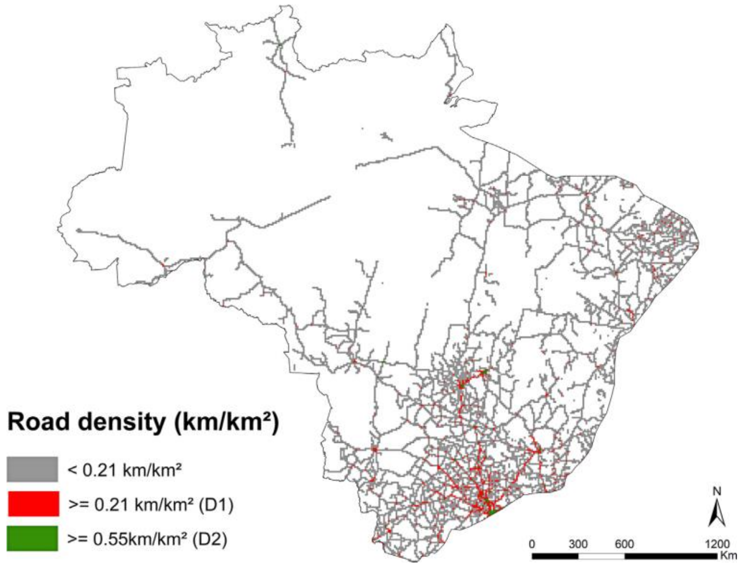


Fig. A2. Paved road density per 10 km × 10 km grid cell over Brazilian giant anteater range showing the results of the scenarios D1 and D2.

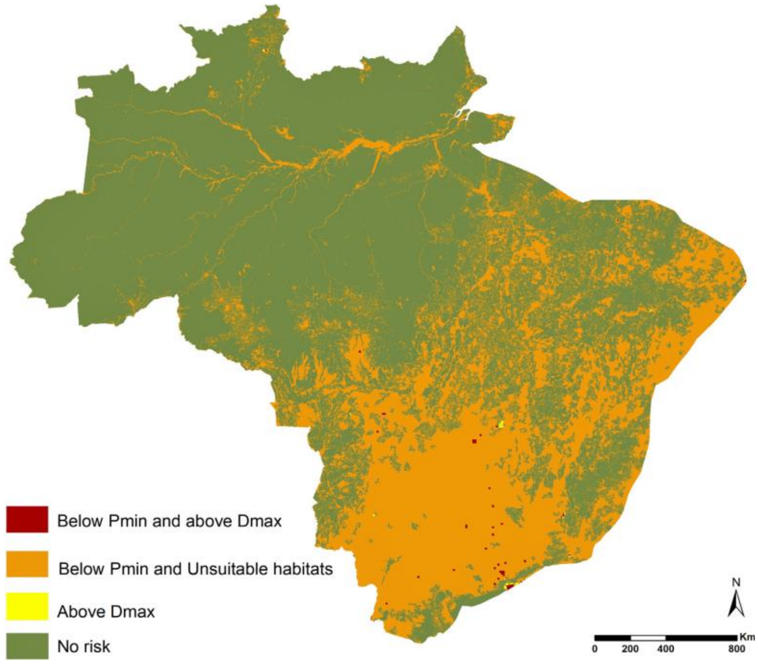


Fig. A3. Critical areas with combined D_2 and P_3 scenarios.

