PASSSES FOR FAUNA CROSSING IN UNDEVELOPED COUNTRIES ROADS: WITHIN BUDGET SOLUTIONS

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ABSTRACT

México es uno de los países con mayor diversidad de fauna en el mundo. El principal efecto ambiental de una carretera sobre la fauna silvestre es la fragmentación de hábitats y la pérdida de conectividad entre ecosistemas; asociados con un importante incremento en atropello de especies, muchas veces protegidas por la Ley. Soluciones caras en ingeniería para mitigar estos impactos como superpasos y túneles son comunes y cada vez mayormente utilizadas en países desarrollados. No obstante, en México, pese a que varios proyectos las han contemplado, a la fecha no existe una sola carretera que incluya este tipo de obras para pasos de fauna; atribuible quizá a su costo y la falta de experiencia en ello.

Una alternativa más apropiada para la realidad económica de nuestro país puede resultar de buscar soluciones económicamente viables, que garanticen la mitigación de los anteriores impactos. El uso de obras de drenaje modificadas para permitir el movimiento de animales a manera de pasos mixtos, aunado a un esquema de reforestación que induzca a la fauna hacia estos cruces, pueden ser medidas de bajo costo que permiten mitigar el efecto barrera y reducir la pérdida de conectividad entre los hábitats en países en desarrollo.

1. INTRODUCTION AND OBJECTIVES

Mexico is one of the countries with the highest biodiversity around the world. An approximate of 10 to 12% of world species is represented in our country, with more than 200 thousand species within our national territory. It has 17 million hectares considered as Natural Preserves which produce direct environmental benefits as they regulate weather, protect hydrological basins, collect rain water, and are habitat for our flora and fauna; resources that eventually are used by people, agriculture or industry, or produce indirect benefits providing of environmental services.

Wild animals move to satisfy their alimentation, coverage and reproduction needs. They disperse from their birth area and (re)colonize nearby unoccupied areas. The displacement tends to increase their efficiency to explode the habitat, although this is naturally limited by physical, ecological and human conditions, like roads (Brody and Pelton 1989, Forman et al 1996, Forman & Alexander 1998, Clevenger 2005).

Roads have become an essential factor for human every-day life. They transport people, food, water, and goods, thereby becoming imperative for a region’s development and sustainability. However, they represent a critical impact upon wildlife. Roads have become a serious obstacle for animal movements as they fragment habitats, induce human penetration and interrupt natural corridors. They imply direct mortality by increasing collisions as highway traffic grows, act as a barrier for the movement and dispersion of wildlife, causing the fragmentation and isolation of populations, which when big enough, can become a contributing factor for species extinction, as isolation reduces genetic plasticity and population numbers.

Barrier effect of roads can increase to distances as big as 800m from road axis, as animals tend to avoid highway noises and lights. Also, an indirect impact of highways is facilitating access to formerly isolated zones, allowing hunters and people to enter more easily, increasing animal mortality and ecosystem deterioration.

From all the previous impacts, the main environmental effect of a road on fauna is habitat fragmentation and connectivity loss within ecosystems; both in association with an important increase in animal vehicle collisions, which in several cases include endangered or protected species. The identification of displacement and dispersion corridors is very useful to mitigate the possible effects produced by roads construction and operation, caused by fragmentation and loss of connectivity, as artificial structures such as underpasses and upper passes can be built to reduce permeability loss due to roads. Expensive engineering solutions to mitigate these effects, like tunnels and overpasses are increasingly common in roads on developed countries like the US and Canada. Nevertheless, in Mexico, despite such structures have been considered in several projects, up to now, there is not one single road that includes these type of fauna crossing passes; due perhaps to its cost and lack of experience. Over and under passes are designed with size and slopes to mainly allow ungulate crossings of large mammals like elk (moose), deer, caribou and even large bears; abundant fauna in temperate zones. Nevertheless, under the tropical conditions of countries like Mexico, mammals are usually not so big, and the most abundant species are medium size mammals, which populations and movements are affected by roads.

A more appropriate alternative for the economic reality of our country could be the search for solutions that are economically more feasible, and guarantee that such impacts could be mitigated. The use of modified drainage structures to work as combined passes for water and fauna, jointly with other modified drainage structures strategically included in the project at sites confirmed as fauna corridors and between attractor features, could be a good less expensive solution. Therefore, two main questions of our study were: Is wildlife using ordinary drainage structures to cross roads? If it is so, what type, size and characteristics of drainage structures are preferred by fauna?

