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Effects of roads on terrestrial vertebrate species in Latin America

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ABSTRACT

Biodiversity in Latin America is at risk today due to habitat loss, land conversion to agriculture and urbanization. To grow their economies the developing countries of Latin America have begun to invest heavily in new road construction. An assessment of research on the impacts of roads on wildlife in Latin America will help define science-based conservation strategies aimed at mitigating road expansion. The aim of this review was to qualitatively and quantitatively assess scientific research papers addressing road impacts on vertebrate species in Latin America. We searched for scientific papers published as early as 1990 to 2017. We reviewed a total of 197 papers. Published research showed an increasing trend in the last decade with a strong geographic bias with a majority of papers from Brazil. Mammals were the most studied taxa followed by birds, reptiles and amphibians. The majority of studies focused on road mortality and at the individual species level. Studies documented an increase in deforestation rates, in land conversion to agriculture, illegal activities (hunting, logging) and the establishment of human settlements. The effects of roads on species richness and populations abundance varied among taxa with no apparent pattern within taxa. Forest-dependent species tended to avoid crossing roads. Amphibians had the highest median road-kill rate, followed by reptiles, mammals and birds. Our results suggest that there is an urgent need for more research, particularly in Central America and to employ predictive tools for difficult-to-sample or understudied species and critical conservation areas. We recommend a two-speed approach to guide future research: one focusing on quantifying individual species responses towards roads and their implications on population viability; a second consisting of regional or continental-scale analyses and modelling of road risks to species and populations to inform road planning immediately.

1. Introduction

Latin America is one of the most biologically diverse regions in the world encompassing eight of 25 world hotspots for biodiversity conservation (Myers et al., 2000). Latin America's wide geographic and latitudinal variation make it unique in terms of highly diverse ecoregions such as tropical forests, savannas, dry forest, montane habitats, and deserts, with high levels of endemisms and species rich communities of animals and plants (Lamoreux et al., 2006).

Biodiversity in Latin America is at risk today with road construction being one of the main drivers in addition to habitat loss, land conversion to agriculture and urbanization (UNEP-WCMC (United Nations Decade on Biodiversity-World Conservation Monitoring Centre), 2016) (e.g. Bager et al., 2015). Current estimates of road network in Latin America (paved and unpaved) exceeds 3 million km (Meijer et al., 2018). Currently there are plans to invest heavily to expand the road network (Laurance and Arrea, 2017). In 2014, there were 579 projects with an investment of $US 163 Bn (COSIPLAN (Consejo Suramericano de Infraestructura y Planeamiento), 2017) and recently China's ambitious Belt and Road Initiative (BRI) has extended to Latin America (Stevenson, 2018). The potential long-lasting impacts of 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.

Road construction and traffic are primary causes of increasing habitat loss effects and additional mortality - two major drivers of biodiversity decline (Isbell, 2010; Laurance and Balmford, 2013; Rytwinski and Fahrig, 2015). Reviews of the effects of roads on wildlife have largely been conducted for developed countries and temperate areas (Trombulak and Frissell, 2000; Taylor and Goldingay, 2010; Kociolek et al., 2010). However, the impacts of roads can be qualitatively and quantitatively different in the ecosystem types occurring in Latin America (Laurance et al., 2009). An assessment and review of research on the impacts of roads on wildlife in Latin America will be important for identifying science-based conservation strategies to mitigate road

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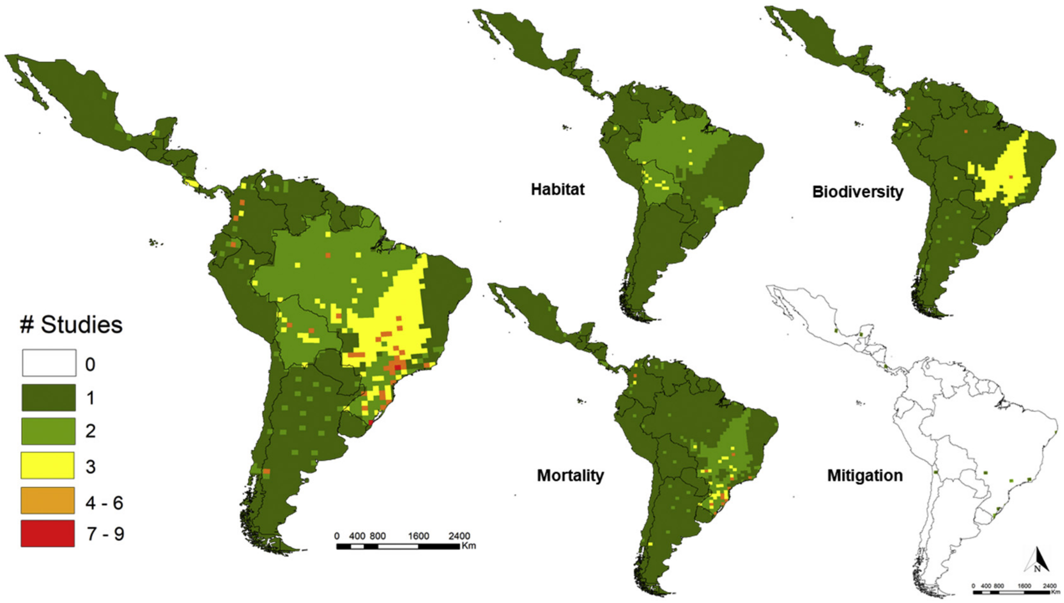

