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Road Permeability Index as a tool for mitigation planning of road impacts on wildlife in Colombia: a case study using mammals

Índice de Permeabilidad Vial como herramienta para la planificación de mitigación de los impactos de las carreteras sobre la fauna silvestre en Colombia: un caso de estudio utilizando mamíferos

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ABSTRACT

Mitigation planning for road projects in Colombia has been largely based on actions aimed at reducing wildlife roadkills. Nonetheless, the efficiency of these actions is compromised because of the absence of robust empirical studies supporting their implementation. In this work, I used the Road Permeability Index (RPI) in conjunction with expert knowledge information to estimate the strength of the barrier effect imposed by an under-construction road (Yuma road, Santander department, Colombia) on nine functional groups of medium and large-sized mammals. The influence of 12 landscape variables on the permeability of each functional group was assessed at 30 locations along the road. The RPI was calculated for each functional group, and the whole studied mammal assemblage at each location. The relative influence of each variable on overall permeability was also estimated. I found that functional groups including terrestrial and semiarboreal species present higher contribution values to overall road permeability, indicating that they represent priority targets for mitigation actions. The RPI identified six highly permeable locations for animal movement—where higher roadkill rates are expected—which are key for implementing mitigation strategies aimed at reducing wildlife road mortality. Forest cover had the strongest influence on road permeability, therefore is crucial for landscape conectivity. Overall, the results of this work show that RPI constitutes a reliable and easily adaptable alternative for identifying priority species, or faunal groups, and locations for road mitigation planning.

Keywords: Barrier effect, expert knowledge, environmental impact assessments, fauna movement, mitigation measures.

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RESUMEN

La planificación de mitigación de proyectos viales en Colombia se ha basado principalmente en acciones para reducir la mortalidad de animales silvestres en carreteras. Sin embargo, la ausencia de estudios empíricos que respalden estas acciones comprometen su eficiencia. En este trabajo se utilizó el Índice de Permeabilidad Vial (RPI por su nombre inglés) junto con información de conocimiento experto para estimar la intensidad del efecto barrera impuesto por una carretera en construcción (vía Yuma, departamento de Santander, Colombia) sobre nueve grupos funcionales de mamíferos medianos y grandes. La influencia de doce variables del paisaje sobre la permeabilidad de cada grupo fue evaluada en 30 sitios a lo largo de la vía. El RPI se calculó para cada grupo funcional y para el ensamblaje de mamíferos en cada sitio. Se estimó la influencia relativa de cada variable sobre la permeabilidad total. Los grupos funcionales que incluyen especies terrestres y semiarborícolas presentaron valores altos de contribución a la permeabilidad vial total, indicando que son objetos prioritarios para acciones de mitigación. El RPI identificó seis sitios de alta permeabilidad—donde se esperan más atropellamientos—los cuales son claves para la implementación de estrategias de mitigación enfocadas en reducir la mortalidad vial de fauna silvestre. La cobertura boscosa tuvo la mayor influencia absoluta en la permeabilidad vial, siendo crucial para la conectividad del paisaje. En general los resultados muestran que el RPI es una alternativa confiable y fácilmente adaptable para identificar especies, o grupos faunísticos, y sitios prioritarios para la planificación de mitigación vial.

Palabras clave: Conocimiento de experto, efecto barrera, evaluaciones de impacto ambiental, medidas de mitigación, movimiento de fauna.

INTRODUCTION

Roads are a significant concern in conservation management as they represent physical barriers to animal movement that cannot be circumvented but rather must be crossed (Beyer *et al.* 2016). The overall barrier effect imposed by roads varies as a function of its permeability, that is, the degree to which a road reduces the capacity of animals to navigate and move across landscapes (Nathan *et al.* 2008, Beyer *et al.* 2016, Assis *et al.* 2019). Road permeability is not homogeneous through landscapes and varies among species according to intrinsic (e.g., body size, age, behaviour, and navigation ability) and extrinsic factors affecting animal movement capabilities such as landscape configuration, resource availability, vehicular traffic, among others (Nathan *et al.* 2008, Reding *et al.* 2013, Gardiner *et al.* 2018, Assis *et al.* 2019). Therefore, certain road sections are easier to traverse for some animals, often presenting high rates of wildlife mortality due to vehicle collisions (i.e., roadkills); while others are unpassable, limiting ecological and genetic flows through landscapes (Jaeger *et al.* 2005, Ramp *et al.* 2005, Assis *et al.* 2019). Thus, a critical question when devising mitigation measures is whether they are sufficiently effective to increase road permeability while reducing roadkill rates (e.g., van der Ree *et al.* 2007).

Understanding how roads influence animal movement is essential for developing more cohesive road planning strategies for wildlife conservation (Beyer *et al.* 2016, Doherty and Driscoll 2017). For example, in fragmented landscapes of the Middle Magdalena Valley—an intermontane basin in north-central Colombia—mammal roadkill hotspots match areas with low regional structural connectivity, where the current flow is influenced by the presence of highly human-modified habitats (Meza-Joya *et al.* 2019). This suggests that local wildlife presents altered movement patterns to respond to changes in resource availability and landscape configuration (e.g., Doherty and Driscoll 2017). In this case, patch-dependent species are probably forced to travel through lower quality habitats when searching for resources, while habitat generalists likely used the anthropogenic matrix as habitat or movement path (Meza-Joya *et al.* 2019). Furthermore, habitat patches alongside roads may also be perceived by animals as movement corridors or navigational features of the landscape, increasing the risk of direct mortality due to collisions with vehicles (Gardiner *et al.* 2018).