The main objective of our study was to analyze several drainage structures along roads that have been built more than 20 years ago using trap cameras and field registers, and identify the presence of different kinds and sizes of mammals, including deer and jaguars, as some of our largest species.

2. PROCEDURE

2.1. Use of trap cameras

Given their elusive behavior, fauna crossings had to be analyzed by indirect techniques like the use of trap cameras. They allow to "capture" the animals in their natural environment as they cross through roads drainage structures, without drastically altering their behavior and with an identification 100% positive in most cases (Culter and Swann 1999).

The studies with trap cameras have a long history in the ecological investigation and its application goes back to the twentieth century (Culter and Swann 1999). Currently they make up a trustable and efficient tool for the quick evaluation of the richness and abundance of species, in short periods of time and in relatively extensive regions, which is fundamental for determining the priorities of conservation for a determined area (Silveria et al. 2003). The technique is particularly useful for faunistic inventories, especially for elusive species that inhabit tropical regions, where the dense vegetation cover makes it difficult to observe the animals directly.

Along with trap cameras inside and outside drainage structures, fauna corridors within the natural environment, as well as animal car hit records were studied on several A2 roads in Mexico; mainly in two sections of Federal Road 200: Compostela-Puerto Vallarta, Nayarit; and Tuito- Melaque, Jalisco; Cancun-Tulum road at Quintana Roo and Merida-Cancun road at Yucatán-Quintana Roo.

Sampled drainage structures like tubes, barrel vaults and box culverts, were selected based on the lack of human presence, as some of these are used by cattle or people, which will make less possible wild animals, will be using them. Detailed recognition of drainage structure surroundings was done and trap cameras were fixed to structure walls or nearby trees. Records were made for a month period.

2.2. Animal – vehicle collisions

Animal car hits in roads are the main cause of mortality, directly connected to modern development, has been increased over the last few decades due to the increase on road networks and on traffic speed and density. Some roads act as severe collision structures while others have less incidents; either way, any road causes animal – vehicle collisions and thousands of vertebrates are killed in roads in our country on a year basis, and much more worldwide (PMVC, 2003). In our study, several roads were surveyed and ran over animals registered over an average period of 15 days.

2.3. Estimating kilometre abundance indexes (IKA)

Kilometer abundance indexes or car hit indexes (IKAs) are a measure of the frequence of vehicle-collisions. This index is obtained by dividing car-hits between studied kilometers and could also be referred to annual situations (Annual IKA= number of killed vertebrates/km/year).

Los índices kilométricos de abundancia o atropellos (IKAs) son una medida de frecuencia que se utilizará en el análisis de resultados. Se expresan mediante un valor numérico, obtenido de dividir el número de atropellos localizados por el de kilómetros prospectados, así como el IKA anual (nº de vertebrados atropellados/km/año).

3. RESULTS

3.1. Use of trap cameras

We found that several types of mammals use different size and shape of drainage structures to cross the roads, as shown in figures 2 and 3. Even small tube drains are used by small and medium mammals when surrounding landscape is well preserved and there is a lack of human presence (figure 3).

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Figure 2 - Large and medium mammals crossing through barrel vaults in several points along Federal Road 200: Compostela-Puerto Vallarta, Nayarit

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Figure 3 - Small and medium mammals crossing through tubular drains in several points along Federal Road 200: Tuito- Melaque, Jalisco

According to our results, table 1 shows mammal species that used barrel vaults at different sites along Federal Road 200: Compostela-Puerto Vallarta, Nayarit, the number of crossings in a month period and the number of vaults that were used by each species.

Table 1 – Recorded mammal crossings on Federal Road 200: Compostela-Puerto Vallarta, Nayarit for a one month sampled period.

SPECIE	COMMON NAME	NUMBER OF BARREL VAULT STRUCTURES USED	NUMBER OF CROSSINGS PER SPECIES
Procyon lotor	Racoon	7	38
Spermophilus annulatus	Ringed tail squirrel	4	26
Nasua narica	White nosed coati	3	10
Odocoileus virginianus	White tail deer	3	8
Urocyon cinereoargenteus	Gray fox	2	29
Didelphis virginiana	Virginia Opossum	2	14
Canis latrans	Coyote	2	14
Conepatus mesoleucus	Squnk	2	5
Pecari tajacu	Collar hog	2	4
Spilogale putorius	Spotted skunk	2	2
Puma concolor	Puma	1	3
Dasypus novemcinctus	Nine-Banded Armadillo	1	1
Leopardus pardalis	Ocelot	1	1

3.2. Index for Kilometer Abundance (IKA) of animal car kills

Jointly with animal crossing information, we had to consider animal deaths by car collisions, in order to identify species or groups in larger risk, as well as zones where more crossing structures were needed. We estimated an index for average kilometer car hits (IKA) to compare between road effects. Table 2 shows estimated values of IKA for several studied roads considering four vertebrate groups.

