RSG REFERENCE 18847-1

Assessing Roadkill Events to Reduce Wildlife Mortality in Roads of the Mid-Magdalena Valley, Colombia: Mammals as Study Case

Overall aim:

The aim of this project was (1) identify mammal species more susceptible to vehicle collisions, (2) assess the main drivers that influence wildlife road mortalities, (3) identify roadkill hotspots (i.e., areas where wildlife mortality is high), (4) quantify connectivity from the landscape (i.e., areas used by the species as dispersal corridors), and (5) promote effective community engagement to wildlife-vehicle conflict.

Authors:

Fabio Leonardo Meza-Joya
Coordinador de Programas de Investigación
Aso ciación Colombia Endémica
E-mail: fleonardo78@gmail.com

Eliana Ramos Pallares
Investigadora
Asociación Colombia Endémica
E-mail: elianar86@gmail.com

Diana Marcela Cardona Ramírez
Investigadora
Asociación Colombia Endémica
E-mail: dianicardoni@gmail.com

ATROPELLAMIENTO VEHICULAR DE FAUNA SILVESTRE RUTA 45

The Rufford Foundation
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COLOMBIA ENDÉMICA

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Project partners & Collaborators

During this project we had the invaluable opportunity to meet a lot of interesting and caring people including scientists, conservationists, teachers, students, and community leaders with a strong environmental focus. In this sense, we wish to extend our acknowledgements to everyone that participated in any way in our project. None of this work would have been possible without the trust and financial support that The Rufford Foundation deposited on our team. We are grateful to Asociación Colombia Endémica who was an important input in terms of additional financial support. We thank Carlos Hernández, Gloria Pallares, Ramón Ramos, Gabriela Cáceres, and Sergio Pallares for assistance during surveys and educational activities. Special thanks goes to Policía Nacional de Colombia for their cooperation during sensitization campaigns on roads.

Summary

Wildlife-vehicle collisions kill millions of wild animals around the world, however this number could be underestimated because the absent of systematic monitoring of roadkill events. In Colombia few studies have assessed wildlife mortality on roads, but none has intended to identify the factors promoting this phenomenon. In the absent of this kind of studies, we are still far to implement effective corrective actions aimed to mitigate the road-wildlife conflict. Wild mammal mortality on roads is a problematic with profound deleterious effects, including reductions in population sizes, increases local extinction, and loss of exosystemic functionality. During one-year period, we recorded a total of 419 road killed mammals belonging to 12 species. The road section with the highest number of roadkill events was the four-lane highway. Overall, this road presents the highest roadkill rate compared to the other roads in Colombia. Spatial distribution of roadkill's was non-random, indicating that mortalities were aggregated in some locations, some of which match with areas of high connectivity. Based on our results, as well as the social and economic context of the study region, we consider that mitigation measures should focus mainly on (1) designing and promoting effective educational activities among adults and children to increase public awareness and to promote a behavioural change among drivers towards the protection of wildlife, (2) installing mitigation measures involving speed bumps, road wildlife signals, and wildlife crossing structures based on studies evaluating the critical points for their implementation.

Overall aim

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Materials and methods

Study Area

The Ruta del Sol highway extends through more than 1,000 km, from Villeta (Cundinamarca department) to Ciénaga (Magdalena department), passing through the Middle Magdalena Valley. The stretch investigated is located between corregimiento La Lizama (Barrancabermeja municipality, Santander department) and the municipality of Aguachica (Cesar department), with 83.8 km of two-lane and 61.9 km of four-lane highway (**Figure 1**). This region comprises extensive lowland alluvial plains with swampy ecosystems interspersed with non-flooded areas (Garzón and Gutiérrez 2013). The entire basin is located on the warm altitudinal zone, with a mean annual temperature that oscillates between 24 and 28 °C, a bimodal rainfall regime, and a mean annual precipitation near to 3,000 mm (Garzón and Gutiérrez 2013).