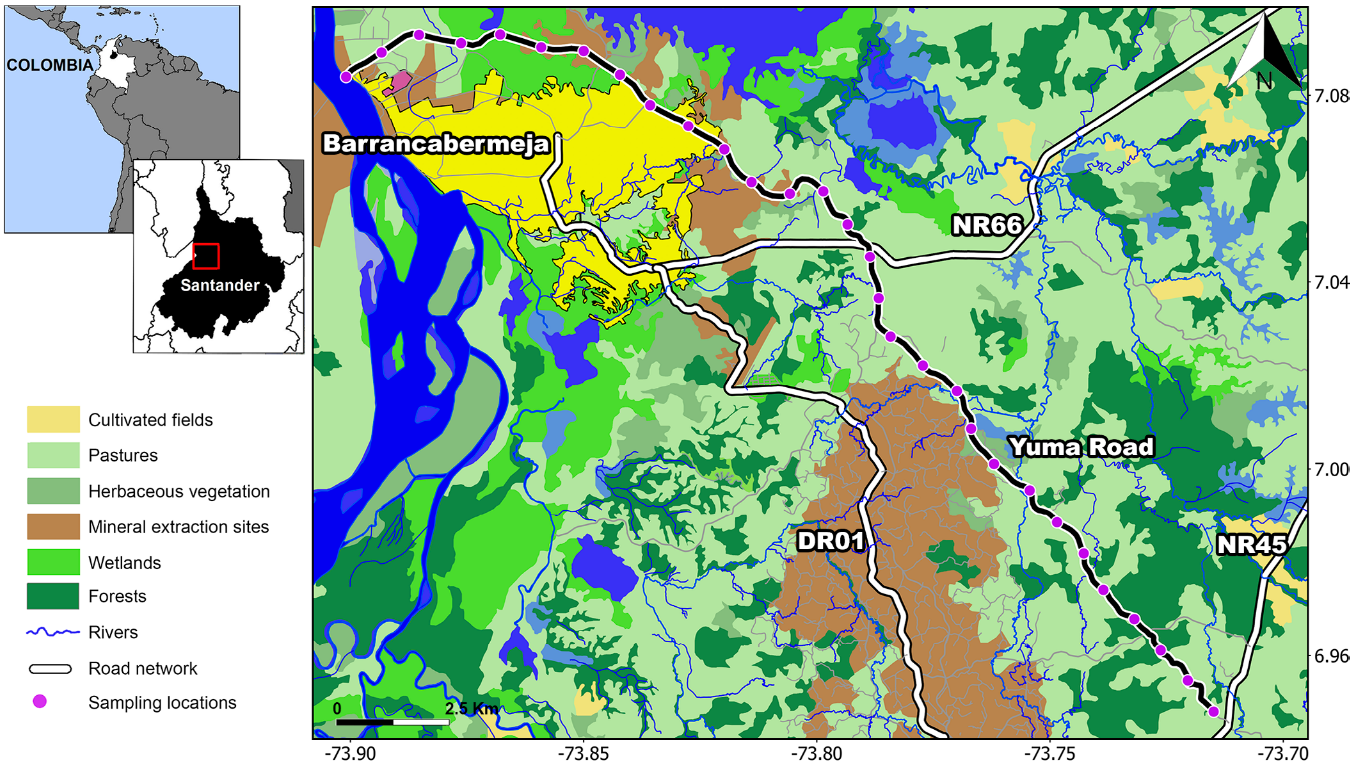

Figure 1. Study area in the Middle Magdalena Valley, Santander, Colombia.

The impact of mortality due to vehicle collisions on wildlife has received little attention in Colombia and its effects remain vastly underestimated. Most studies have provided both systematic and incidental counts of road-killed animals on national roads (e.g., de La Ossa-V and Galván-Guevara 2015, Meza-Joya *et al.* 2015, 2018, Monroy *et al.* 2015), whilst just a few have attempted to test spatio-temporal patterns of wildlife-vehicle collisions and estimate roadkill rates (e.g., Payan *et al.* 2013, Ramos and Meza-Joya 2018, Meza-Joya *et al.* 2019, Rincón-Aranguri *et al.* 2019). Adding to the rarity of road ecology research, environmental licensing in Colombia was recently regulated (Law 99 of 1993, Decree 1220 of 2005, Toro *et al.* 2010). Consequently, most roads in the country lack mitigation measures (e.g., crossings structures such as ecopassages and warning signs), and when required by the national environmental legislation, they are installed intuitively in the absence of robust empirical studies supporting their location and effectiveness (Payan *et al.* 2013, Meza-Joya *et al.* 2019). Unfortunately, the most implemented mitigation strategy on regional roads around the study area (i.e., warning signs) is ineffective (Meza-Joya *et al.* 2019). As implementing mitigation measures is expensive, studies based on reliable 'before mitigation' empirical data (e.g., movement, behavioural, population, and roadkill counts) are needed to inform the best actions to manage the potential effects of roads on wildlife (Teixeira *et al.* 2016).

Gathering reliable 'before mitigation' data, however, can be extremely challenging and time-consuming (Grilo *et al.* 2018, Assis *et al.* 2019), especially when planning decisions must be taken rapidly despite the shortage of empirical data (Assis *et al.* 2019). In such cases, alternative approaches integrating the available knowledge are required to assist the decision-making process (Grilo *et al.* 2012, Assis *et al.* 2019). In this paper, I used the Road Permeability Index (RPI; Assis *et al.* 2019) to estimate the strength of the barrier effect imposed by an under-construction road on medium and large-sized mammals in the Magdalena Valley of Colombia. This novel method estimates road permeability for fauna by combining biotic and abiotic environmental data and expert knowledge in situations where 'before mitigation' empirical data are not available (Assis *et al.* 2019). This work shows that the RPI represent a promissory tool that can be used for both a fast and reliable identification of priority species (or faunal groups) for road mitigation strategies and to inform decision-makers about the best mitigation strategy and locations for implementing management actions.