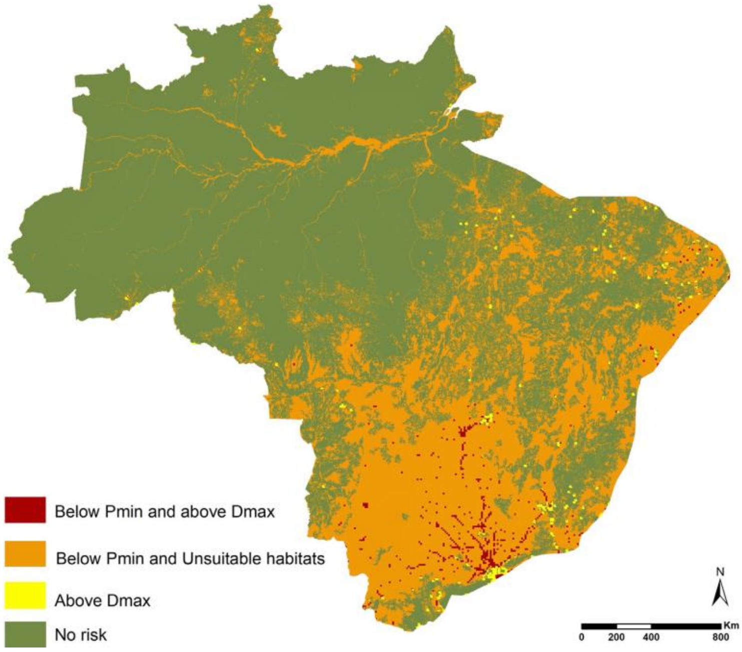


Fig. A4. Critical areas with combined D_1 and P_2 scenarios.

References

Anderson, S.C., Farmer, R.G., Ferretti, F., Houde, A.L.S., Hutchings, J.A., 2011. Correlates of vertebrate extinction risk in Canada. Bioscience. https://doi.org/10.1525/bio.2011.61.7.8.

Ascensão, F., Desbiez, A.L.J., Médici, E.P., Bager, A., 2017. Spatial patterns of road mortality of medium–large mammals in Mato Grosso do Sul, Brazil. Wildl. Res. https://doi.org/10.1071/WR16108.

Bager, A., Borghi, C.E., Secco, H., 2015. The influence of economics, politics and environment on road ecology in South America. In: Handbook of Road Ecology, https://doi.org/10.1002/9781118568170.ch50.

Balkenhol, N., Waits, L.P., 2009. Molecular road ecology: exploring the potential of genetics for investigating transportation impacts on wildlife. Mol. Ecol. https://doi.org/10.1111/j.1365-294X.2009.04322.x.

Balkenhol, N., Pardini, R., Cornelius, C., Fernandes, F., Sommer, S., 2013. Landscape-level comparison of genetic diversity and differentiation in a small mammal inhabiting different fragmented landscapes of the Brazilian Atlantic Forest. Conserv. Genet. https://doi.org/10.1007/s10592-013-0454-2.

Basille, M., Van Moorter, B., Herfindal, I., Martin, J., Linnell, J.D.C., Odden, J., Andersen, R., Gaillard, J.M., 2013. Selecting habitat to survive: the impact of road density on survival in a large carnivore. PLoS One. https://doi.org/10.1371/journal.pone.0065493.

Beaudry, F., de Maynadier, P.G., Hunter Jr., M.L., 2008. Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. Biol. Conserv. https://doi.org/10.1016/j.biocon.2008.07.016.

Bender, D.J., Contreras, T.A., Fahrig, L., 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology 79, 517–533.

Benítez-López, A., Alkemade, R., Verweij, P.A., 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biol. Conserv. https://doi.org/10.1016/j.biocon.2010.02.009.

Bertassoni, A., Mourão, G., Ribeiro, R.C., Cesário, C.S., de Oliveira, J.P., de Cassia Bianchi, R., 2017. Movement patterns and space use of the first giant anteater (*Myrmecophaga tridactyla*) monitored in São Paulo State, Brazil. Stud. Neotropical Fauna Environ. https://doi.org/10.1080/01650521.2016.1272167.

Bissonette, J.A., Adair, W., 2008. Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings. Biol. Conserv. https://doi.org/10.1016/j.biocon.2007.10.019.

Borda-De-Água, L., Navarro, L., Gavinhos, C., Pereira, H.M., 2011. Spatio-temporal impacts of roads on the persistence of populations: analytic and numerical approaches. Landsc. Ecol. https://doi.org/10.1007/s10980-010-9546-2.

