WILDLIFE ROAD CROSSING AND MORTALITY: LESSONS FOR WILDLIFE FRIENDLY ROAD DESIGN IN COLOMBIA

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ABSTRACT

A study on vertebrate road mortality and wildlife road crossing was undertaken to influence the design of the expansion of an inter-departmental road in Colombia. The study site is located in the Inter-Andean valley of the Magdalena river at sea level. The two lane highway is intended to be upgraded to a four lane motorway. Before works began a 178.8 km stretch was surveyed every two days to register road kills, live animals by the road, dimensions of crossing structures and landscape variables. Additionally six camera traps where located under six bridges that could operate as crossing structures for medium mammals. We report vertebrate kill rates, number of appropriate crossing structures for large and medium mammals, use of crossing structures by wildlife and vertebrate mortality per 10 km segment along of road. Vulnerability of species to vehicle collisions is discussed per species and biomass, dimensions of appropriate crossing are reported, influence of landscape on each road segment is considered and relative abundance indices of camera trapped species crossings are compared. A total of 2753.4 km were surveyed with 340 wild vertebrates (equivalent to an estimated 1,201 kg of biomass) killed by vehicle collisions from at least 32 species. Estimators suggest a potential impact of 37 species. Kill rates of wild vertebrates where around 45/ind/km/yr. Mammals where the most prevalent victims represented by the highest number of species fallen to traffic collisions, and the highest rates of individuals killed and associated biomass. Birds followed in number of species, but reptiles recorded higher number of individuals killed and biomass lost. Non-identified anurans had the lowest quantitative representation of the vertebrate guild. The most significantly impacted vertebrates where tamanduas, common opossum, crab-eating foxes and boas. Species vulnerability was not significantly associated to home range size, number of crossing structures, or rivers crossing the segments. Segment relative road kill rates ranged from 0.05-0.21 per km. We identify the need to create seven new underpasses, adapt 123 existing ones and propose the creation of wildlife friendly segments along the road. The segment are implemented through zoning, where at certain key stretches (identified by road crossing and road mortality) both sides of the road have human productive practices restricted, coincide with an ideal underpass and have forest at both edges of road.

Key words: Carnivores, Colombia, crossing structures, highway design, kill rates, Magdalena.

INTRODUCTION

Road construction and upgrading in Latin America is booming. Roads are one of the main drivers of habitat fragmentation and connectivity loss (Beckmann et al. 2010; Forman et al. 2003). Habitat degradation caused by roads goes farther than vehicle caused mortality on wildlife; it implies development at road borders and penetration for hunters and loggers. In the tropics where planned development and zoning isn't prevalent, roads bring the creation of local commerce at edges and small hamlet establishment incrementing the barrier effect to unsourmontable proportions for sensitive species (Kerley et al. 2002). Roads and trails have also proven to increment access to hunters and loggers in the tropics (Broadbent et al. 2008; Laurance et al. 2006; Peres & Lake 2003).

Consequently, road design in developing countries should approach not only mitigation of wildlife mortality by collisions, but land management along road edges as a main topic of concern. The latter is even more of a challenge in developing countries, like Colombia, where funding is scarce and corruption impedes proper funds execution. A special case where proper wildlife design might exert more effects is under foreign financing frameworks where good practices and impact measures are obligatory to road funding. In any scenario, it is thus of utmost importance to produce locally relevant data on road mortality and ensue science-based recommendations to government and builders.

Colombia is in an embryonic stages of road ecology with only three published papers on road impacts, two on reptiles and amphibians, and one on mammals (Delgado 2007; Quintero-Ángel et al. 2012; Vargas-Salinas et al. 2011). Here we present the most comprehensive road ecology study to date for the country where kill rates are reported for all registered vertebrates and road segments assessed for their road mortality intensity. Because road kills are good predictors of wildlife crossing hotspots (Gomes 2009; Huijser et al. 2010; Langen et al. 2009) we base our road design recommendations to mitigate wildlife-highway conflict on these and actual wildlife crossing data.

MATERIALS AND METHODS

Study site

The study area is located in the Magdalena valley between the Central and Eastern Andes mountain chains in Colombia (Fig. 4). The site is flanked to the west by the Magdalena river.