MATERIALS AND METHODS

Study area

This study was conducted in the municipality of Barrancabermeja, located in the Middle Magdalena Valley, Santander department, Colombia (Fig. 1). This area encompasses extensive lowland alluvial plains with swampy ecosystems interspersed with non-flooded areas (Garzón and Gutiérrez 2013). The climate is warm and humid, with a bimodal rainfall pattern, mean annual precipitation of 2917 mm, mean annual temperature of 27.9 °C, and relative humidity of 80 % (IDEAM c2016). The vegetation corresponds to Tropical Moist Forest (Holdridge 1987). Native vegetation has been historically transformed, today remaining less than 15 % of its original coverage (Etter *et al.* 2006, Garcia-Ulloa *et al.* 2012, Garzón and Gutiérrez 2013). Roads are ubiquitous landscape features in the study area, with three two-lane paved roads (NR66, NR45, and DR01)—with an average pavement width of ten m—connecting the city of Barrancabermeja with other regions of the country (Fig. 1). In addition, a four-lane highway road—Gran Vía Yuma (hereafter Yuma road)—has been under construction since 2009 following the alignment of an existing tertiary unpaved road that was primarily used for local traffic and transport of agricultural products to the city of Barrancabermeja (Supplementary Material, Fig. S1). This 30-km-long road corridor seeks to reduce cargo and passenger transportation times, boosting the region's competitiveness, productivity, and economic inputs (ANI c2020).

Data collection

Medium and large-sized native mammals were chosen as study system because in the area: (i) there is information about species richness for this assemblage (Meza-Joya *et al.* 2020), and (ii) these animals are highly prone to vehicle collisions and roadkills (Meza-Joya *et al.* 2015, 2019). The studied mammal assemblage includes species with different mobility abilities and movement behaviours; therefore, for the analyses I used nine functional groups (Fig. 2) defined by Meza-Joya *et al.* (2020). These groups were delimited based on species-specific traits (trophic category, life-history characteristics, social structure, body size, and environmental sensitivity; for details see Meza-Joya *et al.* 2020) by applying Gower distances (Gower 1966) and the Calinski criterion (Calinski and Harabasz 1974). I also selected twelve environmental variables representing landscape features (Table 1) believed to influence animal displacements (Brady *et al.* 2011, Assis *et al.* 2019, Silva *et*

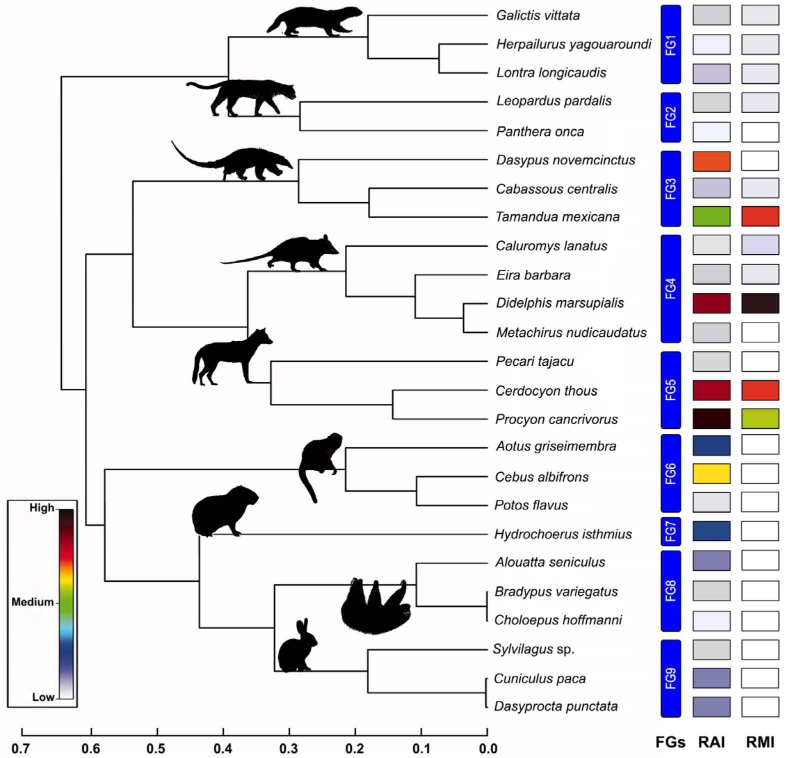

Figure 2. Functional diversity dendrogram grouping medium and large-sized mammals in the study area. The nine main functional groups (FG) used for the analyses are shown in decreasing order. These groups are roughly defined as terrestrial mesocarnivores (FG1), terrestrial apex carnivores (FG2), mid-sized terrestrial omnivores/semiarboreal insectivores (FG3), mid-sized semiarboreal omnivores (FG4), medium and large-sized terrestrial omnivores (FG5), mid-sized arboreal frugivores (FG6), large-sized semiacuatic herbivores (F7), large-sized arboreal frugivores/folivores (F8), medium and large-sized terrestrial herbivores/frugivores (FG9). Relative Road Mortality Index (RMI) was taken from Meza-Joya **et al.** (2019) and Relative Abundance Index (RAI) was estimated based on data from Meza-Joya **et al.** (2020).

al. 2020), regardless of the reasons for movement or the potential response of species or individuals towards fragmentation or matrix effects.