Instant IKA refers to observed car killed animals within a short time period, for example, the 30 day period of fieldwork; while annual IKA represents average car killed animals within a year.

Though instant IKA is a good estimated index to compare road kill effect between several roads, it varies a lot within a year, depending on the season (for animals and road users as well). Migratory, reproduction and resource search movement trend to increase collision risks, whereas for road users, vacation seasons and weekends increase traffic on roads, as well as car hit possibilities. Therefore, IKA will only be useful to compare animal kills by kilometer within the same period of time, as shown in table 1. Annual IKA is a better estimator of the potentiality of animal kills within a road.

Table 2 – Vehicle – animal collisions and estimated IKA values on several paved and dust roads in the Yucatan peninsula, Mexico.

Road	Studied distance (km)	Vehicle – animal collisions species/Individuals					Instant IKA		Annual IKA	
		Amphibians	Reptiles	Birds	Mammals	Total	Species	Individuals	Species	Individuals
Paved: Federal Cancun - Tulum	110	1/1	11/20	7/9	12/40	31/70	0.28	0.63	2.29	5.17
Federal Merida – Cancún	40	3/6	9/9	2/2	3/5	17/22	0.42	0.55	3.45	4.47
Autopista Merida – Cancun	162	0/0	6/15	5/5	9/23	20/43	0.12	0.26	1.03	2.15
Puerto Morelos – Leona Vicario	35	1/14	12/28	2/2	2/5	17/49	0.48	1.40	3.94	11.38
Dust roads: Ejido de Playa del Carmen	30	1/2	11/16	1/1	1/1	15/20	0.50	0.66	4.06	5.42
Tulum – Pachen	55	0/0	5/6	1/1	3/4	9/11	0.16	0.20	1.33	1.62
Total	432	4/23	27/94	13/21	19/77	63/215	0.14	0.49	1.18	4.04

This results show that for an average of a 30 day period, a total of 63 species were ran over, from which 4 were amphibians, 27 reptiles, 13 birds and 19 mammals; for a total of 215 individuals. From the above, reptiles and mammals are the most affected groups, with 94 and 77 organisms killed during the surveyed 30 day period. The most dangerous road was Puerto Morelos – Leona Vicario, for which special mitigation measures had to be taken.

3.3. Animal – vehicle collisions at the Yucatan peninsula studied roads

As shown in the previous table, mammals and reptiles were the most affected groups by car collisions; therefore, they will be analyzed in order to identify types and sizes of wild animals that need crossing facilities in the studied Mexican roads.

The most ran over species of mammals at the Yucatan peninsula roads were the Virginia opossum (*Didelphis virginiana)* followed by the northern tamandua (*Tamandua mexicana*), the tropical opossum, raccoons, coati and even bats. From the above, only *T. mexicana* is protected by law (NOM-059-SEMARNAT-2010) (table 3).

Table 3 – Estimated annual IKA values for mammals in paved and dust studied roads on the Yucatan peninsula for a year period.

Species	UTM coordinates		Date	Number of hits	Annual IKA
Artibeus jamaicensis	464244	2251471	22/08/2010	9	0.169
*Coendou mexicanus**	514192	2318712	10/07/2010	1	0.018
Conepatus mesoleucus	401974	2300043	16/08/2010	2	0.037
Dasyprocta punctata	469665	2260561	10/07/2010	1	0.018
Dasypus novemcinctus	431034	2308355	16/08/2010	5	0.094
Didelphis marsupialis	478725	2319363	16/08/2010	9	0.169
Didelphis virginiana	475606	2267204	10/07/2010	14	0.263
Eumops glaucinus	372103	2294270	16/08/2010	1	0.018
Glossophaga soricina	473647	2265309	10/07/2010	2	0.037
*Leopardus pardalis**	458646	2241856	04/07/2010	1	0.018
Nasua narica	465930	2254264	11/08/2009	8	0.150
Pecari tajacu	432121	2280063	04/07/2010	1	0.018
Procyon lotor	463317	2249444	26/08/2009	8	0.150
Rattus rattus	489573	2282003	20/08/2009	1	0.018
Sciurus yucatanensis	494915	2366828	06/07/2010	1	0.018
Sylvilagus floridanus	403132	2300394	16/08/2010	1	0.018
Spilogale putorius	469225	2260227	11/08/2009	1	0.018
*Tamandua mexicana**	468357	2258634	20/08/2009	9	0.169
Urocyon cinereoargenteus	460531	2244566	26/08/2009	2	0.037

*Species protected by law (NOM 059 SEMARNAT, 2010)

Reptiles were the second most affected group, specially, coral snake (*Micrurus diastema*), the basiliscus (*Basiliscus vittatus*), Terrestrial Snail Sucker (*Tropidodipsas sartorii*), Boa (*Boa constrictor*) and the Mexican Snail-eating snakes (*Dipsas brevifacies*). From the above, the boa is protected by Mexican law. In table 4, we present IKA values for reptile species.

