Research and conservation priorities to protect wildlife from collisions with vehicles

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Short communication

Research and conservation priorities to protect wildlife from collisions with vehicles

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ABSTRACT

The rapidly expanding global road network poses threats to wildlife, including direct mortality. Given limited knowledge and resources, strategic allocation is critical. We introduce a method to identify areas and taxa affected by vehicle collisions as priorities to study and protect. The method is illustrated using Latin America as a case study. In this region high biodiversity and an expanding road network can result in high impacts from roads, yet emerging research expertise offers opportunities for action. To identify priority targets, we combined predicted spatially-explicit roadkill rates for birds and mammals with information about the current road network and species conservation status. Priority areas for conservation (with many species susceptible to roadkill but few or inexistent roads) were largely concentrated in the Amazon, while priority areas for research (unstudied regions with many roads and many species susceptible to roadkill) occur in various areas from Southern Mexico to Chile. Priority taxa for conservation reflected studied, roadkill-susceptible groups (e.g., vultures and armadillos), while priority taxa for research were defined as either poorly-studied roadkill-susceptible groups or unstudied groups of conservation concern (e.g., cuckoos and shrew opossums). Our approach offers a tool that could be applied to other areas and taxa to facilitate a more strategic allocation of resources in conservation and research in road ecology.

1. Introduction

Roads are widespread features in our planet and already fragment some of the world's last remaining wilderness areas such as the Amazon (Laurance et al., 2014; Meijer et al., 2018). By 2050, an additional 25 million km of new roads will be constructed primarily in Africa, South and East Asia, and Latin America (Laurance et al., 2014). Roads are one of the main anthropogenic causes of wildlife mortality worldwide (Hill et al., 2019), and the primary cause in some regions (Taylor-Brown et al., 2019). For example, an estimated 194 million birds and 29 million mammals are killed in European roads, 340 million birds in the United States, and twelve million birds and five million mammals in Latin America (Grilo et al., 2020; Loss et al., 2014; Medrano-Vizcaíno et al., 2022).

The relentless expansion of roads affects wildlife worldwide, but impacts can vary across different regions and habitats depending on the vulnerability of the present species. Research shows evidence that roadkill risk varies among taxa due to their distinct morphological and ecological characteristics. For example, higher roadkill rates are found in larger, ground-foraging birds with more diverse diets and also in medium-sized, diurnal, scavenging mammals (Caceres, 2011, González-Suárez et al., 2018). Habitat preferences and use can also influence roadkill incidence (Medrano-Vizcaíno et al., 2022). These generalized links between road mortality, traits and habitats suggest we could use existing information to predict wildlife mortality patterns across large geographical and taxonomic scales and thus, identify priority targets for research, infrastructure design and planning, and conservation management.

The application of prioritization tools to inform future research actions is particularly valuable in areas where risks are expected to be high (i.e., biodiverse areas with expanding road networks) but where empirical estimates of impacts are scarce. Latin America is a highly biodiverse region harboring eight biodiversity hotspots and unique endemism (Myers et al., 2000) as well as ~3.5 million km of roads

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(Meijer et al., 2018). Road impacts threaten Latin-American wildlife, but assessments are still rare with few, albeit rising, road ecology studies (Pinto et al., 2020). This makes Latin America an ideal case study to test the proposed approach that capitalizes on existing spatially-explicit roadkill rates predicted for bird and mammal species known to suffer mortality from collisions (obtained from Medrano-Vizcaíno et al. (2022)). These data, combined with information on road network and species conservation status offer a way to identify priority areas and taxa for conservation and research.

To identify priorities, we propose that conservation efforts to reduce road impacts should focus on areas where many species susceptible to roadkill and few roads coincide (high vulnerability, low exposure). On the other hand, priority areas for research should be those currently unstudied but with many species susceptible to roadkill and many roads (high vulnerability, high exposure, Fig. 1). Similarly, we define priority taxa for conservation considering taxonomic orders with a high proportion of species recorded as roadkill and high predicted roadkill rates. We propose priority taxa for research should be currently understudied groups for which available roadkill rates are high, as well as unstudied groups in which many species are considered to be of conservation concern (Fig. 2). This approach can be applied to other regions and different taxonomic or functional groups offering a tool to guide resource allocation in road ecology and conservation.