To apply the RPI, I divided the Yuma road into 30 locations separated by 1-km, where the influence of each predictor variable on road permeability was assessed. To capture the potential influence of habitat amount in the surrounding landscape on species navigability (Plante *et al.* 2019), I evaluated each variable within a 200 m-radius (sampling window; Supplementary Material, Fig. S2). This scale was chosen because it corresponds to the smallest radius at which roadkill aggregations occur on other roads in the study area (Meza-Joya *et al.* 2019). Larger scales were avoided to prevent overlap between adjacent locations and control for non-independence in permeability data. I performed a field assessment of the potential influence of each landscape variable on road permeability for each functional group at each location. Then, I contacted via email eight expert mastozoologist from different institutions (non-governmental organisations and academic institutions) to validate field observations. Five experts responded to the call and three agreed to participate in the knowledge elicitation exercise (see acknowledgements). The elicitation process was conducted through individual online interviews based on a questionnaire designed to assess road permeability and supporting information, including updated satellite imagery (CNES/Airbus 2020) from Google Earth Pro (https://www.google.com/earth) for each sampling window (Supplementary Material, Fig. S2). Analyses were made using a ‘consensus variable influence matrix’ resulting from aggregating knowledge statements of experts from the elicitation process.

Data analyses

Experts’ opinions about the influence of each variable on road permeability for each functional group at each location (sampling window) were coded as follows: −1 when it was negative, 1 when it was positive, 0 when it was indifferent, and NA when it was absent or not available in that location (Assis *et al.* 2019). I quantified among-expert variability (i.e., uncertainty) as the number of experts disagreeing about the influence of a given variable on habitat permeability divided by the number of locations where it was assessed. Lower values (near to 0) indicate low uncertainty, while higher values (close to 1) indicate high uncertainty. I calculated the RPI for each functional group and the whole studied mammal assemblage (average value) using the consensus matrix resulting from the expert knowledge elicitation process. Lower RPI values (near to −1) indicate locations with reduced road and landscape permeability, while higher values (close to 1) indicate highly permeable locations where more roadkills are expected (Assis *et al.* 2019). The relative influence of each variable was calculated for each functional group and the overall mammal assemblage (average magnitude). The resulting RPI values were mapped to detect differences among functional groups and identify frequently crossed locations (i.e., potential roadkill hotspots). Estimates were made using the R code provided by Assis *et al.* (2019). I checked for Pearson’s correlations between functional groups using a scatterplot matrix of RPI values. The relationship between species’ roadkill rate (Road Mortality Index, RMI) and abundance (Relative Abundance Index, RAI) was assessed with non-parametric Spearman correlation (raw data) and

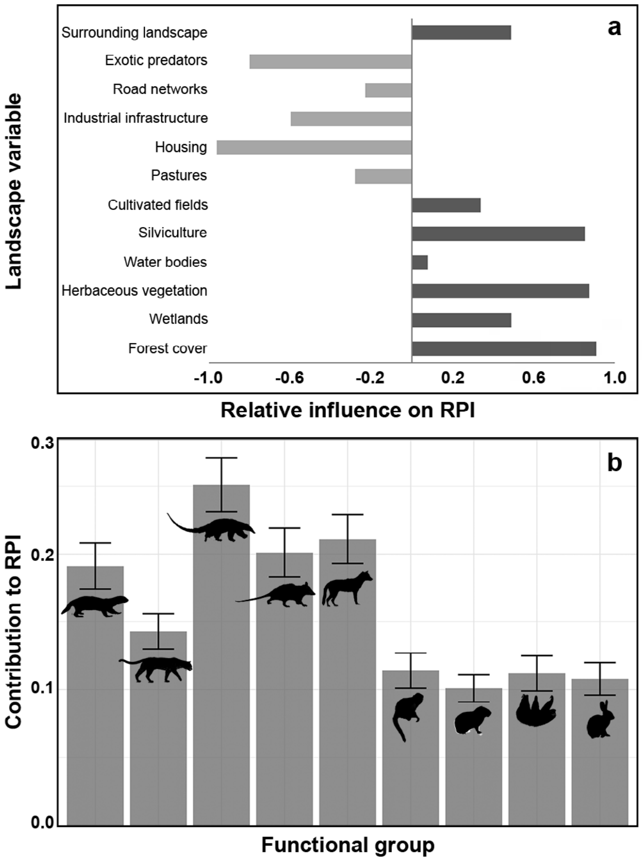

Figure 3. Influence of landscape attributes on road permeability and importance of each functional group to overall permeability. **a.** Relative influence of landscape variables on overall road permeability determined throughout expert opinion elicitation, varying between −1 and 1. Signs (−) for negative and (+) for positive influence. **b**. Relative contribution of each functional group to overall Road Permeability Index (RPI). Bars represent mean values across locations, and whiskers represent standard errors.

linear regression (log-transformed data) using data from Meza-Joya *et al.* (2019, 2020), respectively. All statistical analyses were performed using R environment (R Core Team c2020).

RESULTS

Expert knowledge validation of field data was highly consistent (uncertainty ≤ 0.2), except for complex and hard-to-assess variables such as 'housing' and 'exotic predators' (Supplementary Material, Fig. S3). As expert knowledge elicitation was conducted remotely, a higher weight was given to field observation for these variables but in agreement with the expert panel. Overall, forest cover had the strongest positive influence on road permeability, followed by the presence of herbaceous vegetation and silviculture (Fig. 3a). Conversely, road permeability is negatively influenced by exotic predators (dogs), housing, and industrial infrastructure. As expected, the influence of each predictor variable on road permeability differed among functional groups (Supplementary Material, Fig. S4). Regarding the relative importance of each functional group (FG) to overall permeability, our analysis showed that groups including terrestrial, semiarboreal, and habitat and diet generalist species (e.g., FG3–5), presented the highest contribution to overall road permeability, while groups including arboreal and habitat specialist species (e.g., FG6–9) presented the lowest contribution (Fig. 3b).