Braga, F.G., 2010. Ecologia e comportamento de tamanduá-bandeira *Myrmecophaga tridactyla* Linnaeus, 1758 no município de Jaguariaíva, Paraná. Universidade Federal do Paraná (Tese. Doutorado em Ciências Florestais. 119 pp.).

Brito, D., De Viveiros Grelle, C.E., 2004. Effectiveness of a reserve network for the conservation of the endemic marsupial Micoureus travassosi in Atlantic Forest remnants in southeastern Brazil. Biodivers. Conserv. 13, 2519–2536. https://doi.org/10.1023/B:BIOC.0000048450.85086.00.

Brook, B.W., O'Grady, J.J., Chapman, A.P., Burgman, M.A., Akçakaya, H.R., Frankham, R., 2000. Predictive accuracy of population viability analysis in conservation biology. Nature 404, 385–387. https://doi.org/10.1038/35006050.

Camilo-Alves, C.D.S.E.P., Mourão, G.D.M., 2006. Responses of a specialized insectivorous mammal (Myrmecophaga tridactyla) to variation in ambient temperature. Biotropica. https://doi.org/10.1111/j.1744-7429.2006.00106.x.

Cardillo, M., Mace, G.M., Jones, K.E., Bielby, J., Bininda-Emonds, O.R.P., Sechrest, W., Orme, C.D.L., Purvis, A., 2005. Multiple causes of high extinction risk in large mammal species. Science 309, 1239–1241.

Carvalho, F.M.V., De Marco Junior, P., Ferreira, L.G., 2009. The Cerrado into-pieces: habitat fragmentation as a function of landscape use in the savannas of central Brazil. Biol. Conserv. https://doi.org/10.1016/j.biocon.2009.01.031.

de Carvalho, N.C., Bordignon, M.O., Shapiro, J.T., 2014. Fast and furious: a look at the death of animals on the highway MS-080, Southwestern Brazil. Iheringia. Sér. Zool. https://doi.org/10.1590/1678-4766201410414349.

Ceia-Hasse, A., Borda-De-Água, L., Grilo, C., Pereira, H.M., 2017. Global exposure of carnivores to roads. Glob. Ecol. Biogeogr. https://doi.org/10.1111/geb.12564.

Chen, H.L., Koprowski, J.L., 2016. Barrier effects of roads on an endangered forest obligate: influences of traffic, road edges, and gaps. Biol. Conserv. https://doi.org/10.1016/j.biocon.2016.03.017.

Chiquito, E.A., Percequillo, A.R., 2009. Myrmecophaga tridactyla. In: Bressan, P.M., Kierulff, M.C., Sugieda, A.M. (Orgs) (Eds.), Fauna ameaçada de extinção no Estado de São Paulo: Vertebrados. Fundação Parque Zoológico de São Paulo e Secretaria do Meio Ambiente, São Paulo.

Ciocheti, G., de Assis, J.C., Ribeiro, J.W., Ribeiro, M.C., 2017. Highway widening and underpass effects on vertebrate road mortality. Biotropica. https://doi.org/10.1111/btp.12480.

Clozato, C.L., Miranda, F.R., Lara-Ruiz, P., Collevatti, R.G., Santos, F.R., 2017. Population structure and genetic diversity of the giant anteater (Myrmecophaga tridactyla: Myrmecophagidae, pilosa) in Brazil. Genet. Mol. Biol. https://doi.org/10.1590/1678-4685-GMB-2016-0104.

Cosgrove, A.J., McWhorter, T.J., Maron, M., 2018. Consequences of impediments to animal movements at different scales: a conceptual framework and review. Divers. Distrib. 24, 448–459. https://doi.org/10.1111/ddi.12699.

Crooks, K.R., Burdett, C.L., Theobald, D.M., King, S.R.B., Di Marco, M., Rondinini, C., Boitani, L., 2017. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. Proc. Natl. Acad. Sci. https://doi.org/10.1073/pnas.1705769114.