The study area is in what has known as the para-caribbean dry belt, composed of a matrix of grassland dissected by dry tropical forest (or riparian forest). This area has a hot tropical climate with an annual average temperature of 27°C. There are two rainfall seasons with annual rainfall between 1000-2600mm. Rainfall is basically bimodal, with a wet season covering the months of May and November (Rangel-Ch & Velazquez 1997; Rodríguez & Armenteras 2005).

We studied a section of the Magdalena highway (National Route 45), now known as the *Ruta del Sol*, prior to its upgrade to a four lane carriageway. The area contains important populations of endangered species such as jaguar (*Panthera onca*) (NT), puma (*Puma concolor*) (LC), tapir (*Tapirus terrestris*) (VU), collared peccary (*Pecari tajacu*) (LC) and blue-billed curassow (*Crax alberti*) (CR), (Diaz-Pulido et al. 2011).

Monitoring road kills

Surveys recording road kill began at dawn every third day, with the observer driven at the back of a motorcycle. Early morning surveys are recommended to ensure a minimum of underestimation due to scavenged carcasses (Degregorio *et al.* 2011). Carcasses found were identified to species level, photographed, location georeferenced with a GPS (Datum: WGS 1984) and removed from tarmac to avoid recounting. All dead specimens found on the road were we assumed to have been killed by vehicular traffic. Surveys were conducted from April to June, 2010 on a 178.8 km road stretch known as section II, of the "Ruta del Sol" highway that connects the Municipalities of San Roque and San Alberto in the Colombian Department of Cesar.

The entire road stretch was separated in 17 segments of approximately 10 kilometers (total 178.8 km). Here surveys for the entire stretch of road were conducted for 13 days. Road works limited access to segments 1-8 (80 km) on day 14th, and so segments 9-17 (98.8 km) where surveyed 4 more days to total 17 days. Kill rates (Ind./km) per species and per segment are presented and relative abundance of vertebrates killed per km where also calculated. Live wildlife crossing road was also recorded along the entire stretch of studied road.

Using program EstimateS 8.2, we ran a rarefied species accumulation curve to estimate completeness of species detected and used Ace, Chao 1 and Jack 1 estimators to have an approximate estimate of the potential species affected by road mortality. All species of identified species of road kill where assigned an adult mean mass from the literature to estimate biomass killed per km. Biomass was calculated using mean adult weights from the literature for mammals (Eisenberg & Thorington Jr 1973; Emmons & Feer 1997; Taylor et al. 1970) reptiles (Row et al. 2006; Swanson 1950; Yanosky & Mercolli 1992) and birds (Marini et al. 1997; Wallace & Temple 1987).

Monitoring use of multiple use structures

Multiple Use Structures (MUS; box culverts and bridges) are those that wildlife uses to cross roads but where not initial designed for this purpose. To evaluate MUS use and functionality by vertebrates, throughout the surveyed section, six camera traps where located at six MUS (Fig. 4). We counted MUS per segment and identified the limiting factors for wildlife road crossing (Payan et al. In Press). Crossing structures ideal for large mammals where considered those that where more than 12 meters wide and four meters high, and ideal from medium mammals with dimensions between seven meters wide and three meters high (Carsignol 1993; Clevenger et al. 2001; Jansen et al. 2010). Relative abundance indices where calculated with independent photographs of individuals (O'Brien *et al.* 2003).

Recommendations for design

Data on road mortality was overlaid with vegetation cover and towns and human habitations to understand at patterns of animal crossings. Additionally, the jaguar corridor initiative model (Rabinowitz & Zeller 2010) was also used as a layer to understand impact on connectivity and the road in question. Based on the collected data we produce a series of recommendations for MUS design (Carsignol 1993; Clevenger & Waltho 2005; Iuell et al. 2003).

RESULTS

Species composition and road kill rates

A total of 2753.4 km were surveyed, consisting of 13 days of surveys in all transects and four days more of surveys restricted to transects 9-17. These detected 374 individual animals killed by traffic collisions (wild and domestic), of which 340 wild vertebrates from at least 32 species of mammals (55.9% individuals), 11 species of birds (17.4%), seven species of reptiles (25.3%), and non-specified species of Anurans (1.5%) (Table 1). Estimations of affected species using ACE, Chao 1, and Jack 1 suggest impact of vehicle collisions along studied road could affect 37 species. Consequently, the rarefied species accumulation curves for all wild vertebrates do not level off confirming an incomplete detection of species (Figure 2), i.e. further sampling would reveal more road killed species.