Mean RPI values considering all functional groups were positive in most sampled sites (24 windows), while the remaining six presented a negative direction, although the magnitudes varied (Fig. 4). Negative values were related to high-density housing and industrial infrastructure located around the periphery of the city of Barrancabermeja. In contrast, high positive values were largely related to forest cover and wetlands. A gradient of possibly auto-correlated RPI values was observed along the southern stretch of the road, where it disrupts a large forested area. The RPI identified six highly permeable locations for animal movement, indicating more frequently crossed locations where more roadkills are expected (Fig. 4). Overall, RPI values were highly variable across functional groups (Supplementary Material, Fig. S5) but in most cases highly correlated among them (Supplementary Material, Fig. S6). Functional groups including arboreal species showed

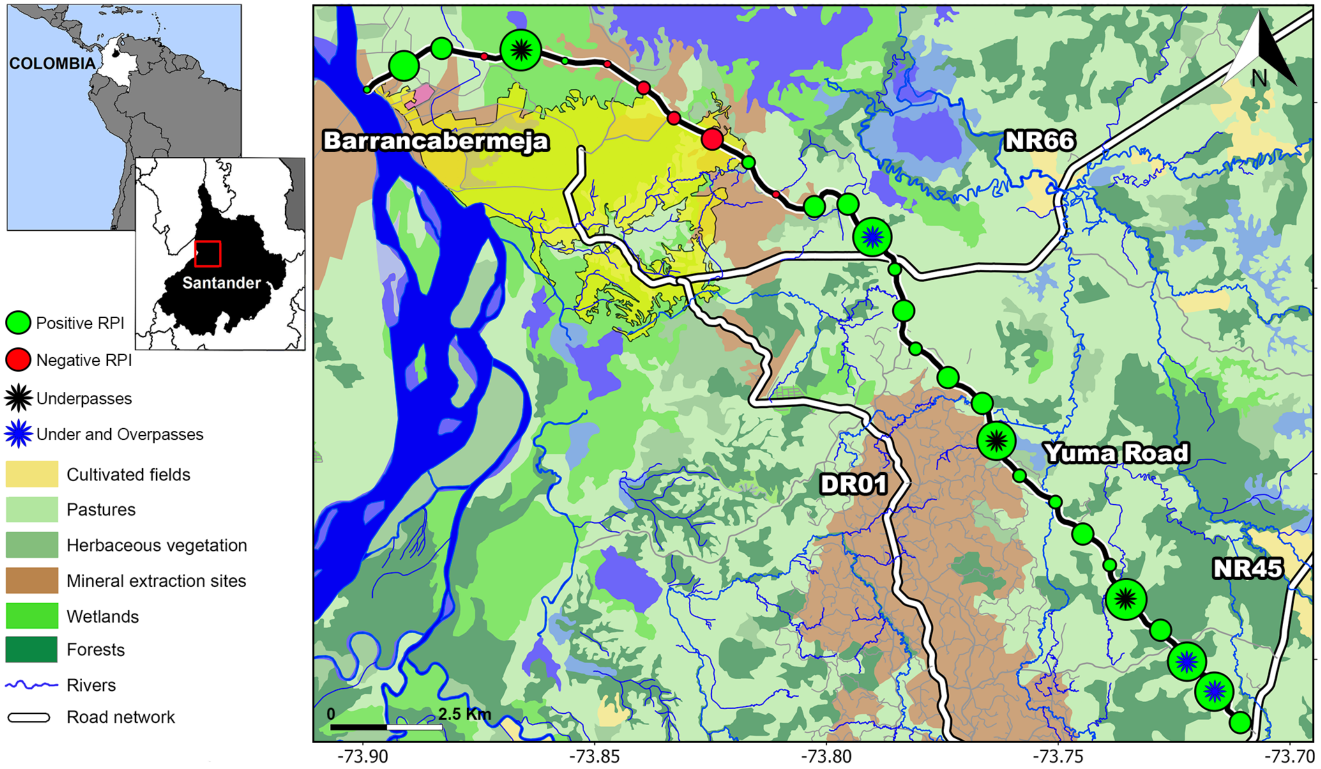

Figure 4. Mean Road Permeability Index (RPI) for each location analysed. Red and blue represent negative and positive RPI values, respectively. Circle size represents the magnitude of RPI.

lower Pearson correlation values ($r < 0.6$) when compared with those including terrestrial species. Correlations were higher than 0.8 between all other functional groups. There was a significant positive relationship between RAI and RMI values (Spearman's rho = 0.76; $P = 0.01$; linear regression adjusted $R^2 = 0.87$, $P < 0.001$).

DISCUSSION

Roads are usually considered homogeneous linear structures in environmental risk assessments, which may cause their effects on landscape connectivity and wildlife to be greatly underestimated; therefore, challenging the effectiveness of environmental impact studies to make qualified decisions aimed at avoiding, mitigating, monitoring, and compensating for any potential adverse impact on biodiversity (Viloria-Villegas *et al.* 2018). This is exemplified in the environmental impact study for the licencing and construction of the Yuma road, which proposed the construction of wildlife crossing structures to avoid 'increasing vehicular traffic on faunal populations' (see Resolution 0829 of 2016, ANLA c2019) but lacks robust conceptual and methodological approaches to guarantee their effectiveness in reducing wildlife mortality and restoring or enhancing landscape connectivity.