Table 4 – Estimated annual IKA values for reptiles in paved and dust studied roads on the Yucatan peninsula for a year period

Species	UTM coordinates		Date	Number of hits	Annual IKA
Ameiva undulata	463834	2314962	17/07/2010	2	0.037
Aspidoscelis angusticeps	441756	2248439	22/08/2010	1	0.018
Basiliscus vittatus	484921	2277079	14/08/2010	7	0.131
*Boa constrictor**	470864	2262144	24/08/2009	7	0.131
Bothrops asper	485973	2276453	14/07/2010	6	0.112
Coniophanes schimidti	466457	2314152	19/07/2010	1	0.018
Conophis lineatus	490800	2308820	07/07/2010	2	0.037
*Crotalus simus**	489246	2282216	25/08/2009	3	0.056
*Ctenosaura similis**	482885	2273912	11/08/2009	3	0.056
*Dipsas brevifacies**	497974	2306750	17/07/2010	7	0.131
Drymarchon melanurus	392570	2297280	26/08/2010	5	0.094
Elaphe flavirufa	447244	2243579	22/08/2010	3	0.056
*Kinosternon leucostomum**	504911	2298111	10/07/2010	1	0.018

Species	UTM coordinates		Date	Number of hits	Annual IKA
*Laemanctus serratus**	506980	2306053	22/07/2010	2	0.037
Lampropeltis triangulum *	487630	2313258	06/07/2010	2	0.037
Leptodeira frenata	498912	2306678	18/08/2010	3	0.056
*Leptophis mexicanus**	479439	2288437	30/06/2010	6	0.112
Micrurus diastema	466871	2256027	20/08/2009	9	0.169
Oxybelis aeneus	485750	2283079	26/08/2009	3	0.056
Oxybelis fulgidus	486101	2283479	30/06/2010	2	0.037
*Porthidium yucatanicum**	488493	2282670	15/07/2010	1	0.018
Sibon nebulatus	483490	2278866	23/08/2010	1	0.018
Spilotes pullatus	470926	2262238	20/08/2009	3	0.056
Stenorhina degenhardtii	486431	2282369	24/08/2009	1	0.018
*Symphimus mayae**	503917	2306285	18/08/2010	2	0.037
*Thamnophis proximus**	475634	2319611	24/08/2010	4	0.075
Tropidodipsas sartorii	452493	2229511	26/08/2009	7	0.131

*Species protected by law (NOM 059 SEMARNAT, 2010)

For amphibians, only a few species were found in car kills, mainly during the rainy season. Also, as frogs and some toads are small animals, their corpses frequently cannot be identified from the pavement. In table 5 we show IKA values for amphibians.

Table 5 – Estimated annual IKA values for amphibians in paved and dust studied roads on the Yucatan peninsula for a year period

Species	UTM coordinates		Date	Number of hits	Annual IKA
Hypopachus variolosus	466148	2305874	19/07/2010	1	0.018
*Lithobates berlandieri**	507705	2305996	17/08/2010	7	0.131
Ollotis valliceps	485475	2276037	21/08/2009	10	0.188
Smilisca baudini	486896	2314114	17/08/2010	5	0.094

Our results show that for each 6.95 km, a different species is run down by a car, an amphibian, reptile, bird or mammal; while for each 0.49 km, there is one individual killed by a car hit in the Yucatan peninsula.

According to such results, the main objective of a road must be to allow a higher rate of wildlife survival, increasing habitat connectivity and enableling animal populations to safely cross from one side to the other. Therefore, mitigation actions, and in particular, crossing structures need to be included.

As shown in our results, fauna within the studied area is composed mainly by medium and small sized mammals as well as small reptiles and amphibians, for which the construction of large overpasses, and their expenses, may not be entirely justified. There are a few large and very important mammals within our study area, like pumas and jaguars. But in this work, we will try to find low budget solutions to reduce barrier effect on the rest and most abundant mammals.