Mammals represented the mayor number of killed vertebrate species and the highest total biomass. Birds had more recorded species killed, but reptiles had more individuals killed than birds and translated to a higher biomass. Ninety percent (n=306) of all wild vertebrate road kill was composed of 16 species, four mammals (n=173, 51%): *northern tamandua; common opossum; crab-eating fox* and *crab-eating racoon*, all with an average adult species body mass of 4.5 kg; at least six species of birds (n=49, 14%): yellow-headed caracara*; barn owl, black vulture;, smooth-billed ani; great kiskadee;* and unspecified Picidae; with an average species body mass of 0.6 kg; and at least six species of reptiles (n=84, 25 %): *common iguana,* boa constrictor*, scarlet kingsnake,* non-identified snakes, *tegu lizard*, and *spectacled caiman* with an average adult species weight of around 10 kg.

Overall wild vertebrate road kill rate was 0.0034 individuals per kilometer surveyed, with particular kill rates for mammals averaging 0.0053, reptiles 0.0045, birds 0.0019 and anurans 0.0018 (Table 1). Total recorded road kill rates translated into biomass equaled over a ton, 1.201 kgs.

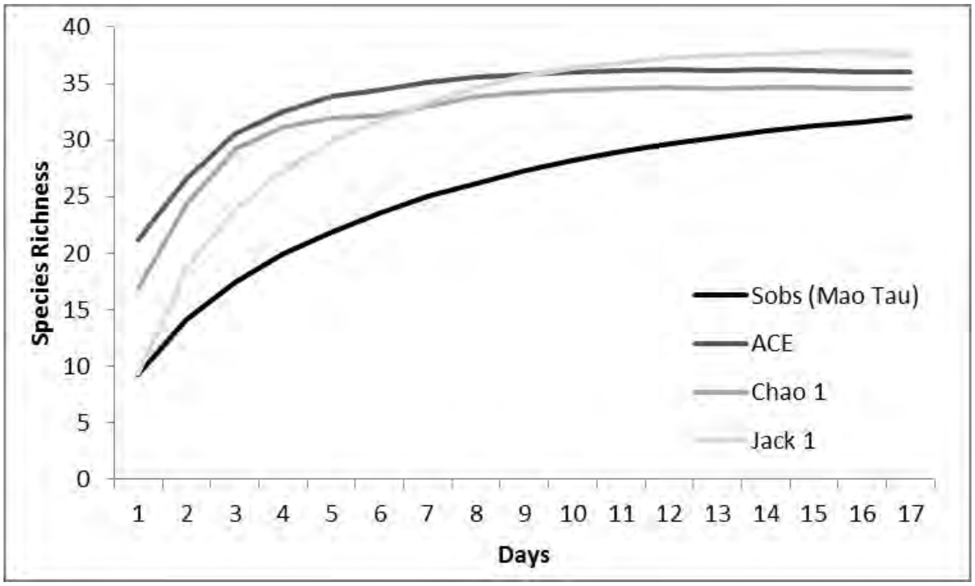

FIGURE 1 Estimation of potential species vulnerable to road kill by means of ACE, Chao 1 and Jack 1 estimators. Jack 1, with the best behavior, suggest up to 37.5 species potentially affected.