Fig. 1. Number of studies reporting road effects on wildlife in Latin America per 100 × 100 km grid cell. Maps show the geographic distribution of all studies (left) and by research areas.

expansion in the decades to come. We reviewed existing research on the effects of roads on wildlife and their impacts in Latin America, identified critical research gaps of knowledge and define future directions for research and conservation.

2. Methods

2.1. Literature search and research effort

We searched only peer-reviewed studies published between 1990 and 2017 using the following search engines and databases: Web of Science, Scopus and Science Direct. Our search included three main subjects: Geographic range (all Latin American countries), taxonomic group (amphibians, reptiles, birds and mammals), and road related common terms. We specifically looked for the following words in English, Spanish and Portuguese: (specific Latin America country) AND ("wildlife*" OR "vertebrates*" OR "amphibians*" OR "reptiles*" OR "birds*" OR "avian*" OR "mammals*") AND ("roads*" OR "vehicle*" OR "traffic*" OR "highways*" OR "motorway*" OR "unpaved*" OR "roadkill*" OR "transport*" OR "mitigation*").

Publications were then classified by research area and sub-topics (Appendix 1), geography range, taxonomic group (amphibians, reptiles, birds, mammals), level of biological organization (genes, individuals, populations, communities/ecosystems Noss, 1990), and type of roads (1–2 lanes unpaved, 1–2 lanes paved, and > 2 lanes highways). The same publication could be assigned to more than one research area and/or sub-topic.

2.2. Effects of roads on terrestrial vertebrate species

We examined the road effects by classifying papers among four research areas (habitat, biodiversity, mortality and mitigation) with associated sub-topics (see Appendix 1). Habitat consisted of studies on the effects of roads on species habitat, interpreted as habitat loss or habitat fragmentation from road construction (direct effects) and also the opening of new areas for human settlements and deforestation (indirect effects). Biodiversity consisted of the effect of roads (single roads or road networks) and traffic on species richness, population abundance and species behaviour. Mortality examined which species are road-killed (species composition), road-kill rates and road-kill spatial/temporal patterns. Mitigation comprised studies that recommended or evaluated mitigation measures.

We categorized the main effects of roads as negative, positive, neutral or contrasting effects, for taxonomic group and by species. The conclusions about the types of effects were generalizations based on the authors' interpretation from each original paper. We focused the classifications of type of effects only for the habitat and biodiversity research areas showed as a table of effects by species and taxonomic group (Appendix 2). We consider that mortality studies always represented a negative effect imposed by traffic at individual species level, summarized as a road-kill rates table per species (Appendix 3). We identified gaps in knowledge to suggest future research by intersecting research areas and sub-topics with taxonomic groups displayed as a heat map.

3. Results

3.1. Research effort on the effects of roads on terrestrial vertebrates

We found a total of 197 studies presenting road effects on terrestrial vertebrate species in Latin America (see Appendix 4). The majority of studies were from South America (89%), of which more than a half of studies were conducted in Brazil ($n = 102$, 52%), followed by Argentina ($n = 22$), Colombia ($n = 17$), Bolivia ($n = 15$) and Ecuador ($n = 12$), Chile ($n = 7$), Venezuela ($n = 5$), Peru ($n = 4$), and French Gyuana ($n = 3$). Only 11% of the studies were from Central America: Mexico (n = 10), Costa Rica (n = 10) and Panama (n = 3; Fig. 1). One study covered all Latin American countries, which consisted of a global analysis of carnivore exposure to roads (Ceia-Hasse et al., 2017; Fig. 1). The number of studies has grown since 1990, with a peak in 2013 and decline slightly since then (Appendix 5). Studies predominantly focused on mortality effects for most of the years (Appendix 5).