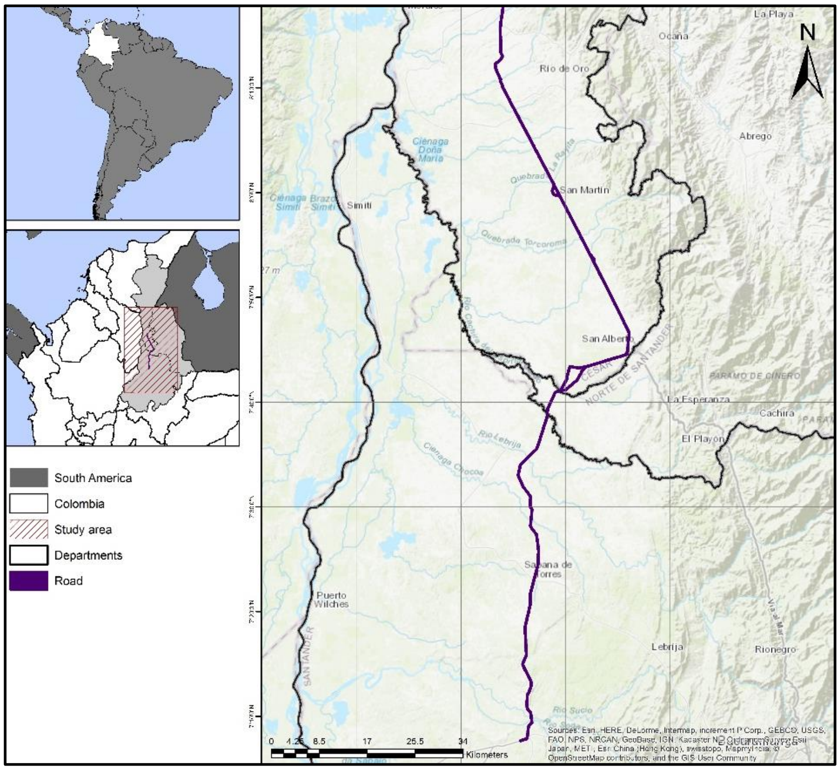

Figure 1. Map of the study area in the Middle Magdalena Valley (Colombia)

Road Surveys

Roadkill surveys were conducted by two observers (driver and passenger) driving a car at slow speed (≤ 40 km/h), twice per month from December 2017 to December 2018 including rainy and dry seasons. The observers drove along the roadside searching on both sides of the studied roads for mammal mortalities. Dead animals were removed from the road to avoid subsequent recounts. Road killed animals were identified in field to species level using the taxonomy arrange of Wilson and Reeder (2005). Animals severely deteriorated were categorized as unidentified taxa.

Roadkill Estimates

Mammal roadkill diversity was estimated as the number of species (S) found dead on the surveyed road segments. We used a Mann-Whitney U test to determine if differences of observed counts of roadkill among climatic seasons were statistically significant ($p < 0.05$). Mortality rates (i.e., per day and per km) were estimated for each road using Siriema (Spatial Evaluation of Road Morality) Software v2.0 (Coelho et al., 2014). To avoid overestimations in mortality rates, we used the mean values for searchers' efficiency (i.e., 0.47) and for removal time characteristic for mammals (i.e., 4.93 days) estimated by Teixeira et al. (2013). Our estimates of daily mortality rates were multiplied by 365 to generate an annual estimate. For practical purposes, we compare our results with those from other studies estimating a relative road mortality rate by dividing the number of roadkill's into the sampling effort (i.e., the overall number of km surveyed).

Roadkill Hotspots

The dispersion of roadkill events on different spatial scales was evaluated using a modified Ripley's K (Coelho et al., 2008) with an initial radius of 100 m, a radius increases of 400 m, confidence level of 95%, and 1,000 Monte Carlo simulations, following Teixeira et al. (2013b). Values above the confidence limit obtained from the simulations indicate scales with significant aggregations (Coelho et al., 2014). To detect the road sections with high mortality rates (hotspots), we implemented the 2D HotSpot Identification analysis. For this, each road was divided into 200 m segments and a circle of 300 m radius (i.e., the smallest radius at which the roadkill aggregations were significant in 2D Ripley's K test). The significance of potential aggregations was evaluated at a confidence level of 95% and 1,000 simulations. For analyses in this section we used Siriema v2.0 (Coelho et al., 2014).

Factors Explaining Roadkill Occurrence

We used multiple logistic regression to determine which landscape and roadway characteristics were important in the occurrence of roadkill. Models were designed using presence/absence of roadkill's as dependent variables, and landscape and road characteristics as independent variables. A null model with a constant (intercept = 1) was included (**Table 1**). We selected the best-fitted model using Akaike's Information Criterion with correction for small samples. Analyses were run using R version 3.3.1 (R Development Core 2016).