Cushman, S.A., 2006. Effects of habitat loss and fragmentation on amphibians: a review and prospectus. Biol. Conserv. https://doi.org/10.1016/j.biocon.2005.09.031.

de Souza, J.C., da Cunha, V.P., Markwith, S.H., 2015. Spatiotemporal variation in human-wildlife conflicts along highway BR-262 in the Brazilian Pantanal. Wetl. Ecol. Manag.

https://doi.org/10.1007/s11273-014-9372-4.
Desbiez, A.L.J., Medri, Í.M., 2010. Density and Habitat Use by Giant Anteaters (*Myrmecophaga tridactyla*) and Southern Tamanduas (*Tamandua tetradactyla*) in the Pantanal Wetland, Brazil. 11. BioOne, pp. 4–10. https://doi.org/10.1896/020.011.0102.
Diniz, M.F., Brito, D., 2013. Threats to and viability of the giant anteater, Myrmecophaga tridactyla (Pilosa: Myrmecophagidae), in a protected Cerrado remnant encroached by urban expansion in central Brazil. Zoology. https://doi.org/10.1590/S1984-46702013000200005.
Diniz, M.F., Brito, D., 2015. Protected areas effectiveness in maintaining viable giant anteater (Myrmecophaga tridactyla) populations in an agricultural frontier. Nat. Conserv. https://doi.org/10.1016/j.ncon.2015.08.001.
DNIT (Departamento Nacional de Infraenstrutura de Transporte), 2013. Sistema de Gerencia de Pavimentos. Relatório dos levantamentos funcionais das rodovias federais. Available on. www.dnit.gov.br.
Durigan, G., de Siqueira, M.F., Franco, G.A.D.C., 2007. Threats to the Cerrado remnants of the state of São Paulo, Brazil. Sci. Agric. https://doi.org/10.1590/S0103-90162007000400006.
Eduardo, A.A., Nunes, A.V., Brito, D., 2012. Do the protected areas network of the state of minas gerais maintain viable populations of the lowland tapir (Tapirus terrestris). Nat. Conserv. https://doi.org/10.4322/natcon.2012.005.
Ferreras, P., Gaona, P., Palomares, F., Delibes, M., 2001. Restore habitat or reduce mortality? Implications from a population viability analysis of the Iberian lynx. Anim. Conserv. 4, 265–274. https://doi.org/10.1017/S1367943001001317.
Fischer, W.A., 1997. Efeitos da rodovia BR-262 na mortalidade de vertebrados silvestres: Síntese naturalística para a conservação da região do Pantanal, MS. Universidade Federal do Mato Grosso do Sul, Campo Grande, MS (Dissertação de Mestrado, 38 pp.).
Freitas, C.H., Justino, C.S., Setz, E.Z.F., 2014. Road-kills of the giant anteater in south-eastern Brazil: 10 years monitoring spatial and temporal determinants. Wildl. Res. https://doi.org/10.1071/WR14220.
Geofabrik, 2016. OpenStreetMap-Shapefiles. Available at. http://download.geofabrik.de/, Accessed date: June 2016.
Gibbon, J.W., Scott, D.E., Ryan, T.J., Buhlmann, K.a., Tuberville, T.D., Metts, B.S., Greene, J.L., Mills, T., Leiden, Y., Poppy, S., Winne, C.T., 2000. The global decline of reptiles, Déjà Vu amphibians. Bioscience 50, 653–666. https://doi.org/10.1641/0006-3568(2000)050[0653:TGDORD]2.0.CO;2.
Gibbs, J.P., Shriver, W.G., 2002. Estimating the Effects of Road Mortality on Turtle Populations. Conserv. Biol. 16, 1647–1652.
GLC (Global Land Cover Share), Lathan, John, Cumani, Renato, Rosati, Ilari, Bloise, Mario, 2014. Database Beta-release, Version 1.0.
Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Holt, R.D., Lovejoy, T.E., Sexton, J.O., Austin, M.P., Collins, C.D., Cook, W.M., Damschen, E.I., Ewers, R.M., Foster, B.L., Jenkins, C.N., King, A.J., Laurance, W.F., Levey, D.J., Margules, C.R., Melbourne, B.A., Nicholls, A.O., Orrock, J.L., Song, D.-X., Townshend, J.R., 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Sci. Adv. https://doi.org/10.1126/sciadv.1500052.
Haines, A.M., Tewes, M.E., Laack, L.L., Horne, J.S., Young, J.H., 2006. A habitat-based population viability analysis for ocelots (Leopardus pardalis) in the United States. Biol. Conserv. https://doi.org/10.1016/j.biocon.2006.04.035.
Herrmann, H.W., Pozarowski, K.M., Ochoa, A., Schuett, G.W., 2017. An interstate highway affects gene flow in a top reptilian predator (*Crotalus atrox*) of the Sonoran Desert. Conserv. Genet. https://doi.org/10.1007/s10592-017-0936-8.
IBGE, 2017. Brazilian Institute of Geography and Statistics. Available in. https://www.ibge.gov.br, Accessed date: October 2017.
IUCN, 2018. The IUCN Red List of Threatened Species. Version 2018-1. http://www.iucnredlist.org Downloaded on 05 March 2018.
IUCN (International Union for Conservation of Nature), 2014. Myrmecophaga tridactyla. In: The IUCN Red List of Threatened Species. Version 2017-3.
Jackson, N.D., Fahrig, L., 2011. Relative effects of road mortality and decreased connectivity on population genetic diversity. Biol. Conserv. https://doi.org/10.1016/j.biocon.2011.09.010.
Klink, C.A., Machado, R.B., 2005. Conservation of the Brazilian Cerrado. Conserv. Biol. https://doi.org/10.1111/j.1523-1739.2005.00702.x.
Laurance, W.F., Arrea, I.B., 2017. Roads to riches or ruin? Science 358 (6362), 442–444. https://doi.org/10.1126/science.aao0312.
Medici, E.P., Desbiez, A.L.J., 2012. Population viability analysis: using a modeling tool to assess the viability of tapir populations in fragmented landscapes. Integr. Zool. https://doi.org/10.1111/j.1749-4877.2012.00318.x.
Medri, I.M., 2002. Área de vida e uso do habitat de tamanduá-bandeira Myrmecophaga tridactyla Linnaeus, 1758 nas Fazendas Nhumirim e Porto Alegre, Pantanal da Nhecolândia, MS. Universidade Federal de Mato Grosso do Sul, Campo Grande (Dissertação. 83 pp. 2002).
Medri, I.M., Mourão, G., 2005. Home range of giant anteaters (Myrmecophaga tridactyla) in the Pantanal wetland, Brazil Home range of giant anteaters (*Myrmecophaga tridactyla*) in the Pantanal wetland, Brazií. J. Zool. 266, 365–375. https://doi.org/10.1017/S0952836905007004.
Miraldo, A., Sen, Li, Borregaard, M.K., Flórez-Rodriguez, A., Gopalakrishnan, S., Rizvanovic, M., Wang, Z., Rahbek, C., Marske, K.A., Nogués-Bravo, D., 2016. An anthropocene map of genetic diversity. Science 353 (6307), 1532–1535. https://doi.org/10.1126/science.aaf4381.
Miranda, G.H.B., 2004. Ecologia e conservação do tamanduá-bandeira (Myrmecophaga tridactyla Linnaeus, 1758) no Parque Estadual das Emas. Universidade de Brasília (Tese. Doutorado em ecologia. 2004. 81 pp.).
Miranda, F., Bertassoni, A., Abba, A.M., 2014. *Myrmecophaga tridactyla*, Giant Anteater. *Myrmecophaga tridactyla*. In: IUCN Red List Threat. Species, https://doi.org/10.2305/IUCN.UK.2014.