Studies covered a wide range of taxa, mostly on mammals ($n = 61$, 31%), followed by birds ($n = 23$, 12%), reptiles ($n = 17$, 8%) and amphibians ($n = 7$, 4%). The remaining wildlife studies were multi-taxon (n = 61; 31%) or assessments of the road effects on habitat ($n = 28$, 14%). Two-thirds of studies were at the individual species level (66%), followed by community/ecosystems (26.5%), populations (7%) and genes (0.5%). More than half of the studies were conducted on 2-lane paved roads (64%), 26% on unpaved roads and only 10% on

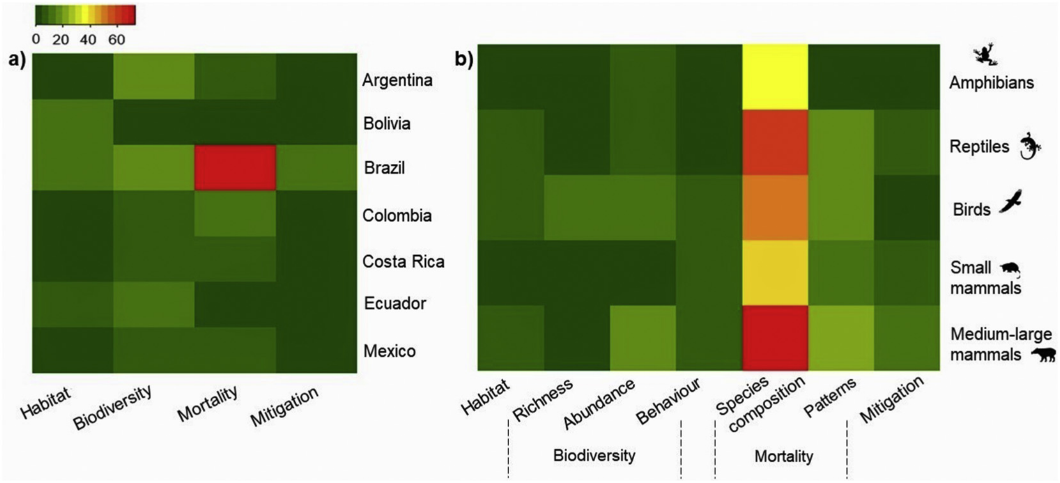

Fig. 2. a) Number of studies by research area and country (countries that account for > 10 studies). b) Number of studies by sub-topics and taxon. Colour scale indicates the number of studies, hotter colours represent larger number of studies.

highways (paved roads with > 2-lanes).

Of the research areas (sub-topics) exploring road effects on wildlife, mortality ($n = 110$; 79% species composition, 21% spatial and temporal patterns) was the most addressed topic followed by biodiversity ($n = 56$; 21% species richness, 50% abundance, 29% species behaviour), habitat ($n = 35$) and mitigation measures ($n = 15$; 56% recommendations, 44% evaluating effectiveness). Habitat studies were concentrated mainly in the Amazon Basin countries, while biodiversity studies were distributed throughout South American countries (Fig. 1). Brazil was the only country with studies in all research areas (Fig. 2a). Studies were focused mostly on medium-large mammals and reptiles (Fig. 2b).

3.2. *Effects of roads on terrestrial vertebrates*

3.2.1. *Habitat*

Among the 35 papers related to habitat the majority of studies reported negative effects caused by roads (Appendix 2). Most of the studies documented an increase in deforestation rates (Soares-Filho et al., 2004; Bottazzi and Dao, 2013) and adverse effects due to increased human access (Espinosa et al., 2014), illegal logging (Freitas et al., 2013), establishment of human settlements (Bilsborrow et al., 2004; Mertens et al., 2004).

Nearly 95% of all deforestation in the 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 proximity to 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 access in protected areas in the Amazon basin (Kauano et al., 2017). Similar to the relationship between road networks and deforestation, fragmentation and land conversions for agriculture was found in the Brazilian Atlantic Forest and the Cerrado (e.g. Freitas et al., 2010; Casella and Filho, 2013) and in the Bolivian Amazon (Locklin and Haack, 2003; Forrest et al., 2008; Tejada et al., 2016).