Table 1. Competing models used in Akaike's Information Criterion (AIC) selection, where dependent variables were presence or absence of roadkill's in the Ruta del Sol highway

Model	Independent variables
1	Herbaceous vegetation
2	Herbaceous vegetation + pastures
3	Herbaceous vegetation + Forest
4	Herbaceous vegetation + Distance of the nearest river
5	Herbaceous vegetation + Distance of the nearest curve
6	Agriculture
7	Agriculture + Urban areas
8	Agriculture + Forest
9	Agriculture + Distance of the nearest river
10	Agriculture + Distance of the nearest curve
11	Pastures
12	Pastures + Forest
13	Pastures + Distance of the nearest river
14	Pastures + Distance of the nearest curve
15	Forest
16	Forest + Distance of the nearest river
17	Forest + Distance of the nearest curve
18	1

Landscape Connectivity

We created a resistance-surface for the study area using data from: i) Corine Land Cover vector data of Instituto Geográfico Agustín Codazzi (http://www.igac.gov.co), ii) Normalized

Difference Vegetation Index (NDVI; Bailey et al., 2004), (iii) proximity maps (Euclidean distance) to rivers and roads, and (iv) forest and non-forest map of the Environmental Information System of Instituto de Hidrología, Meteorología y Estudios Ambientales (www.ideam.gov.co). We reclassified data in each map as a function of dispersal-cost (1 = permeable, 100 = impermeable) to generate resistance-surface. We mapped the omnidirectional landscape connectivity using the advanced mode option in Circuitscape software (Mcrae et al., 2008).

Results

Roadkill Estimates

We recorded 419 road killed mammals belonging to 12 species. The most frequently road killed species were (**Figure 2**): *Tamandua mexicana* (n = 160; RMI = 0.382), *Cerdocyon thous* (n = 99; RMI = 0.236), *Didelphis marsupialis* (n = 93; RMI = 0.222), and *Procyon cancrivorus* (n = 49; RMI = 0.117; **Table 2**). Together, these species represent about 96% of the mammal road mortalities in the study area.

Table 2. Mammals recorded as road killed during monitoring surveys and the road mortality index (RMI). Bold type indicates the most frequently road killed species

Taxa	Road kill	RMI
CARNIVORA		
Canidae		
Cerdocyon thous (Linnaeus, 1766)	99	**0.236**
Felidae		
Leopardus pardalis (Linnaeus, 1758)	2	0.005
Mustelidae		
Galictis vittata (Schreb, 1776)	2	0.005
Procyonidae		
Procyon cancrivorus (Cuvier, 1798)	49	**0.117**
CINGULATA		
Dasypodidae		
Dasypus novemcinctus (Linnaeus, 1758)	8	0.019
DIDELPHIMORPHIA		
Didelphidae		
Didelphis marsupialis (Linnaeus, 1758)	93	**0.222**
LAGOMORPHA		
Leporidae		
Sylvilagus brasiliensis (Linnaeus, 1758)	2	0.005
PILOSA		
Megalonychidae		
Choloepus hoffmanni (Peters, 1858)	1	0.002
Myrmecophagidae		
Tamandua mexicana (Saussure, 1860)	160	**0.382**
PRIMATES		
Aotidae		
Aotus griseimembra (Elliot, 1912)	1	0.002
Atelidae		
Alouatta seniculus (Linnaeus, 1766)	1	0.002
Cebidae		
Cebus versicolor (Pucheran, 1845)	1	0.002
Total road mortalities	**419**	---

Figure 2. Most frequently road killed mammal species on the study area in Middle Magdalena Valley (Colombia). *Tamandua mexicana* (A), *Cerdocyon thous* (B), *Didelphis marsupialis* (C), *Procyon cancrivorus* (D)

Most of roadkill events occurred during the dry season (Z = 1.89, DF = 1, P = 0.043). There were two roadkill peaks: the first one in May, when 40 animals were found, and a second one in December, when 65 animals were found. The road section with the highest number of roadkill events (**Figure 3a**) and highest roadkill rates was the four-lane highway (n = 237; **Table 3**). Overall, our projections indicate that at least 2,698 wildlife mammals are roadkill each year in the surveyed road.