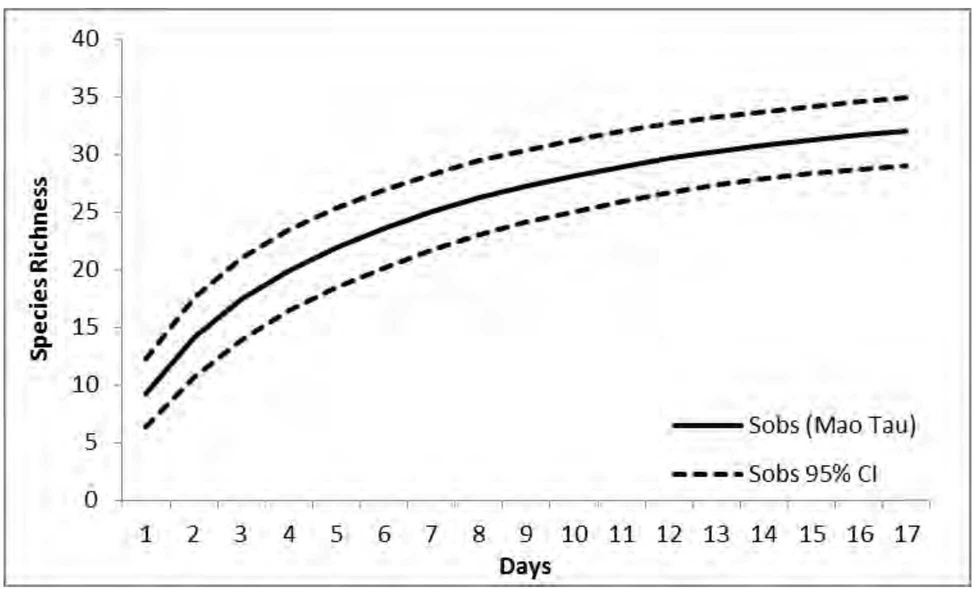

FIGURE 2 Rarefied road kill wild vertebrate species accumulation curve as detected in the studied road tract (n =340).

TABLE 1 Vertebrate species found as road kill.

SP	Species	Common name	No. Ind.	Ind/km[a]	Ind. mass (kg)[a]	Total biomass (kg)	%
	MAMMALIA						
1	*Tamandua mexicana*	Northern tamandua	92	0,0334	5,6	515,2	27,1
2	*Didelphis marsupialis*	Common opossum	46	0,0167	1,3	59,8	13,5
3	*Cerdocyon thous*	Crab-eating fox	31	0,0113	5,8	179,8	9,1
4	*Procyon cancrivorus*	Crab-eating racoon	4	0,0015	5,4	21,6	1,2
5	*Chiroptera*	Non-Id bat	3	0,0011	NA	NA	0,9
6	*Coendou prehensilis*	Brazilian porcupine	3	0,0011	4,0	12,0	0,9
7	*Alouatta seniculus*	Red howler	2	0,0007	8,0	16,0	0,6
8	*Puma yagouaroundi*	Jaguarundi	2	0,0007	6,7	13,4	0,6
9	*Choloepus hoffmanni*	Two-toed sloth	2	0,0007	6,3	12,6	0,6
10	*Didelphidae*	Non-Id Opossum	1	0,0004	NA	NA	0,3
11	Muridae	Non-Id. wild mouse	1	0,0004	NA	NA	0,3
12	*Sylvilagus floridanus*	Eastern cottontail	1	0,0004	1,0	1,0	0,3
13	Felidae	Non-Id felid	2	0,0007	NA	NA	0,6
		SUBTOTALS	190	0,0053	4,9	831	55,9
	AVES						
1	*Milvago chimachima*	Yellow-headed caracara	13	0,0047	0,3	4,16	3,8
2	*Tyto alba*	Barn owl	12	0,0044	0,4	4,32	3,5
3	*Coragyps atratus*	Black vulture	8	0,0029	1,5	12	2,4
4	*Crotophaga ani*	Smooth-billed ani	6	0,0022	0,6	3,54	1,8
5	*Pitangus sulphuratus*	Great kiskadee	6	0,0022	0,1	0,40	1,8
6	Picidae	Non-Id woodpecker	4	0,0015	NA	NA	1,2
7	*Jacana jacana*	Wattled jacana	3	0,0011	0,2	0,48	0,9
8	*Icteridae*	*Turdus sp.*	3	0,0011	0,1	0,18	0,9
9	*Buteo magnirostris*	Roadside hawk	2	0,0007	0,3	0,5	0,6
10	Icteridae	Non-Id blackbird	1	0,0004		0	0,3
11	*Troglodytes aedon*	House wren	1	0,0004	0,01	0,01	0,3
		SUBTOTALS	59	0,0019	0,4	26	17,4
	REPTILIA						
1	*Iguana iguana*	Common iguana	36	0,0131	3,0	108	10,6
2	*Boa constrictor*	Boa constrictor	19	0,0069	11,5	218,5	5,6
3	*Lampropeltis triangulum*	Scarlet kingsnake	10	0,0036	0,2	1,65	2,9
4	Colubridae	Non-Id snake	8	0,0029	NA	NA	2,4
5	*Tupinambis teguixin*	Tegu lizard	8	0,0029	2,0	16	2,4
6	*Caiman crocodilus*	Spectacled caiman	3	0,0011	36,0	108	0,9
7	Testudinoidea	Non-Id turtle	2	0,0007	NA	NA	0,6
		SUBTOTALS	86	0,0045	11	344	25,3
	AMPHIBIA						
1	Anura[b]	Non-Id frog	5	0,0018	NA	NA	1,5
		SUBTOTALS	5	0,0018			
		TOTALS	340	0,0034		1201	100