This study highlights the suitability of expert-based approaches such as the RPI for providing early and rapid management guidelines while other empirical data such as roadkill counts and population trends are collected (Assis *et al.* 2019). One of the most interesting applications of this index is the reliable and fast identification of target species or faunal groups for mitigation strategies. For the medium and large-sized mammal assemblage analysed here, functional groups including mainly terrestrial, semiarboreal, and habitat and diet generalist species (i.e., FG3–5) presented higher contribution values to overall road permeability, indicating that they represent priority targets to be considered when designing mitigation actions (Fig. 3b). These results are not surprising as these functional groups include abundant species with high roadkill rates on the roads of the study area (Meza-Joya *et al.* 2019, 2020; Fig. 2) such as *Didelphis marsupialis* Linnaeus, 1758, *Tamandua mexicana* (Saussure, 1860), *Cerdocyon thous* (Linnaeus, 1766), and *Procyon cancrivorus* (Cuvier, 1798).

Table 1. Description of landscape variables used to calculate the Road Permeability Index (RPI) for Yuma road. Although the variable 'exotic predators' is not a landscape feature, it was included because the presence of dogs affects fauna movement patterns (Vanak and Gompper 2010).

Variable	Description
Forest cover	Native Tropical Moist Forest, in some cases highly disturbed, small patches (<1 ha)
Wetlands	Lowlands flooded by water, either permanently or seasonally, usually with vegetation on it
Herbaceous vegetation	Non-woody vegetation (herbs) and shrubs, sometimes with sparse arboreal elements on it
Water bodies	Rivers or watercourses, a lake, a lagoon
Silviculture	Areas with cultivation of trees, mainly rubber (*Hevea brasiliensis*)
Cultivated fields	Agricultural areas with annual or perennial crops
Pastures	Grassland areas for cattle growing, sometimes with weeds and sparse trees on it
Housing	Any type of construction for people to live in, but with a certain degree of aggregation
Industrial infrastructure	Any facility required to support industrial activities, mainly oil industry infrastructure
Road networks	Interconnected roads and other infrastructure (e.g., highways, primary and secondary roads)
Exotic predators	Usually the presence of owned dogs, sometimes rural free-ranging dogs
Surrounding landscape	Native habitat surrounding each sampling window

The RPI also provide a consistent approach for identifying management strategies depending on the proposed mitigation goals (e.g., to increase habitat connectivity and road permeability and/or prevent roadkills). Clearly, mitigation should not solely focus on reducing mortality counts, as it underestimates or neglects other critical processes affecting wildlife population dynamics, such as habitat availability and connectivity. Based on RPI results (Fig 4, Supplementary Material, Fig. S4), an integrated multi-scale management strategy appears to be the best choice to diminish the impact caused by the Yuma road on biodiversity. From a local scale, mitigation should be focused on installing crossing structures, overpasses and underpasses—the latter accompanied by sufficiently long guide fencing (Plante *et al.* 2019)—in locations with high RPI values to minimise roadkills and improve landscape connectivity (Fig. 4). From a regional scale, mitigation should be focused on increasing habitat connectivity by protecting, restoring, and connecting existing forest patches as they were identified as critical for road permeability (Fig. 3a). Furthermore, environmental education campaigns to improve driver attitudes to benefit wildlife conservation are desirable as complementary actions.

Although the results of this work support the utility of the RPI for road mitigation planning and management, some crucial points should be considered before its application. The RPI requires a rigorous knowledge elicitation process to generate reliable outputs applicable for decision-making; thus, surveying an expert panel for each taxon, group, or species of interest (this index can be applied to single species) is highly recommended (Assis *et al.* 2019). Expert knowledge uncertainty must be addressed to improve reproducibility and transparency (Drescher and Edwards 2019). Empirical knowledge of species abundances and roadkill rates is also desirable for RPI validation. Although the RPI could be calculated as a continuous variable along the road, it is recommendable to use an adequate scale to avoid or at least diminish spatial correlation while including as many locations as possible to accurately estimate the relative contributions of variables to overall road permeability (Assis *et al.* 2019).

Some complex variables might be problematic as they are hard to assess objectively, leading experts to infer their effects less consistently. This is the case of the variable 'housing', whose effects vary depending on factors like people's attitudes toward wildlife and human-derived food subsidies to wild animals (Newsome *et al.* 2015). Similarly, the effects of 'exotic predators' depend on dog densities and how they interact with wildlife being either predators, prey or competitors (Vanak and Gompper 2010). Seasonality may also influence how some variables affect animal movements. For instance, the presence of wetlands positively affects the movement of most species during the dry season but may constitute an impassable barrier when flooded. Access to resources and reproductive patterns may vary seasonally, influencing animal movement and increasing mortality risk on roads of the study area (Meza-Joya *et al.* 2019). Despite these facts, most variables considered here were easily spatialised and assessed, favouring the utility of this index for road planning strategies for wildlife conservation. Furthermore, integrating expert knowledge with empirical data is essential to refine the inferences about the relative contributions of variables on permeability and gain wider acceptance of study results.

There is an urgent need to strengthen the technical quality of environmental studies and the evaluation system used by national environmental agencies to effectively address the impacts of roads on biodiversity (Viloria-Villegas *et al.* 2018). Environmental impact studies should include clearly stated questions and objectives, adequate sampling—at appropriate spatial scales—and rigorous analyses that serve as the basis for making qualified decisions (Teixeira *et al.* 2016). Methodological transparency and robustness are critical for risk assessments to accurately foresee outcomes and allow for risk inferences validation and repeatability. Road projects and concessions should also be required to systematically collect open-access roadkill data for further environmental studies and road ecology research (Schwartz *et al.* 2020). Although roadkill is the most evident effect of roads on biodiversity, many others (e.g., habitat loss and fragmentation, rapid spread of alien species and diseases) need to be considered by road managers and policy and decision-makers. Indeed, the absence of roadkills might indicate population-level effects (e.g., population depletion and subdivision) rather than low impacts or successful mitigation (van der Ree *et al.* 2007, Ascensão *et al.* 2019). Thus, knowledge about the status of wildlife populations (e.g., sizes and vital rates) inhabiting roadscapes or adjacent habitats may result in integral assessments of the impacts of roads on biodiversity (van der Ree *et al.* 2007). Nevertheless, mitigation plans should be the object of a continuous monitoring process to ensure that mitigation measures are properly implemented, operated, and maintained (Riffat and Khan 2006, Toro *et al*. 2010).