Table 3. Roadkill rate estimates for the surveyed road during monitoring trips

Section	Roadkill animals	Length (km)	Roadkill rate per km	Roadkill rate per day	Roadkill rate per year
Two-lane	182	83.8	0.04	3.21	1,172
Four-lane	237	61.9	0.07	4.18	1,526
Total	419	145.7	0.05	7.39	2,698

The overall estimates of relative road mortality rate (roadkill's per km) for Ruta del Sol was higher when compared to other studies in Colombia (**Table 4**).

Table 4. Relative road mortality rate (RMR, roadkill's per km surveyed) for roadkill studies including wild mammals in Colombia

Location	Elevation (m)	Roadkill mammals	Total km surveyed	RMR	Source
Middle Magdalena Valley, Santander, Norte de Santander, and Cesar department	70-162	419	3,643	0.115	This study
Middle Magdalena Valley, Santander department	74-100	112	1,200	0.093	Meza-Joya et al. (in preparation)
Andean region, Cordillera Occidental, Cauca department	639-1757	259	4,600	0.056	Castillo et al. (2015)
Caribbean region, Sucre department	14-32	104	2,352	0.044	Monroy et al. (2015)
Caribbean region, Sucre department	45-307	104	19,066	0.005	de la Ossa-Nadjar and de la Ossa-V (2015)
Caribbean region, Sucre department	6-64	121	1,306	0.092	de La Ossa-V and Galván-Guevara (2015)
Caribbean region, Sucre department	45-307	114	9,536	0.012	de la Ossa-Nadjar and de la Ossa-V (2013)

Roadkill Hotspots

The results of Ripley's K analyses showed that spatial distribution for roadkill's was non-random, indicating that mortalities were aggregated in some locations, which correspond to potential road-kill hotspots. 2D HotSpot analyses identified 18 hotspots, six in the two-lane section and 12 in the four-lane section (**Figure 3b**).

Factors Explaining Roadkill Occurrence

Mammal roadkill's were associated with river proximity and forest. Two other models were also considered relevant: (1) including river proximity and herbaceous vegetation, and (2) herbaceous vegetation and forest. All selected models showed a better performance than the null model (**Table 5**).

Table 5. Regression models selected by AICc to explain mammal roadkill's in the study area. Bold type indicates the best-fitted model

Model	AICc
Forest + Distance of the nearest river (16)	**198.3**
Herbaceous vegetation + Distance of the nearest river (4)	215.3
Herbaceous vegetation + Forest (3)	218.7
Intercept (18)	312.2

Landscape Connectivity

Most important current flow are associated to forests patches located on north-western slopes of the Eastern Andes, especially through riparian forests of rivers, and swamps. When there is limitation for access between forest patches, the current flow is forced across non-forested areas (e.g., agriculture, agroforestry, permanent arboreal crops, grasses), despite their high resistance. The studied road does not constitute an impenetrable barrier to the movement of mammals, which influence roadkill events. Most roadkill hotspots intersect with sections of high connectivity that are critical for mammal movement across landscape (**Figure 3b**).