Camera trapping in crossing structures and live sightings

Camera trapping effort equaled 36 trap-nights, detected 7 vertebrate species from 75 independent photographs, two carnivores (crab-eating racoon and *crab-eating fox*), two rodents (paca; *Cuniculus paca* and guinea pig; *Cavia porcellus*), one marsupial (common opossum), and two reptiles (*common iguana* and *tegu lizard*) (Figs. 3 and 4). All species photographed where also recorded as road kill, except the paca and guinea pigs both which are nocturnal. All mammals where detected at night and reptiles by day. All species where recorded travelling through the crossing structures, but the crab-eating raccoons where also detected feeding and foraging, the iguana was also photographed foraging.

Nine vertebrate species where sighted directly (Figure 3). Of these, three species, common opossum, common iguana and tegu lizard, where photographed using crossing structures. Opossums, iguanas, tegus, and boas where seen crossing the road, yellow-headed caracaras, black vultures and barn owls where seen feeding of carcasses on the road.

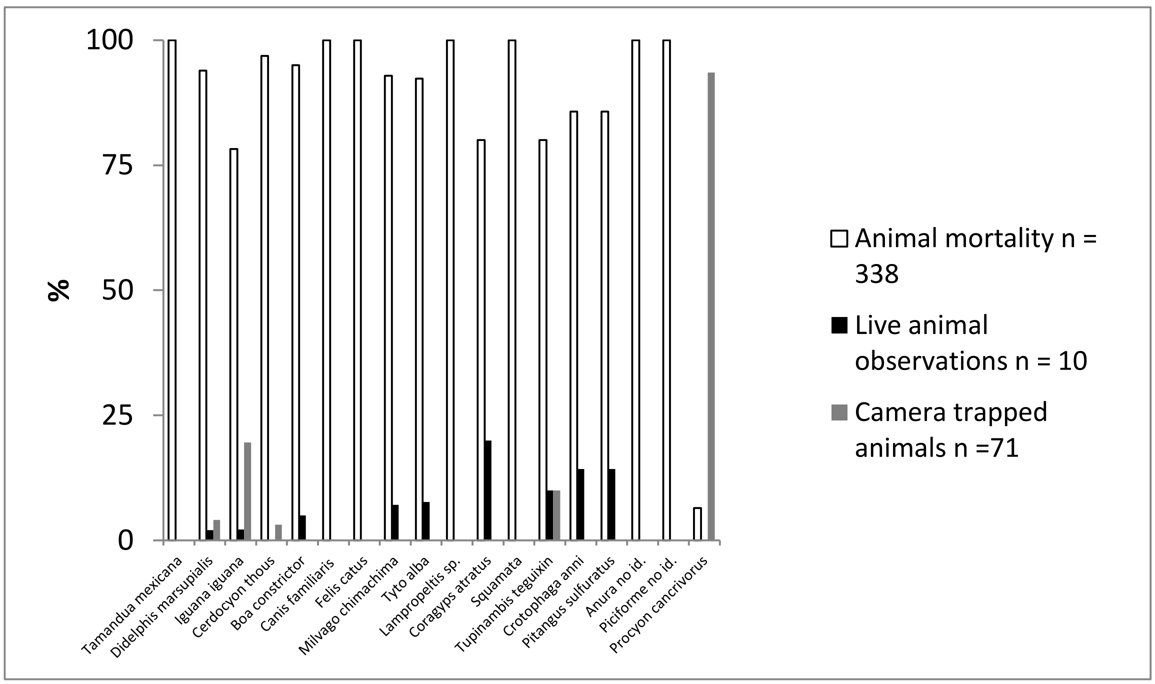

FIGURE 3 Percentages of species killed by vehicle collisions, observed alive along road and camera tapped under bridges. The 12 most commonly found road kill species are shown.

Segment analysis

Coincided with forest cover y ya. Relative abundance of killed animals per segment per km averaged 0.14 with a range of 0.07-0.19 (SD 0.05) (Fig. 4). No significant differences between road kill rates per segment where found. The stretches with RAI values that are above the average plus 1 SD (segments 1,3,10 and 13) are dispersed. All segments (n=17) crossed at least one small forest fragment (had forest to the east less than 10 km away) and one cattle field, and

94% crossed at least one river, 75% crossed croplands, of which at least in 2010, was 31% oil palm. Five segments cross the jaguar corridor but this does not seem to affect lower or higher mortality rates along these segments (Fig. 4). The relationship between relative abundance indexes of animals killed and the number of functional crossing underpasses, the number of rivers crossing the road per segment or the home range of killed animals showed no significant lineal variance explained the dependent variable (all $R^2<0.6$). Rather, the segments with highest number of functional underpasses had also high or above average road kill indices, suggesting other explanatory variables, such as association to forest.