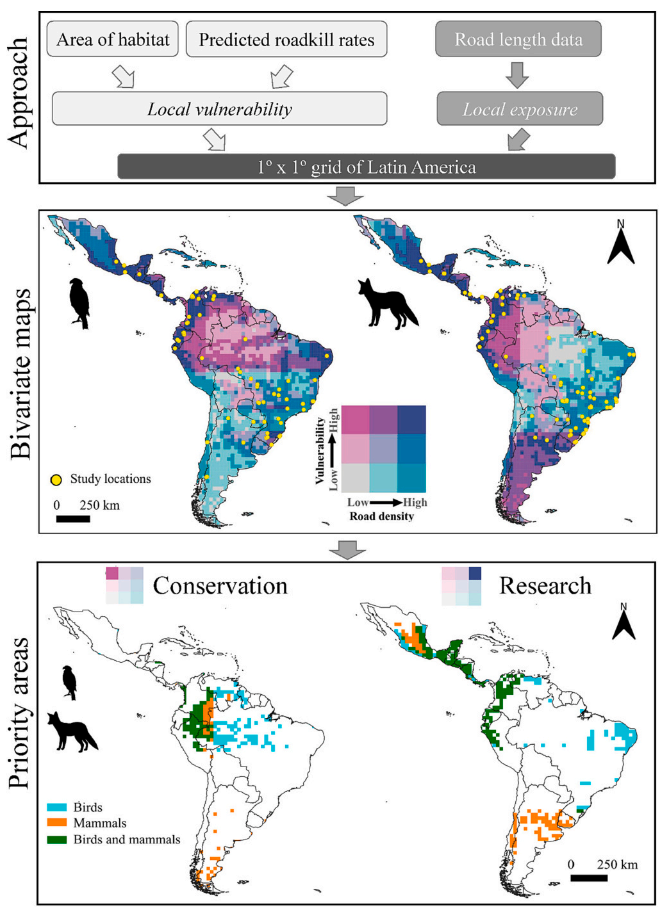

Fig. 1. Summary of proposed approach to identify priorities (top panel) with resulting output representing maps of local vulnerability and exposure (middle panel) and the proposed priority areas for conservation and research for Latin American birds and mammals (bottom panel). Middle panel shows bivariate choropleth maps with nine categories based on terciles values for local vulnerability and exposure, with yellow symbols showing where data were collected. Bottom panel shows proposed priority areas for conservation and research based on bivariate maps (the modified legends on top of this panel highlights that we considered high vulnerability and low exposure for conservation priorities, and high vulnerability and high exposure for research priorities). Animal silhouettes were obtained from Phylopic (http://phylopic.org). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Priority areas

We capitalized on existing data to calculate three metrics for each 1° × 1° grid cell in Latin America (Fig. 1). We defined local vulnerability to road mortality as the sum of predicted roadkill rates for all species occurring in that cell (see details below). We approximated local exposure by calculating as the total length of primary and secondary roads using data from Meijer et al. (2018). Finally, each cell was classified as either studied, if at least one systematic roadkill survey had been conducted in that area (centroid of the study area overlap the cell), or unstudied, if no studies were found. Values for the three metrics in all grid cells are available at https://doi.org/10.6084/m9.figshare.20166359 in Appendices 1 and 2.