3.4. Preferences in drainage structures by mammals and some proposed designs

As shown in paragraph 3.1, tropical environment mammals in our study areas use existing drainage structures to cross roads; even small 1m diameter tubes, therefore, our proposal is to include modified regular drainage structures in strategic places so that they may work as fauna crossings. With some preliminary data on our study in the Tuito-Melaque road, at the state of Jalisco, we tried to identify if there was a type of structure preferably used by animals (table 6). At this study site, most abundant mammals were badger, racoon, white tail deer, wild boar, ocelot, fox and armadillo; most of them, except for the deer, small and medium mammal's crossing over different drainage structures along the road.

Table 6 – Mammals crossings recorded on Federal road 200, Tuito –Melaque, Jalisco.

Road fragment	Drainage structures				Run over animals					Number of recorded crossing individuals/camera	Num. Species
	Barrel vaults	Tubes	Box culverts	Total	Mammals	Birds	Reptiles	Amphibians	Total		
0+000-10+000	17	55	3	75	4	1	2	0	7	30	4
10+001-20+000	4	44	11	59	19	1	6	1	27	31	4
20+001-30+000	7	49	3	59	6	0	5	0	11	6	2
30+001-40+000	5	37	14	56	11	4	6	0	21	0	0
40+001-50+000	4	29	25	58	18	2	7	2	29	12	2
50+001-60+000	8	46	9	63	6	1	5	2	14	12	5
60+001-70+000	1	35	6	42	13	3	6	2	24	0	0
70+001-80+000	6	27	16	49	3	4	3	1	11	13	5
80+001-90+000	3	20	15	38	5	0	1	0	6	11	2
90+001-100+000	3	12	10	25	6	3	4	1	14	0	0
100+001-110+000	4	17	11	32	6	0	5	0	11	0	0
110+001-120+000	11	37	5	53	11	1	3	0	15	3	1
120+001-130+000	0	22	4	26	4	1	2	1	8	0	0
130+001-140+000	1	10	8	19	10	3	3	3	19	0	0
140+001-150+000	2	35	4	41	4	2	2	0	8	0	0
150+001-160+000	5	38	0	43	5	0	0	0	5	7	1
160+001-169+300	9	50	3	62	3	0	0	0	3	2	1
Total	90	563	147	800	134	26	60	13	233		

With this data, we found that there is a moderate relationship between drainage structure number and animal crossings, accounting for almost 40% of the variance (figure 1). This structures were not intended to work as fauna passes, but to allow water flow, therefore we consider they have eventually became animal crossings and a lot of animals are using them.

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Figure 1- Relationship between total amount of drainage structures within each road fragment, and registered mammals crossings.

We wanted to see if there was also a relationship between animal crossings and type of drainage structure. As presented in figures 2a, 2b and 2c, animals do cross more through barrel vaults and tubes, rather than box culverts. We believe that box culverts are large enough for cattle to go through, therefore, some of them they may be used for such purposes, which will explain wild mammal preferences.

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Figure 2- Different types of drainage structures in relation to animal crossings

Even though our results are preliminary, we think that simple modifications to existing drainage structures and the addition of some of these structures to new roads (figure 3), strategically built along wildlife corridors, will be a good, low budget solution to road barrier effect in tropical undeveloped countries like Mexico. It is easier to build a large enough amount of drains in roads, to reduce connectivity blocking, than to build large and expensive overpasses.

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Figure 3 - Example design of modifications for existing drainage structures to allow fauna crossings as well as water flow, in a mix function to increase road permeability.

4. CONCLUSION

As an answer to our original questions, is wildlife using ordinary drainage structures to cross roads? We can rely on our results for different roads in tropical ecosystems in Mexico and say, yes they are. Also, to the question of what type, size and characteristics of drainage structures are preferred by fauna? Our data so far show that animals prefer barrel vaults (probably because of their size and shape) and tubes (larger than 1m diameter), over wide box culverts that may be also used by cattle. Nevertheless, we are still acquiring new data and will analyze them in detail to be able to identify optimal size and characteristics of drainage structures to different types of animals.

Road mitigation main purpose is to reduce fragmentation and barrier effect within a region. Design and construction of drainage structures to work as fauna crossings will fulfil such purposes, as they will imply more and better options for animals to use, reducing car kill risks.

According to our results, we consider that modification and adjustment of existing and regularly used drainage structures on roads, which imply an increase in their dimension, addition of shelves or sidewalks, etcetera (example figure 3), as well as their strategic localization; in association with a vegetation restoration scheme to induce fauna movements towards such structures, could be, low cost mitigation measures for barrier effect and connectivity loss in undeveloped countries.

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