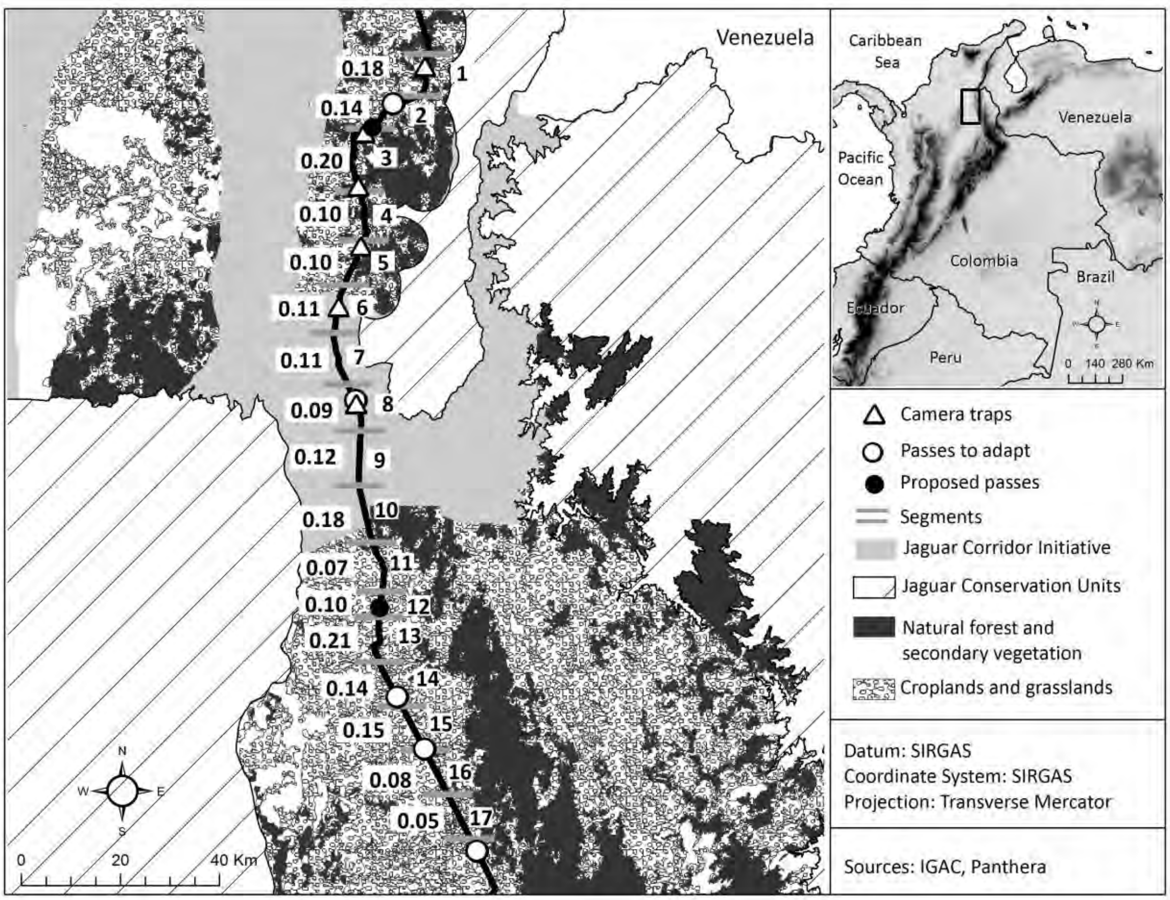

FIGURE 4 Spatial detail of relative abundance indices of road kill per 10 km segment along the studied road, proposed underpasses and location of camera traps along MUS. Land cover has been clumped and classified as broad forest or croplands. The jaguar corridor model is also included.

TABLE 2. Characteristics of MUS per road segment. An X denotes if the segment crosses forest fragments, cattle fields, general plantations, oil palm plantations, has a neighboring mountain, has canopy cover over road, crosses the jaguar corridor and how many rivers cross the segment. Segments in bold have higher than average plus one SD indices of wildlife mortality.