Predicted roadkill rates (number of individuals killed per kilometer of road per year, ind./km/year) were available for 346 bird and 159 mammal species reported at least once as roadkill in a recent compilation of systematic road survey studies (Medrano-Vizcaíno et al., 2022). Predicted roadkill rates for each species and 1° × 1° grid cell across Latin America were obtained using trait-based machine learning Random Forest models that related observed roadkill rates from 85 systematic roadkill surveys with study location, species trait data (ecological, life-history, and morphological characteristics) and habitat preferences. Random Forests methods have a high predictive accuracy, capture nonlinear relationships and interactions, can account for similarity of traits that related taxa may share due to common evolutionary history, and have shown to be useful to predict roadkill rates based on traits (Bielby et al., 2010; González-Suárez et al., 2018; Grilo et al., 2020; Medrano-Vizcaíno et al., 2022). Predictions were made for each cell in a species' area of habitat using current distribution ranges (IUCN, 2022) from which areas without suitable habitat were removed to better represent where species are likely to be present (Brooks et al., 2019). Suitable habitats were defined based on habitat preferences of each species (described in Medrano-Vizcaíno et al., 2022) using high resolution (30 arc-sec^2, ~1 km^2) land cover data (Latham et al., 2014).

All grid cell values of local vulnerability and local exposure for birds and mammals were grouped into terciles for each metric which combined resulted in nine joint categories (Fig. 1) and were mapped using bivariate choropleth maps in QGIS v.3.18.2-Zürich (https://qgis.org/en/site/). Conservation priority areas were proposed as those falling in the category representing the top tercile of local vulnerability and the bottom tercile of road abundance (low exposure). Top research priorities were defined as unstudied areas that fell in the top terciles of both local vulnerability and local exposure. Using terciles, intuitively divides data into low, medium and high values. However, different criteria could be used depending on the interests, needs, and resources available. We present as supplementary results priorities based on two more restricted criteria considering quartiles and quintiles (25 % and 20 % of values respectively. Supplementary Figs. S1.1, and S2.1).

2.2. Priority taxa

Using predicted roadkill rates from Medrano-Vizcaíno et al. (2022) and the IUCN Red List categories (IUCN, 2022) we calculated several metrics for each taxonomic order of birds and mammals including: the total number and percentage of species reported as roadkill, the number and percentage of species classified as Threatened (Critically Endangered, Endangered, and Vulnerable), Data Deficient, and Not Threatened (Near Threatened and Least Concern) by the IUCN Red List (IUCN, 2022). We also calculated the average predicted roadkill rate for each