In the Ecuadorian Amazon the establishment of roads by oil companies has caused changes attributed to indigenous settlements and activity (Franzen, 2006). Among these the most important was the emergence of a wild meat market and increase in settlements along roads, thus reducing diversity of birds and mammals due to hunting pressure in Yasuní Biosphere Reserve (Suárez et al., 2009, 2013). Roads facilitated rates of bushmeat extraction and trade as hunters were located closer to markets and concentrated their effort on large-bodied species (Espinosa et al., 2014). Nevertheless, non-public access to oil roads reduce land conversions for agriculture compared to public access roads (Baynard et al., 2013).

3.2.2. *Biodiversity – species richness*

How roads result in changes in species richness were covered in 17 studies of which 50% were related to birds, 22% to amphibians, and 14% to mammals and reptiles. The effects of roads on species richness varied among taxa; half were found to be negative and both the positive and neutral effects represent 25% each (Appendix 2).

Roads had mainly negative effects on species richness for amphibians in Colombia (Vargas-Salinas et al., 2011) and Ecuador (Whitworth et al., 2015). In the Brazilian Amazon species richness of forest bird communities were negatively affected where roads were present (Ahmed et al., 2014). Since no significant correlation was found between roadless areas and forest cover, it was suggested that the negative effects of roads could be related to other effects not captured by habitat cover, such as selective logging, fire, hunting, traffic disturbance, edge effects and road-induced fragmentation (Ahmed et al., 2014). In the Colombian Andes forest bird richness decreased in areas with high road access and disturbance (Aubad et al., 2010). Similarly, in the Ecuadorian Amazon illegal trade and bushmeat market access from industry roads resulted in reduced bird and mammal richness (Suárez et al., 2013). New habitats created on road edges reduced species richness of savannah-dwelling birds in Brazil (Silva et al., 2017). Mixed responses were found for forest birds communities in Ecuador where understory bird richness decreases with the proximity of an unpaved road while the overall species richness increases (Whitworth et al., 2015). Studies with no significant effects of roads on bird species richness were also reported (Astudillo et al., 2014, Ávalos and Bermúdez, 2016, Bager and Rosa, 2012; Appendix 4). Increased species richness for reptiles and mammals communities were observed close to roads in Colombia (Vargas-Salinas and Berrío-Baca 2009; Vargas-Salinas et al., 2011) and Argentina (Di et al., 2013; Di Bitetti et al., 2014) respectively. New habitats created on road edges and on unpaved roads (< 1 vehicle/day) for these species may explain the positive effect.

3.2.3. *Biodiversity – species abundance*

The effects of roads on species abundance were addressed in 36 studies: 44% on mammals, 32% on birds, 13% and 11% respectively on amphibians and reptiles (Fig. 2b). Road effects on abundance varied among taxa and species groups; more than half of the studies found negative effects (74%), 14% positive and 12% neutral effects (Appendix 2).

Decreases in species abundance near roads occurred for Bromeliad amphibians in Ecuadorian Amazon (McCracken and Forstner, 2014) and for amphibians and reptiles in a lowland Amazonian rainforests of Ecuador (Maynard et al., 2016). The establishment of coastal roads and an increase in the anthropogenic impacts (e.g. road access, habitat loss, and degradation) reduce the abundance of sand-dune lizards *Liolaemus lutzae* in Brazil (Rocha et al., 2009), and *Liolaemus gracilis* and *Liolaemus multimaculatus* in Argentina (Vega et al., 2000). González-Trujillo et al. (2014) found a negative relationship between Morelet's Crocodile (*Crocodylus moreletii*) population density with increases in road density in Mexican wetlands. Changes in bird abundance close to roads was best explained by traffic noise (Arévalo and Newhard, 2011), and habitat changes along road edges (Ávalos and Bermúdez, 2016; Silva et al., 2017).

We found contrasting effects of roads on mammal abundance. In a fragmented landscape in Brazil, ground-dwelling small mammal species were more abundant near to road edges while the opposite pattern was found for arboreal small mammal species (Rosa et al., 2017). Similarly, the response of carnivores was also species-specific as the relative abundance of Chilean cat (*Oncifelis guigna*) was higher in forest habitats far from roads and close to large habitat patches while the opposite was found for Andean foxes (*Pseudalopex culpaeus*) (Acosta-Jamett and Simonetti, 2004). Occupancy models showed a negative relationship between pumas (*Puma concolor*) and road presence in the Argentinian Chaco (Quiroga et al., 2016). Mixed responses to roads were also reported within the same species. The relative abundance of wild boar (*Sus scrofa*) was higher with distance from roads in protected areas in montane deserts (Cuevas et al., 2013) while the occupancy likelihood was higher close to roads, used for travel across habitat patches in Andino-Patagonian regions (Gantchoff and Belant, 2015) both in Argentina. High levels of hunting pressure, deforestation and other human activities associated with roads and increased access explained declines in primates numbers in Peruvian Amazon and French Guiana (Aquino and 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).