Miranda, F.R., Chiarello, A.G., Röhe, F., Braga, F.G., Mourão, G.M., Miranda, G.H.B., Silva, K.F.M., Faria-Corrêa, M.A., Vaz, S.M., Belentani, S.C.S., 2015. Avaliação do Risco de Extinção de *Myrmecophaga tridactyla* Linnaeus, 1758 no Brasil. Processo de avaliação do risco de extinção da fauna brasileira. ICMBio. http://www.icmbio.gov.br/portal/biodiversidade/fauna-brasileira/lista-de-especies/7049-mamiferos-myrmecophaga-tridactyla-tamandua-bandeira.htm.
Mourão, G., Medri, Í.M., 2007. Activity of a specialized insectivorous mammal (Myrmecophaga tridactyla) in the Pantanal of Brazil. J. Zool. 271, 187–192. https://doi.org/10.1111/j.1469-7998.2006.00198.x.
Mumme, R.L., Schoech, S.J., Woolfenden, G.E., Fitzpatrick, J.W., 2000. Life and death in the fast lane: demographic consequences of road mortality in the Florida Scrub-Jay. Conserv. Biol. 14, 501–512. https://doi.org/10.1046/j.1523-1739.2000.98370.x.
Paviolo, A., De Angelo, C., Ferraz, K.M.P.M.B., Morato, R.G., Martinez Pardo, J., Srbek-Araujo, A.C., Beisiegel, B. de M., Lima, F., Sana, D., Xavier da Silva, M., Velázquez, M.C., Cullen, L., Crawshaw Jr., P., Jorge, M.L.S.P., Galetti, P.M., Di Bitetti, M.S., de Paula, R.C., Eizirik, E., Aide, T.M., Cruz, P., Perilli, M.L.L., Souza, A.S.M.C., Quiroga, V., Nakano, E., Ramírez Pinto, F., Fernández, S., Costa, S., Moraes Jr., E.A., Azevedo, F., 2016. A biodiversity hotspot losing its top predator: the challenge of jaguar conservation in the Atlantic Forest of South America. Sci. Rep. https://doi.org/10.1038/srep37147.
Pereira, H.M., Daily, G.C., 2006. Modeling biodiversity dynamics in countryside landscapes. Ecology. https://doi.org/10.1016/B978-0-12-384719-5.00334-8.
Pereira, H.M., Leadley, P.W., Proenca, V., Alkemade, R., Scharlemann, J.P.W., Fernandez-Manjarres, J.F., Araujo, M.B., Balvanera, P., Biggs, R., Cheung, W.W.L., Chini, L., Cooper, H.D., Gilman, E.L., Guenette, S., Hurtt, G.C., Huntington, H.P., Mace, G.M., Oberdorff, T., Revenga, C., Rodrigues, P., Scholes, R.J., Sumaila, U.R., Walpole, M., 2010. Scenarios for global biodiversity in the 21st century. Science 330, 1496–1501.
Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J.P.W., Sutherland, W.J., Vira, B., 2010. Biodiversity conservation: challenges beyond 2010. Science 329 (80), 1298–1303. https://doi.org/10.1126/science.1189138.
Rodrigues, A.S.L., Andelman, S.J., Bakar, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., et al., 2004. Effectiveness of the global protected area network in representing species diversity. Nature 428, 640–643.
Row, J.R., Blouin-Demers, G., Weatherhead, P.J., 2007. Demographic effects of road mortality in black ratsnakes (Elaphe obsoleta). Biol. Conserv. 137, 117–124. https://doi.org/10.1016/j.biocon.2007.01.020.
Rytwinski, T., Fahrig, L., 2012. Do species life history traits explain population responses to roads? A meta-analysis. Biol. Conserv. https://doi.org/10.1016/j.biocon.2011.11.023.
Schipper, J., et al., 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. Science 322, 225–230.