SUPPLEMENTARY MATERIAL

Figures S1–S6 are presented as supplementary material.

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CONFLICT OF INTEREST

No competing interests declared.

LITERATURE CITED

[ANI] Agencia Nacional de Infraestructura Colombia. c2020. Ficha proyecto 4G: Bucaramanga–Barrancabermeja–Yuma. [Revisada en: 10 feb 2020]. https://www.ani.gov.co

[ANLA] Agencia Nacional de Licencias Ambientales Colombia Infraestructura. c2019. Gaceta: Resolución 0829 del 8 Agosto 2016. [Revisada en: 21 may 2019]. http://portal.anla.gov.co

Ascensão F, Kindel A, Teixeira FZ, Barrientos R, D'Amico M, Borda-de-Água L, Pereira HM. 2019. Beware that the lack of wildlife mortality records can mask a serious impact of linear infrastructures. Glob. Ecol. Conserv. 19:e00661. doi: https://doi.org/10.1016/j.gecco.2019.e00661

Assis JC, Giacomini HC, Ribeiro MC. 2019. Road Permeability Index: Evaluating the heterogeneous permeability of roads for wildlife crossing. Ecol. Indic. 99:365–374. doi: https://doi.org/10.1016/j.ecolind.2018.12.012

Beyer HL, Gurarie E, Börger L, Panzacchi M, Basille M, Herfindal I, Van Moorter BR, Lele S, Matthiopoulos J. 2016. 'You shall not pass!': quantifying barrier permeability and proximity avoidance by animals. J. Anim. Ecol. 85(1):43–53. doi: https://doi.org/10.1111/1365-2656.12275

Brady MJ, McAlpine CA, Possingham HP, Miller CJ, Baxter GS. 2011. Matrix is important for mammals in landscapes with small amounts of native forest habitat. Landsc. Ecol. 26:617–628. doi: https://doi.org/10.1007/s10980-011-9602-6

Calinski T, Harabasz J. 1974. A dendrite method for cluster analysis. Commun. Stat. Theory Methods 3(1):1–27. doi: https://doi.org/10.1080/03610927408827101

de la Ossa-V J, Galván-Guevara S. 2015. Registro de mortalidad de fauna silvestre por colisión vehicular en la carretera Toluviejo–ciénaga La Caimanera, Sucre, Colombia. Biota Colomb. 16(1):67–77.

Doherty TS, Driscoll DA. 2017. Coupling movement and landscape ecology for animal conservation in production landscapes. Proc. R. Soc. B 285:20172272. doi: https://doi.org/10.1098/rspb.2017.2272

Drescher M, Edwards RC. 2019. A systematic review of transparency in the methods of expert knowledge use. J. Appl. Ecol. 56(2):436–449. doi: https://doi.org/10.1111/1365-2664.13275

Etter A, McAlpine C, Pullar D, Possingham H. 2006. Modelling the conversion of Colombian lowland ecosystems since 1940: drivers, patterns and rates. J. Environ. Manage. 79(1):74–87. doi: https://doi.org/10.1016/j.jenvman.2005.05.017

Garcia-Ulloa J, Sloan S, Pacheco P, Ghazoul J, Koh LP. 2012. Lowering environmental costs of oil-palm expansion in Colombia. Conserv. Lett. 5(5):366–375. doi: https://doi.org/10.1111/j.1755-263X.2012.00254.x

Gardiner MM, Riley CB, Bommarco R, Öckinger E. 2018. Rights-of-way: a potential conservation resource. Front. Ecol. Environ. 16(3):149–158. doi: https://doi.org/10.1002/fee.1778

Garzón NV, Gutiérrez JC. 2013. Deterioro de humedales en el Magdalena Medio: un llamado para su conservación. Bogotá DC: Fundación Alma e Instituto de Investigación de Recursos Biológicos Alexander von Humboldt.

Gower JC. 1966. Some distance properties of latent root and vector methods used in multivariate analysis. Biometrika 53(3-4):325–338. doi: https://doi.org/10.1093/biomet/53.3-4.325

Grilo C, Molina-Vacas G, Fernández-Aguilar X, Rodriguez-Ruiz J, Ramiro V, Porto-Peter F, Ascensão F, Román J, Revilla E. 2018. Species-specific movement traits and specialization determine the spatial responses of small mammals towards roads. Landsc. Urban Plan. 169:199–207. doi: https://doi.org/10.1016/j.landurbplan.2017.09.014

Grilo C, Sousa J, Ascensão F, Matos H, Leitão I, Pinheiro P, Costa M, Bernardo J, Reto D, Lourenço R, Santos-Reis M, Revilla E. 2012. Individual spatial responses towards roads: implications for mortality risk. PLoS One 7(9):e43811. doi: https://doi.org/10.1371/journal.pone.0043811

Holdridge L. 1987. Ecología basada en zonas de vida. San José: Instituto Interamericano de Cooperación para la Agricultura.