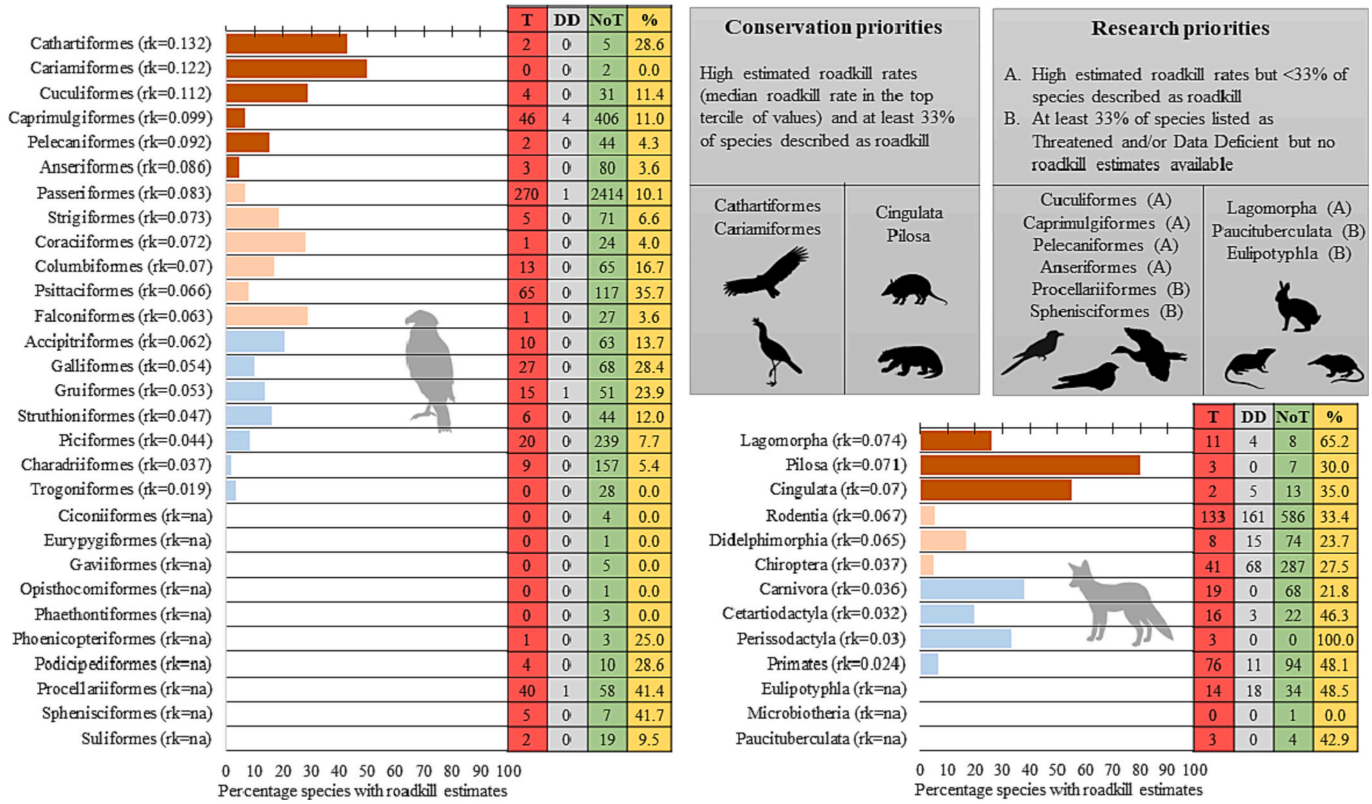

Fig. 2. Priority conservation and research taxa and criteria values for bird and mammal taxonomic orders. Top right inset describes the proposed criteria for prioritization and the orders identified as conservation and research priorities. Plots show the percentage of species per order for which roadkill data was available in our compilations used as criteria. Order names are followed by the estimated median roadkill rates (rk) calculated from the species rates predicted by trait-based Random Forest models (Medrano-Vizcaíno et al., 2022). Orders are listed from highest to lowest rk with bar color indicating the terciles of the median roadkill rates used as criteria (brown-orange bars = top tercile, peach bars = medium tercile, and light blue bars = bottom tercile). We also provide for each order the number of species classified by the IUCN as Threatened (T), Data Deficient (DD), Not Threatened (NoT) and the percentage (%) of the total listed as T and DD which was used in the criteria. Animal silhouettes were obtained from Phylopic (http://phylopic.org). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

order as the median across of all predicted roadkill rates for species in that group. We focused on taxonomic orders as priority targets to illustrate the method, but priorities could be defined at different taxonomic levels or for example considering functional groups. We propose as conservation priorities to orders with at least 33 % of species reported as roadkill and high predicted roadkill rates (median roadkill rate in the top tercile of values). We suggest two types of research priorities: type A for understudied but likely susceptible orders (high predicted roadkill rates – median roadkill rate in the top tercile of values, but roadkill data available for <33 % of species), and type B for unstudied groups of conservation concern (no roadkill data available and at least 33 % of species listed as Threatened or Data Deficient). As above, we present as supplementary results priorities based on two more restrictive criteria that identified as conservation priorities orders with at least 40 % or 45 % of species recorded as roadkill, and median roadkill rates in the top quartile or top quintile respectively. The more restrictive research priorities type A represented groups with fewer than 40 % or 45 % species with reported roadkill data and median roadkill rates in the top quartile or top quintile respectively; while research priorities type B were groups with no roadkill data available and at least 40 % or 45 % of species listed as Threatened or Data Deficient (Supplementary Figs. S1.2, and S2.2).