Segment	Length (km)	Forest fragment	Cattle fields	Plant.	Oil palm plant.	Bordering mountains	Canopy cover	Jaguar corridor	Rivers crossing
S1	10	X	X	X	X	X	X		2
S2	11,5	X	X	X	X	X			3
S3	11,4	X	X	X					0
S4	9,7	X	X	X					4
S5	10	X	X						1
S6	10	X	X	X			X	X	2
S7	10	X	X					X	1
S8	10	X	X		X			X	2
S9	10	X	X	X				X	3
S10	10,9	X	X				X	X	4
S11	11,9	X	X	X		X	X		2
S12	6	X	X	X		X			3
S13	10	X	X	X			X		3
S14	10	X	X	X					5
S15	10	X	X	X					6
S16	10	X	X	X					5
S17	10	X	X	X	X		X		7

Segments 9-17 contained 202 bridges and box culverts that could be used as crossing structures. Seventy nine of these underpasses where appropriate for medium and large mammal use. The rest where too small, had obstacles (rocks, cement, construction debris, or fence). Nevertheless, these underpasses might serve smaller vertebrates and if adapted, i.e. cleared of obstacles and their substrates converted to soil and some vegetation could be perfectly fit for rodent, reptile and marsupial crossings.

Based on the relative abundance road kill indices, the adjoining landscape (Gomes 2009) and the jaguar corridor connectivity shown we propose construction of seven new underpasses to be constructed (Fig. 4) and 123 crossing structures to be adapted to be used as underpasses for all types of wildlife. Details of the design of crossing structures can be found in Payan et al. In Press.

DISCUSSION

A total of 2753.4 km were surveyed with 340 wild vertebrates from at least 32 species. Total kill rates of wild vertebrates for segments 1-8 (80 km) was 45/km/yr and for segments 9-17 (98.8 km) was 48/km/yr. Mammals where the most prevalent victims represented by the highest number of species fallen to traffic collisions, and the highest rates of individuals killed and associated biomass. Birds followed in number of species, but reptiles recorded higher number of individuals killed and biomass loss (Table 1). Species vulnerability was not significantly associated to home range size, number of crossing structures, or rivers crossing the segments.

The most significantly impact mammal species are generalists, mid-sized (average 5 kg). Northern tamanduas are the most impacted vertebrate species by road traffic collisions (27%) with half a ton in biomass recorded during the survey (Table 1). Tamanduas, where followed by common opossum, iguanas, crab-eating foxes, yellow-headed caracaras, barn owls and reptiles. Noteworthy and nationally endangered species include boas, spectacled caiman, jaguarundis and two-toed sloths (Rodríguez-Mahecha et al. 2006; Rueda-Almonacid 1999). Road mortality is now being considered one of the threats to the survival of many species, particularly those threatened (Aguiar 2004; Beaudry et al. 2008; Ferreras et al. 1992; Grilo et al. 2010; Jansen et al. 2010; Kamler et al. 2003; Tewes & Hughes 2001)

There are 52 records of presence of jaguars and pumas on the stretch of road, but with a clear pattern of aversion of the road. As distance from road increased in the study site, the more the records of jaguar (Payan et al. In Press). This has also been reported for jaguars in Mexico with a specially strong avoidance by females (Colchero *et al.* 2011). Road kills are a significant threat to wildcats around the world, in particular for Florida panther (*Puma concolor coryi*), bobcat (*Lynx rufus*) and Iberian lynx (*Lynx pardinus*) (Foster & Humphrey 1995; Jansen et al. 2010; Kramer-Schadt et al. 2004; Tigas et al. 2002). It has been found that pumas and bobcats adapt well and use appropriately designed underpasses, specially males (Gloyne & Clevenger 2001; Jansen et al. 2010).

Road design for mitigation of wildlife-highway conflict

Animal crossings as deducted from traffic collisions did not show a clear pattern with respect to bordering forest fragments, the jaguar corridor or bordering mountains. All key elements in the habitat for mammals. We believe, this is due to the nature of the landscape matrix, where all segments had some form of forest and river associated and in general the area is still not too degraded. Additionally, all the reported species killed by vehicles, seen or camera trapped are human tolerant species (Emmons & Feer 1997; Hunter & Barrett 2011).