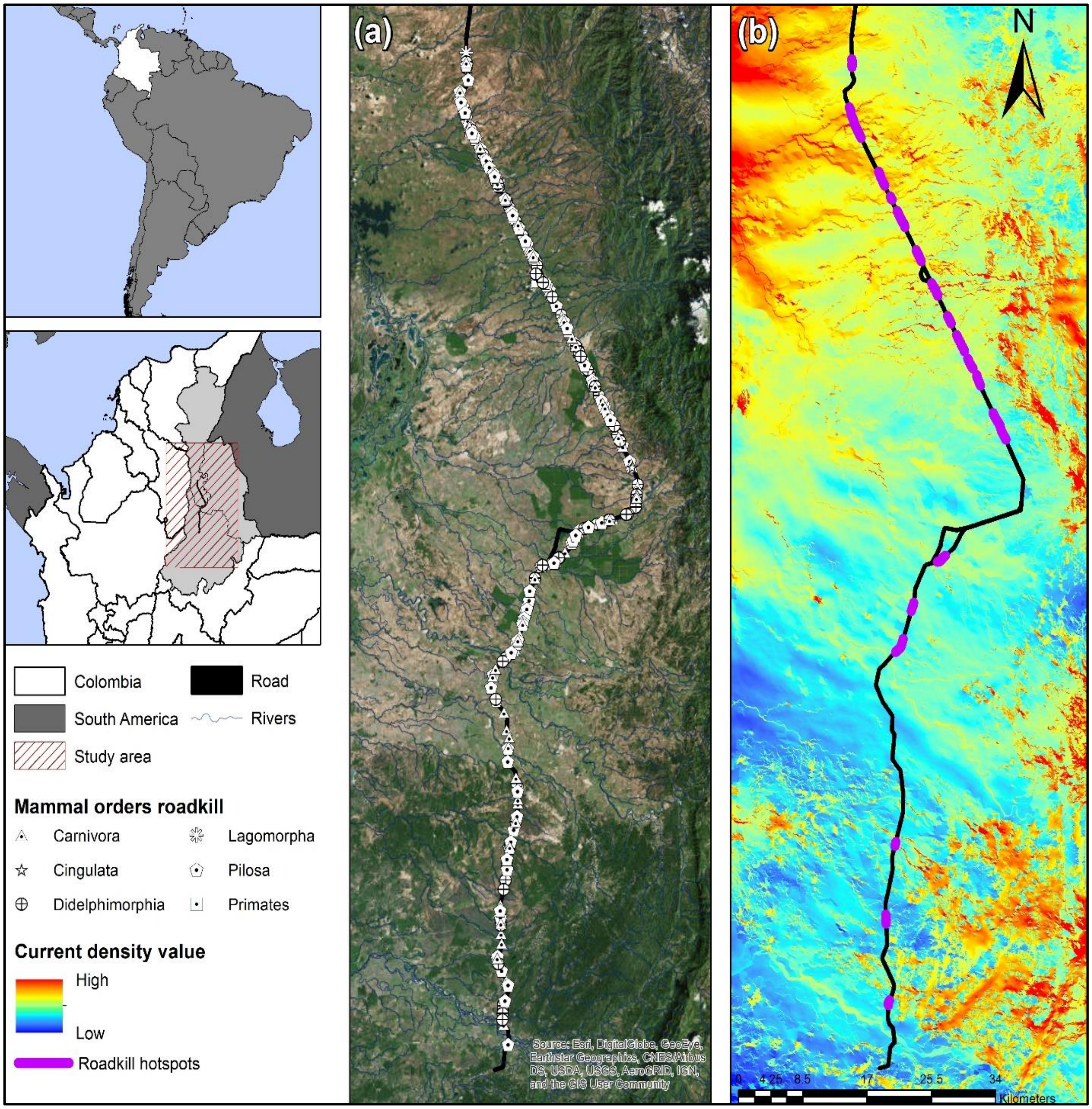

Figure 3. Study area indicating the surveyed road in the Middle Magdalena Valley. Inset: location of the study area in Colombia. (a) Spatial distribution of the roadkill along the studied road. (b) Roadkill hotspots along with connectivity landscape

Communication

The results of our project were disseminated through different communication channels targeting a varied public, including the website of the Red Colombiana de Seguimiento de

Fauna Atropellada (http://www.recosfa.net/), a Facebook Fan Page created for the project (https://www.facebook.com/atropellamientofaunacolombia/), printed materials (e.g., brochures, flyers, adhesives, and Christmas cards; **Figure 4 and 5**), meetings with local stakeholders such as decision makers (Instituto Nacional de Vías), universities, schools, local non-governmental organisations (NGO's), environmental police, transportation companies, students, and teachers; and the scientific community through academic conferences, symposiums, and seminars (**Figure 6**).

People were very receptive with the educational materials and conferences, being amazed by the profound effects of roads on wildlife, participating actively and expressing their concerns and ideas about nature conservancy. All information produced reached local communities in the urban and rural areas, as well as through social media allowing this initiative to be widely spread. The greater significance of these outputs is that young generations and adults will become ambassador conservationists that will keep our conservation messages alive and will transmit them to the next generations.