3. Results

3.1. Priority areas

Local vulnerability and exposure are heterogeneously distributed across Latin America, but vulnerability is generally higher in tropical areas for both birds and mammals (Fig. 1). The bivariate maps show priority conservation areas (those with high vulnerability but low exposure) in most of the Amazon region with smaller areas in southern Argentina, northeastern Honduras, and the border of Panama with Colombia (Fig. 1). Bird and mammal conservation areas partially overlap but are not identical, reflecting different distributions of species vulnerable to roadkill (Fig. 1). Top research priorities (unstudied areas with high vulnerability and high exposure) occurred in most of Central America, northern regions of Venezuela and Colombia, a great part of Ecuador, western Perú, southern Chile, Uruguay, central Argentina, and eastern Brazil (particularly for birds) (Fig. 1). Using more restrictive criteria we identified fewer priorities areas but results were consistent, with the Amazon as a conservation priority and, Central America, northern Colombia, northern and western Ecuador, western Perú, central Argentina, and eastern Brazil as research priorities (Supplementary Figs. S1.1, and S2.1).

At a national scale we note that we found no reported roadkill surveys for five countries that overlap with identified top research priority areas (Belice, El Salvador, Honduras, Nicaragua, and Uruguay).

3.2. Priority taxa

Roadkill estimates were available for only 7.50 % and 8.55 % of Latin American birds and mammals respectively, and entire orders had no reported roadkill records (Fig. 2). From the 29 bird orders present in Latin America, we found data for about two thirds (19) but for represented orders fewer than 50 % of the species had reported roadkill estimates. Mammals were better represented with data for species in 10 of the 13 orders in Latin America and data for >50 % of species for two orders, but still roadkill estimates reflected a relatively small fraction of mammalian diversity (Fig. 2). Median predicted roadkill rates ranged from 0.019 to 0.132 ind./km/year in bird taxonomic orders (SD ranging from 0.018 to 0.129), and from 0.024 to 0.074 in mammalian orders (SD 0.018 to 0.281).

Using our main suggested criteria, Cathartiformes and Cariamiformes should be considered as conservation priorities for birds, and Pilosa and Cingulata for mammals (Fig. 2. For more restrictive criteria see Supplementary Figs. S1.2 and S2.2). Cathartiformes are New World vultures that as scavengers can be attracted to roads to forage on roadkill increasing their risk of collision. This group has the highest predicted rate for birds, and more than one third of species (42.86 %) have been reported as roadkill. Cathartiformes includes threatened species for which estimates of roadkill are still not available but could be vulnerable to road mortality such as the Andean condor (*Vultur griphus*) and the California condor (*Gymnogyps californianus*). Cariamiformes has the second highest predicted rates for birds, with roadkill data available for one out of two existing species.

Sloths and anteaters (Pilosa) are also found frequently as roadkill (likely their slow movements increase probability of collisions when crossing roads), and more than two thirds of species (80 %) have been reported as roadkill. Armadillos (Cingulata) also show vulnerability to roadkill (high rates) and are a group with an uncertain conservation status (five species classified as Data Deficient. Fig. 2).

Cuckoos (Cuculiformes), Caprimulgiformes, Pelecaniformes, and Anseriformes were identified as research priorities type A for birds because roadkill estimates were high, yet risk for many species in the group remains unknown (Fig. 2). Procellariiformes sea birds, and penguins (Sphenisciformes) are research priorities type B because these groups are of conservation concern, but no studies have evaluated roadkill risks. Given these priorities, road ecology research in coastal areas and islands seems particularly necessary to better understand risk for avian species in Latin America. Roadkill rates could be very low for these species, particularly those that spend most of their life at sea but, some species in these groups are known to be affected in other areas. For example, penguins have been reported as roadkill (Heber et al., 2008).