Crossing structures have been very efficient for mitigation of wildlife road mortality (Clevenger & Ford 2010; Forman et al. 2003). Here, it is evident that species such as iguanas, tegu lizards, opossums, raccoons, foxes and wildcats would benefit from appropriately designed and placed crossing structures. Literature suggests amphibians and reptiles in general, and marsupials, rodents, ungulates, and carnivores in particular (including ocelots, pumas and jaguars) would also use safe passages (Grilo et al. 2010; Huijser & McGowen 2010; Jansen et al. 2010; Sparks

& Gates 2012). But, wildlife-highway mortality mitigation measures should be multiple and complementary and thus we believe the underpass creation and adaptation proposed here, should be accompanied by speed limits, road signals, high mortality segments signs, fencing, driver education and zoning (Huijser *et al.* 2010).

Zoning is any form of geographically differentiated land management where different forms of potentially conflicting land use are given priority in different areas (Linnell *et al.* 2005). Zoning along selected stretches of road maybe a way to limit wildlife mortality along road kill hotspots and permit connectivity. Roads as barriers are much more than their tarmac, roads enable human demographic process associated to further disturbance along the road, effectively increasing the barrier effect and permitting penetration into previously undisturbed habitats (Laurance *et al.* 2006). Along roads, human activity increases the size of the barrier (sprawl, motels, truck stops, restaurants, etc.). In the present case, the Magdalena river crosses perpendicularly the jaguar corridor initiative (Rabinowitz & Zeller 2010) (Figure 4). Thus, we propose the creation and implementation of wildlife friendly segments. Here segments of say 5 km at both side of the road, would have human activities excluded (commerce, production, towns etc) due to prioritized habitat for biodiversity. Panther speed zones have been proposed and implemented in Florida with success (Jansen *et al.* 2010), but we go farther in our proposal and suggest segments zoned for conservation. Hence, we identified several jaguar friendly segments of along the road, where human access is restricted. This implies buying land of land tenure zoning by private owner of funds.

All intervention must be monitored and evaluated to determine their success (Gagnon 2011). We propose a 25 year monitoring and maintenance plan (the same temporal scale as the concession will operate). The general recommendation for monitoring is to assess crossing structure success by recording through camera traps their use by indicator species such as jaguar, puma and ocelot, along with five main prey species. Research allows generating more information to efficiently adjust the mitigation measures in the effect of the road upgrade native wildlife populations. Maintenance should ensure clear paths inside and to reach and exit MUS.

Policy implications

The effectiveness and real influence on policy is growing in North America, but remains indolent in developing nations. We concur that the location of road kills are essential when identifying and prioritizing road sections that require mitigation measures to reduce collisions (Huijser *et al.* 2010).

In the North America animal traffic collision data is typically collected by transportation agencies, law enforcement agencies, and natural resource management agencies (Huijser *et al.* 2010), but not in Colombia or even in Latin America. This is actually the most intense and complete road ecology study to date in the country. It was done entirely by an environmental NGO and the data was sent to the Ministry of Environment, Ministry of Transport and the road project company in charge of the operation. The only applied recommendation adopted was the set-up of wildlife warning signs, which as an individual mitigation strategy has zero effectiveness (Huijser & McGowen 2010), and the country ended up, despite the warning data with another poorly designed road.

The above evidences that even the best possible data without government reception and policy influence will not contribute to conservation. The apathy and lack of interest from government and road construction companies on road ecology is exacerbated in developing countries, particularly in Latin America. Thus, in this case, we must strive to continue to direct strategies to minimize and mitigate wildlife-highway conflict and ensure they have effect. The latter is specially challenging since in the developing world decision makers and constructors have little environmental consciousness. All of the above highlight the need for NGO´s and other honestly environmentally guided entities to strengthen their planning stages, new alliances, lobbying and ensure mechanism of influence on decision makers to permeate policy and execution in Latin America.

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BIOGRAPHICAL SKETCHES

Esteban Payan, Ph.D. Colombian. Received his Ph.D. in 2009 from University College London and the Institute of Zoology, Zoological Society of London. Esteban is currently the Regional Director for Northern South America Programs for Panthera. He is interested in wildcat conservation and ecology, with special interests in road ecology, corridors and wild meat use.

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Angélica Diaz-Pulido, M.S. Colombian. She studied Biology at the Pontificia Universidad Javeriana and did her Masters at the Universidad de Los Andes in jaguar distribution models. She worked as Llanos regional coordinator for Panthera Colombia until 2012.

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