Schumaker, N.H., Brookes, A., Dunk, J.R., Woodbridge, B., Heinrichs, J.A., Lawler, J.J., Carroll, C., Laplante, D., 2014. Mapping sources, sinks, and connectivity using a simulation model of northern spotted owls. Landsc. Ecol. 29, 579–592. https://doi.org/10.1007/s10980-014-0004-4.
Shaw, J.H., Machado-Neto, J., Carter, T.J., 1987. Behavior of free-living giant anteaters (*Myrmecophaga tridactyla*). Biotropica 19, 255–259.
Skellam, J.G., 1951. Random dispersal in theoretical populations. Biometrika 38 (1/2), 196–218.
Strassburg, B.B.N., Brooks, T., Feltran-Barbieri, R., Iribarrem, A., Crouzeilles, R., Loyola, R., Latawiec, A.E., Oliveira Filho, F.J.B., De Scaramuzza, C.A.M., Scarano, F.R., Soares-Filho, B., Balmford, A., 2017. Moment of truth for the Cerrado hotspot. Nat. Ecol. Evol. 1, 1–3. https://doi.org/10.1038/s41559-017-0099.
Teixeira, F., et al., 2016. The need to improve and integrate science and environmental licensing to mitigate wildlife mortality on roads in Brazil. Trop. Conserv. Sci. 9, 24–42.
Thiel, R.P., 1985. Relationship between road densities and wolf habitat suitability in Wisconsin. Am. Midl. Nat. 113, 404–407.
Torres, A., Jaeger, J.A.G., Alonso, J.C., 2016. Assessing large-scale wildlife responses to human infrastructure development. Proc. Natl. Acad. Sci. 113, 8472–8477. https://doi.org/10.1073/pnas.1522488113.
Tucker, M.A., Böhning-Gaese, K., Fagan, W.F., Fryxell, J.M., Van Moorter, B., Alberts, S.C., Ali, A.H., Allen, A.M., Attias, N., Avgar, T., Bartlam-Brooks, H., Bayarbaatar, B., Belant, J.L., Bertassoni, A., Beyer, D., Bidner, L., Van Beest, F.M., Blake, S., Blaum, N., Bracis, C., Brown, D., De Bruyn, P.J.N., Cagnacci, F., Diefenbach, D., Douglas-Hamilton, I., Fennessy, J., Fichtel, C., Fiedler, W., Fischer, C., Fischhoff, I., Fleming, C.H., Ford, A.T., Fritz, S.A., Gehr, B., Goheen, J.R., Gurarie, E., Hebblewhite, M., Heurich, M., Hewison, A.J.M., Hof, C., Hurme, E., Isbell, L.A., Janssen, R., Jeltsch, F., Kaczensky, P., Kane, A., Kappeler, P.M., Kauffman, M., Kays, R., Kimuyu, D., Koch, F., Kranstauber, B., Lapoint, S., Mattisson, J., Medici, E.P., Mellone, U., Merrill, E., Morrison, T.A., Díaz-Muñoz, S.L., Mysterud, A., Nandintsetseg, D., Nathan, R., Niamir, A., Odden, J., Hara, R.B.O., Oliveira-Santos, L.G.R., Olson, K.A., Patterson, B.D., De Paula, R.C., Pedrotti, L., Reineking, B., Rimmler, M., 2018. Moving in the Anthropocene: global reductions in terrestrial mammalian movements. Science 359 (6374), 466–469. https://doi.org/10.1126/science.aam9712.
Van Dyke, F.G., Brocke, R.H., Shaw, H.G., Ackerman, B.B., Hemker, P., Lindzey, F.G., 1986. Lions to logging and of mountain reactions. Source. J. Wildl. Manag. 50, 95–102 Allen Press.
Vynne, C., Keim, J.L., Machado, R.B., Marinho-Filho, J., Silveira, L., Groom, M.J., Wasser, S.K., 2011. Resource selection and its implications for wide-ranging mammals of the Brazilian Cerrado. PLoS One. https://doi.org/10.1371/journal.pone.0028939.
Zanin, M., Palomares, F., Brito, D., 2015. The jaguar's patches: viability of jaguar populations in fragmented landscapes. J. Nat. Conserv. https://doi.org/10.1016/j.jnc.2014.06.003.