3.2.4. Biodiversity – species behaviour

Among the 21 studies addressing how roads impact species behaviour, 50% focused on mammals, 27% on birds, 18% and 5% on amphibians and reptiles respectively (Fig. 2b). More than half of the studies had negative effects on wildlife (70%), 22% were neutral and 8% positive (Appendix 2).

The effect of roads and associated traffic on species behaviour was mainly negative (Appendix 2). Bromeliad frogs (*Andinobates bombetes*) avoided vocalizing during periods of high traffic and noise levels (Vargas-Salinas, 2013). Studies found that forest-dependent species, such as understory birds specialized for forest-interior conditions, avoided road-crossing through forest clearings (Develey and Stouffer, 2001; Laurance et al., 2004). Andean condors (*Vultur gryphus*) were found to change habitat use and feeding behaviour due to roads and traffic, preferring to feed in patches far from roads (Speziale et al., 2008). Negative effects of roads were also reported for small mammals (Appendix 2). Montane akodon rodents (*Akodon montensis*) avoided crossing forest edges near dirt or paved roads compared to roadless edges (Ascensão et al., 2017). Similar road avoidance effects were observed by spider monkeys (*Ateles sp.*) that crossed roads where canopy gaps were narrowest (Asensio et al., 2017). Jaguars (*Panthera onca*) avoided crossing highways and paved roads in Mexico's Mayan forest (Colchero et al., 2011). Small mammals showed reluctance to cross roads in Andean forests and in tropical moist forests of Panama (Vargas-Salinas and López-Aranda, 2012; Lambert et al., 2014). Two endemic small mammals from Cozumel Island (Mexico) 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) which may be explained by behaviour variability among different age and sex classes towards roads. A neutral effect towards roads was found for a rodent species in an agricultural landscape in Argentina since gene flow was documented across roads (Chiappero et al., 2016). Roads had positive effects on guanacos (*Lama guanicoe*) as they perceived the roadside vegetation in open landscapes as safe habitat, thus increasing the detection of potential predators (Marino and Johnson, 2012; Cappa et al., 2017).

3.2.5. Mortality – species composition

Nearly 700 species were recorded as road-kill in Latin America. Birds and reptiles showed the highest richness with 235 and 231 species, respectively; followed by mammals (n = 155) and amphibians (n = 52) (Appendix 3). Estimates of road-kill rates at the species level were provided in 73% (n = 67) of the studies (Appendix 3). Amphibians had the highest median road-kill rate with 0.2 ind./km/year, followed by reptiles with 0.06 ind./km/year, mammals 0.03 ind./km/year and birds 0.02 ind./km/year. Mortality studies (33%) included 28 species listed as Threatened (IUCN, 2018), 16 classified as Near Threatened, 10 as Vulnerable and two as Endangered (Appendix 3). The majority of Threatened species were mammals (n = 19), followed by birds (n = 6), reptiles (n = 2) and amphibians (n = 1). The proportion of road-kills in a population was estimated for the endemic montane toad (*Melanophryniscus* sp.) in Argentina (Cairo and Zalba, 2007). They found that road-kills represented from 2.5 to 5.9% of the population annually.

Only five studies analyzed the implications of road mortality on population viability. Long-term persistence of giant anteaters (*Myrmecophaga tridactyla*) in a protected area of central Brazil was threatened when road-related mortality rates surpassed 5% of the population. Similar results were found in other protected areas in Brazilian Cerrado (Diniz and Brito, 2013, 2015). Population models predicted that road-related mortality could impact jaguar population persistence in Atlantic forests in southern Brazil, causing the reduction of 80% in a metapopulation and 45% in an 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 survival (Tanner et al., 2007). In a global analysis of carnivore exposure to roads, long-term population persistence of species like the Darwin's fox (*Pseudalopex fulvipes*), jaguar and puma could be affected when road densities exceed 0.1 km/km^2 (Ceia-Hasse et al., 2017).