Rabbits (Lagomorpha) were identified as mammalian research priorities type A with high rates combined with a high proportion of unstudied species, while the small mammals in the orders Paucituberculata and Eulipotyphla were considered research priorities type B given the current lack of knowledge and their high proportion of species listed as Threatened and Data Deficient (Fig. 2).

When using more restricted criteria, Cariamiformes, Pilosa and Cingulata were consistently identified as conservation priorities, while Caprimulgiformes, Pelecaniformes and Eulipotyphla remained as research priorities. Finally, while we propose priority taxa for conservation and research at taxonomic order level, vulnerability at taxonomic family and species levels can be evaluated using data in Appendices 3 and 4 (predicted roadkill rates based on Random Forest models from Medrano-Vizcaíno et al., 2022) available at https://doi.org/10.6084/m9.figshare.20166359.

4. Discussion

Our approach capitalizes on existing data to generate quantitative estimates of spatial and taxonomic vulnerability that combined with data on local and taxa-specific risks (e.g., exposure to roads and conservation status) can help identify priorities for conservation and research. We apply this approach to suggest priorities for Latin America based on a set of proposed criteria, but also illustrate priorities under more restrictive rules. Which criteria are used in decision making will depend on the different needs, values, and funding trade-offs. Additionally, other sources of risk could also be considered to further optimize conservation and research resources. For example, the consideration of road traffic to estimate local exposure could offer a more realistic approach; nevertheless, the unavailability of these data for many regions of the world may prevent their inclusion. Our approach aims to provide a unified way to predict and map road vulnerabilities, exposure, and risks, which facilitates the decision process of where and who to protect and study at a large scale. We envision this as a first step in the decision-making process that could complement existing conservation prioritization tools (Zizka et al., 2021) and should be followed with local and regional analyses to develop conservation and research agendas.

Application of the proposed approach to define conservation priorities in Latin America revealed the Amazon as a focal region to minimize development of infrastructure. The presence of many species with high predicted roadkill rates means that expanding the road network in this area without careful planning and adequate mitigation measures will likely have negative consequences for both wildlife and humans, as collisions can result in injuries and even fatalities (Zhao et al., 2010). The Amazon is already considered a priority for conservation due to its unique forest environment, carbon sequestering potential and high biodiversity (Strassburg et al., 2010). New roads would likely lead to increased wildlife mortality, but even if mitigation measures were implemented to reduce mortality, new roads facilitate further degradation and human expansion (Laurance et al., 2009). Worryingly, 12,263 km of roads may be opened or improved (leading to more traffic and higher travelling speeds) in the Amazon in the next few years, and this expansion will likely be accompanied by additional illegal roads which can triple the length of official roads in some areas (Barber et al., 2014; Vilela et al., 2020).

The proposed approach also suggested priority areas for future studies, particularly in Central America, and North-western South America. We hope that by identifying research priorities in Latin America, where expertise is expanding but data are still limited compared to other regions (Silva et al., 2021), our approach will encourage researchers and funding agencies to focus on understudied areas where species are more susceptible to road impacts and roads abound. Research efforts can be driven by individual interests, but funding agencies can also define priorities and propose targeted schemes in these areas, where road systems are expected to have a great expansion. By 2050, many Latin American countries are expected to have expanded road networks including Mexico (13 % increase), Panama (13 %), Costa Rica (21 %), Venezuela, (20 %), Colombia (18 %), and Ecuador (15 %) (Meijer et al., 2018). These areas can be ideal to conduct much needed research on mitigation. Mitigation measures remain rare in Latin America (Pinto et al., 2020) but proposed priorities areas for research are likely suitable to test the effectiveness of mitigation systems (e.g., virtual fences, underpasses, over passes, etc.) particularly if hotspots of mortality are identified. Additionally, research in these areas could evaluate the synergistic effects of road mortality with other anthropic pressures such as deforestation, fragmentation, and land use change, and the implications of the interactions with other species. We do not yet fully understand the interaction of these human-induced processes which is key to get a comprehensive perspective of the challenges that animals need to overcome to guarantee their survival.