Figure 4. Brochure with relevant information about roadkill wildlife in Colombia

Fig. 5. Examples of printed material used during sensitization campaigns and educational activities

Figure 6. Examples educational activities and some members of the local communities reached with our work

Conclusion

The mitigation of road-effects on wildlife has become increasingly common in the last years in Colombia, especially with the Colombia's Fourth Generation (4G) road infrastructure program. However, wildlife crossings structures can be very costly and several questions remain regarding how to best determine locations that will optimize mitigation success. As consequence, wildlife roadkill's occurs very often in national roads, even in those where mitigation action has been developed. In this sense, an understanding of roadkill causes and patterns is necessary for successful management actions. Here, we show that the high number of road-killed mammals in the Ruta del Sol, which may significantly affect wildlife populations of this group of animals. Our projections indicate that at least 2,698 wildlife mammals are run over each year in the surveyed segment (i.e., 145, 7 km), which account for only the 13% of the total extension of this road (i.e., 1,071 km). Using alternative methods (i.e., roadkill hotspot identification, landscape connectivity estimation, and logistic regression), we show that forest and rivers with high connectivity associated to roadkill hotspots represent key areas to install mitigation measures (e.g., wildlife crossing structures, warning signals, and speed reducers). In addition, involve local communities in road ecology programmes are crucial to increase public awareness about the urgency and importance of wildlife conservation on national roads, optimizing both conservation benefits and limited funding. Lastly, is urgent a stronger national government legislation aimed to avoid, minimise, mitigate and compensate the negative effects of roads on wildlife.

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Appendices

Appendix 1. Certificates of participation in scientific and science events

LA ASOCIACIÓN COLOMBIANA DE CIENCIAS BIOLÓGICAS

ACCB CAPÍTULO BUCARAMANGA

Certifica que:

FABIO LEONARDO MEZA JOYA

Participó en calidad de CONFERENCISTA MAGISTRAL, en el III Seminario de Biodiversidad y Conservación de Especies Amenazadas, realizado en la ciudad de Bucaramanga – Santander, del 14 al 16 de Septiembre de 2017, con el trabajo titulado:

Atropellamiento de fauna silvestre en Colombia: De calzadas sencillas a vías 4G.
Autores: Fabio Leonardo Meza-Joya, Eliana Ramos Pallares y Diana Cardona.

Beatriz Helena Mojica Figueroa
Presidenta de la Asociación Colombiana de Ciencias Biológicas
Capitulo Bucaramanga

Diana Marcela Sanchez Lobo
Secretaria de la Asociación Colombiana de Ciencias Biológicas
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ecofaunas
ecología y conservación de fauna silvestre

1er Simposio

"ECOLOGÍA Y CONSERVACIÓN"

UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN

Grupo de Investigación "Ecología y Conservación de Fauna Silvestre y el Departamento de Ciencias Forestales

CERTIFICAN QUE:

Diana Marcela Cardona Ramírez, Eliana Ramos-Pallares & Fabio Leonardo Meza-Joya

Participaron con la presentación oral:

"CONECTIVIDAD FUNCIONAL: RETOS Y OPORTUNIDADES PARA LA MITIGACIÓN DEL ATROPELLAMIENTO VEHICULAR DE MAMÍFEROS A ESCALA DEL PAISAJE"

Néstor Javier Mancera Rodríguez
Líder Gpo ECOFAUNAS

Ligia Stela Urrego Giraldo
Directora
Departamento de Ciencias Forestales

Mauricio Sánchez Sáenz
Director
Área Curricular en Bosques y Conservación Ambiental

Medellín, Antioquia, Colombia 28 de Noviembre de 2017

Institución Universitaria
Acreditada en Alta Calidad

Medellín, 5 de febrero de 2018

A quien pueda interesar:

Por medio de la presente, quiero informar que, Diana Marcela Cardona Ramírez, con cédula de ciudadanía número 24339743, presento el trabajo *"Conectividad funcional: Retos y oportunidades para la mitigación del atropellamiento vehicular de mamíferos a escala de paisaje"* realizado por Cardona Diana; Ramos Eliana; & Meza-Joya Fabio Leonardo, en el marco del Simposio de Atropellamiento de Fauna Silvestre y Medidas de Mitigación, llevado a cabo en Instituto Tecnológico Metropolitano de Medellín – ITM, el día 21 de noviembre 2017.

Atentamente,

Juan Carlos Jaramillo Fayad
Docente Ocasional – Doctor
Organizador del Simposio de Atropellamiento de Fauna Silvestre y Medidas de Mitigación
Facultad de Ciencias Exactas y Aplicadas
Correo electrónico: juanjaramillo@itm.edu.co
Teléfono: 4405100 Ext 5269

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