3.2.6. Mortality – spatio-temporal patterns

Amphibian road-kills were best explained by traffic volume, presence of water bodies near roads and wet seasons in southern Brazil (Coelho et al., 2012). Traffic volume was associated with road-kill occurrence among reptiles in Amazon (Maschio et al., 2016), and in southern Brazil where mortality was also positively associated with proximity to rice plantations (Gonçalves et al., 2017). Reptile road-kills increased during wet seasons in Argentina (Cuyckens et al., 2016) and 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*) (Ojeda et al., 2015) and bats (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).

3.2.7. Mitigation of road effects

Among the 15 studies focused on mitigation strategies seven were specific of mammals, two of amphibians, while six presented a multi-taxon approach. Recommendations include implementation of mitigation structures (mostly underpasses and fences) to reduce road-kill rates for amphibians (Coelho et al., 2012) and medium to large-sized mammals in Brazil (Huijser et al., 2013; Bueno et al., 2015; Ascensão et al., 2017a), for vicunas (*Vicugna vicugna*) in Chile (Mata et al., 2016), and connectivity for jaguars in Central America (Colchero et al., 2011; Araya-Gamboa and Salom-Pérez, 2015).

Two studies evaluated mitigation measures by quantifying road-kill rates before and after underpass and fencing installation (Bager and Fontoura, 2013; Ciocheti et al., 2017). Underpasses were not effective, failing to decrease road-kill rates for medium- and large-sized mammals (Ciocheti et al., 2017) and vertebrate groups i.e., reptiles, birds and mammals (Bager and Fontoura, 2013). However, a rope bridge designed to mitigate road effects on brown howler monkeys (*Alouatta guariba clamitans*) helped restore movements and connectivity (Teixeira et al., 2013).

4. Discussion

The road network in Latin America is expected to increase in the next 25 years (Meijer et al., 2018). Until now the effects of roads on terrestrial vertebrates have been reviewed in temperate regions of North America and Europe (Trombulak and Frissell, 2000; Underhill and Angold, 2000). Our review of the effects of roads on wildlife is of particular importance as it includes some of the most threatened regions on the globe today (Laurance and Arrea, 2017; Habel et al., 2019). Here we describe the knowledge gaps in Latin America and suggest future directions in research that will help develop a planning strategy for road construction and mitigation implementation in Latin America.

4.1. Research gaps

Although we found a growing number of papers documenting road effects in Latin America, there was a clear disparity in the distribution of scientific information, the majority being published from South America and a glaring deficit from Central American countries. Not surprisingly, Brazil was the country with the most research. Brazil is the largest and most populated country in Latin America, with a long history of biodiversity conservation research (Mittermeier et al., 2005), including infrastructure impacts (Reid and Souza Jr., 2005; Fonseca and Rodrigues, 2017). 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-kill is the most conspicuous effect of roads on wildlife, mortality studies are the first step into assessing impacts; they also are low-cost and relatively easy to conduct. Nevertheless, there is a need to move beyond analyses on mortality, species richness, abundance and behaviour and begin understanding how these influence population viability and ultimately increase the risk of species extinction (Chiappero et al., 2016; Cullen et al., 2016) to better define priorities for species conservation and road mitigation.

4.2. Future directions for research

We suggest a two-speed strategy to address the science and decision-making needs to keep up with the fast pace of road building in Latin America (Laurance and 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 for species and populations to inform road planning immediately. Herein we describe some recommendations per research area:

4.2.1. 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 some terrestrial vertebrates to roads using an integrated modelling framework have been applied (e.g. Row et al., 2007; Ceia-Hasse et al., 2017). This framework can help to 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.

4.2.2. 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 behaviour towards 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 also important to know how changes in species abundance and distribution from roads can have implications on the ecological processes (Corlett, 2017).

4.2.3. 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 road-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 (but see González-Suárez 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.

4.2.4. Mitigation

Designing potential solutions and mitigation is context-sensitive to different ecological, socioeconomic and policy environments (Clevenger and Huijser, 2011, Van der Ree et al. 2015). Current lack of mitigation research in Latin America is the consequence of few applied mitigation measures (González-Gallina et al., 2018). 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 road effects 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 et al., 2012; Soler, 2014).

5. Conclusions

Road ecology is an emerging field of research in Latin America and for the most of this territory, the basic science regarding road effects on wildlife communities is still lacking. To adequately estimate the environmental-development trade-offs of 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. 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. Once this is achieved, road projects can be designed with minimal impacts on wildlife communities and biodiversity conservation.

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Declaration of Competing Interest

The authors declare no conflicts of interest. Thank you for your consideration of this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eiar.2019.106337.

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