[IDEAM] Instituto de Hidrología, Meteorología y Estudios Ambientales. c2019. Promedios climatológicos. [Revisada en: 15 may 2019]. http://www.ideam.gov.co

Jaeger JAG, Bowman J, Brennan J. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecol. Model. 185(2-4):329–348. doi: https://doi.org/10.1016/j.ecolmodel.2004.12.015

Nathan R, Getz WM, Revilla E, Holyoak M, Kadmon R, Saltz D, Smouse PE. 2008. A movement ecology paradigm for unifying organismal movement research. Proc. Natl. Acad. Sci. USA. 105:19052–19059. doi: https://doi.org/10.1073/pnas.0800375105

Meza-Joya FL, Ramos-Pallares E, Cardona D, Torres M. 2015. Atropellamiento vehicular de mamíferos silvestre en el Magdalena Medio Santandereano. Mammal. Notes 2:190

Meza-Joya FL, Ramos E, Cediel F, Martínez-Arias V, Colmenares J, Cardona D. 2018. Predicted distributions of two poorly known small carnivores in Colombia: the greater grison and striped hog-nosed skunk. Mastozool. Neotrop. 25(1):89–105. doi: https://doi.org/10.31687/saremMN.18.25.1.0.09

Meza-Joya FL, Ramos E, Cardona D. 2019. Spatio-temporal patterns of mammal road mortality in Middle Magdalena Valley, Colombia. Oecologia Aust. 23(3):575–588. doi: https://doi.org/10.4257/oeco.2019.2303.15

Meza-Joya FL, Ramos E, Cardona D. 2020. Forest fragmentation erodes mammalian species richness and functional diversity in a human-dominated landscape in Colombia. Mastozool. Neotrop. 27(2):338–348. https://doi.org/10.31687/saremMN.20.27.2.0.06

Monroy MC, de La Ossa-Lacayo A, de La Ossa-V J. 2015. Tasa de atropellamiento de fauna silvestre en la vía San Onofre-María la Baja, Caribe Colombiano. Rev. Asoc. Col. Cienc. 27(1): 88–95. doi: https://doi.org/10.47499/revistaaccb.v1i27.106

Newsome TM, Dellinger JA, Pavey CR, Ripple WJ, Shores CR, Wirsing AJ, Dickman CR. 2015. The ecological effects of providing resource subsidies to predators. Global Ecol. Biogeogr. 24(1):1–11. doi: https://doi.org/10.1111/geb.12236

Payan E, Soto C, Díaz-Pulido A, Benítez A, Hernández A. 2013. Wildlife road crossing and mortality: lessons for wildlife friendly road design in Colombia. Proceeding ICOET 2013:2–18.

Plante J, Jaeger JAG, Desrochers A. 2019. How do landscape context and fences influence roadkill locations of small and medium-sized mammals? J. Environ. Manage. 235:511–520. doi: https://doi.org/10.1016/j.jenvman.2018.10.093

R Core Team. 2020. R: A language and environment for statistical computing. Version 4.0.3. Vienna, Austria: R Foundation for Statistical Computing.

Ramos E, Meza-Joya FL. 2018. Reptile road mortality in a fragmented landscape of the Middle Magdalena Valley, Colombia. Herpetol. Notes 11:81–9.

Ramp D, Caldwell J, Edwards KA, Warton D, Croft DB. 2005. Modelling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. Biol. Conserv. 126(4):474–490. doi: https://doi.org/10.1016/j.biocon.2005.07.001

Reding DM, Cushman SA, Gosselink TE, Clark WR. 2013. Linking movement behavior and fine-scale genetic structure to model landscape connectivity for bobcats (*Lynx rufus*). Landsc. Ecol. 28:471–486. doi: https://doi.org/10.1007/s10980-012-9844-y

Riffat R, Khan D. 2006. A review and evaluation of the environmental impact assessment process in Pakistan. J. Appl. Sci. Environ. Sanit. 1:17–29.

Rincón-Aranguri M, Urbina-Cardona N, Galeano SP, Bock BD, Páez VP. 2019. Road kill of snakes on a highway in an Orinoco ecosystem: Landscape factors and species traits related to their mortality. Trop. Conserv. Sci. 12:1–18. https://doi.org/10.1177/1940082919830832

Silva I, Crane M, Savini T. 2020. High roadkill rates in the Dong Phayayen-Khao Yai World Heritage Site: conservation implications of a rising threat to wildlife. Anim. Conserv. 23(4):466-478. doi: https://doi.org/10.1111/acv.12560

Schwartz ALW, Shilling FM, Perkins SE. 2020. The value of monitoring wildlife roadkill. Eur. J. Wildl. Res. 66:18. doi: https://doi.org/10.1007/s10344-019-1357-4

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. Trop. Conserv. Sci. 9(1):34–42. doi: https://doi.org/10.1177/194008291600900104

Toro J, Requena I, Zamorano M. 2010. Environmental impact assessment in Colombia: Critical analysis and proposals for improvement. Environ. Impact. Assess. Rev. 30(4):247–261. doi: https://doi.org/10.1016/j.eiar.2009.09.001

Vanak AT, Gompper ME. 2010. Interference competition at the landscape level: the effect of free-ranging dogs on a native mesocarnivore. J. Appl. Ecol. 47(6):1235–1232. doi: https://doi.org/10.1111/j.1365-2664.2010.01870.x

Viloria-Villegas MI, Cadavid L, Awad G. 2018. Metodología para evaluación de impacto ambiental de proyectos de infraestructura en Colombia. Cienc. Ing. Neogranad. 28(2):121–156. doi: https://doi.org/10.18359/rcin.2941

van der Ree R, van der Grift EA, Gulle N, Holland K, Mata C, Suarez F. 2007. Overcoming the barrier effect of roads: how effective are mitigation strategies? An international review of the use and effectiveness of underpasses and overpasses designed to increase the permeability of roads for wildlife. Proceeding ICOET 2017:423–431