Our analyses also identified taxonomic groups as conservation or research priorities. Further evaluation of species in these target groups may reveal limited risk for some due to behavioral avoidance [which can prevent roadkill but still have negative impacts by reducing gene flow (Holderegger and Di Giulio, 2010)] or preferences for local habitats where roads are absent or rare and thus, risks are few. Deeper evaluation of the proposed, admittedly coarse, priorities would help refine these targets, eliminating taxa unlikely to encounter roads or currently limited to roadless areas. We recognize that targeting taxa during roadkill assessments could present some challenges, as some species are naturally more difficult to detect even if roadkilled. For example, species-level roadkill data for smaller mammals like rodents or shrews is rare, likely because small animals are more often unrecognizable after collision – found as furry spots on roads if at all (Cook and Blumstein, 2013). Additionally, rarer groups of small mammals (e.g., Eulipotyphla and Paucituberculata) may be wrongly classified in broad groups (like "unclassified rodents") which prevents species-specific analyses. Finding ways to address these biases is essential. Improving taxonomic identification skills or consulting with experts can be a solution. Although expensive, another solution would be identification of roadkill samples using molecular techniques. Future research could investigate different approaches to reduce and correct taxonomic biases.

The Latin America and Caribbean region is home to >4600 birds and 1800 mammals (IUCN, 2022), yet estimates of mortality caused by collisions with vehicles are available for <10 % of species (Medrano-Vizcaíno et al., 2022). This means that the magnitude of how roads impact wildlife is likely underestimated. Finding ways to identify priority areas and taxa for research can address this limitation more efficiently to improve knowledge. At the same time, roadkill surveys can provide information about rare and poorly studied species. For example, the western mountain coati *Nasuella olivacea*, considered the least-studied carnivore of the world (Helgen et al., 2009; Medrano-Vizcaíno and Gutiérrez-Salazar, 2020), was the second most roadkilled species in a study in Colombia (Delgado-V, 2007). Specimens collected as roadkill can contribute to understand the biology of organisms that can be difficult to study, making roadkill assessment valuable beyond the estimate of threats (Medrano-Vizcaíno and Brito-Zapata, 2021).

Latin America is not the only region where future road development and lack of road impact assessment coincide. In Asia, systematic studies focused on wildlife mortality have been conducted in only nine out of 48 countries, while in Africa systematic data are only available for only five out of 54 countries (Silva et al., 2021); yet rapid development of infrastructure is expected in these regions (Meijer et al., 2018). While funds to assess potential risk may not always accompany road development plans, identifying regions where this research is particularly needed could aid in more directed investment of limited resources. Our approach could be applied to different taxonomic or functional groups and areas of the world to better plan research and conservation actions. For example, there is a need to prioritize studies on amphibians and reptiles which remain understudied but appear to suffer high mortality in different regions of Africa, Asia, and Latin America (Chyn et al., 2019; Collinson et al., 2019; Pinto et al., 2020). Road ecology is also lacking information on invertebrates. We found no studies in Latin America, and only a few have been conducted in other regions of the world, where reported mortality rates were high (Baxter-Gilbert et al., 2015; Shyama Prasad Rao and Saptha Girish, 2007). Applying our approach to other unknown or vulnerable taxonomic groups in different regions of the world could be highly valuable to guide conservation and research actions.

Our study reveals priority areas and taxa that we hope would be valuable to ecologists, funding agencies, and decision makers in Latin America. Additionally, we provide a comprehensive dataset of predicted mortality rates of birds and mammals across all Latin America, which can be used to propose priorities for different taxonomic levels and geographic scales in this region.

CRediT authorship contribution statement

Pablo Medrano-Vizcaíno: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Clara Grilo:** Supervision, Writing – review & editing. **Manuela González-Suárez:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

All data used for analyses including birds and mammals' vulnerability to roadkill and the grid for Latin America are available as appendices at: https://doi.org/10.6084/m9.figshare.20166359.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.109952.

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