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Mammal use of some crossing structures in a Federal Highway in Jalisco, México

Uso por mamíferos de estructuras de cruce en una autopista federal en Jalisco, México

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Since the construction of Federal Highway 200 in the coast of Jalisco, México, there have been environmentally detrimental processes along its length. With no wildlife crossing structures built at the time, mammal connectivity has been "safely" maintained through streams and rivers and their corresponding bridges. We used photo-trapping to assess 2 bridges and 1 culvert in the vicinities of Careyes within the influence area of the Chamela-Cuixmala Biosphere Reserve from November 2020 to March 2021. We compared bridges with upstream cameras to see whether there were differences in species richness and relative abundance. With 736 camera / nights, we obtained a total of 421 mammal records, of which 252 were crossings of 14 mammal species, 12 native and 2 introduced beneath the highway, 241 through bridges, and 11 through the culvert. Upstream cameras showed higher mammal diversity values compared to the bridges. Streams and bridges serve to maintain mammal connectivity through the highway. Ungulates might cross the highway more often than carnivores due to their reticence of going near roads. Future wildlife crossing structures along this highway should keep this in mind.

Key words: Bridge; Careyes; Chamela-Cuixmala; drainage; underpass.

Desde la construcción de la carretera Federal 200 en la costa de Jalisco, México, se ha generado una serie de procesos de degradación a lo largo de ésta. Sin tener ningún paso de fauna construido, la conectividad "segura" de los mamíferos se ha mantenido a través de arroyos y ríos con sus correspondientes puentes. Utilizamos foto-trampeo para monitorear 2 puentes y 1 alcantarilla en las inmediaciones de Careyes, dentro del área de influencia de la Reserva de la Biosfera Chamela-Cuixmala de noviembre 2020 a marzo 2021. Comparamos los puentes con cámaras arroyo-arriba para ver si existen diferencias en riqueza de especies y abundancia relativa. Con un esfuerzo de 736 noches / cámara obtuvimos un total de 421 registros de mamíferos, de los cuales 252 correspondientes a 14 especies de mamíferos, 12 nativas y 2 introducidas, que cruzaron por debajo de la carretera, 241 a través de puentes y 11 por alcantarilla. Las cámaras arroyo-arriba mostraron una mayor diversidad de mamíferos comparadas con los puentes. Los puentes de los arroyos sirven para mantener la conectividad de los mamíferos a través de la carretera. Los ungulados pueden utilizar la carretera más frecuentemente que los carnívoros debido a su reticencia a acercarse a caminos. Futuras estructuras de paso de fauna en esta carretera deben tener lo anterior en mente.

Palabras clave: Careyes; Chamela-Cuixmala; drenajes; pasos de fauna; puente.

The environmentally most dangerous roads are those that penetrate relatively pristine regions (Laurance *et al.* 2009). New roads in forested areas can greatly increase deforestation because forest loss is spatially highly contagious (Boakes *et al.* 2010) and because an initial road often spawns networks of secondary and tertiary roads that can significantly increase the spatial extent of habitat disruption (Laurance 2015). The coast of Jalisco was practically isolated until the early 1970´s with the construction of Federal Highway 200. With the construction of the highway began a series of environmental deterioration processes with the following increase of human settlements, massive deforestation for agriculture and cattle grazing, and associated illegal hunting (Ceballos and García 1995). One of the few protected areas in that coast is the Chamela-Cuixmala Biosphere Reserve (CCBR; Ceballos and Garcia 1995), located on the coast of the State of Jalisco, protecting 13,142 ha of natural areas, mainly comprised of deciduous forest, gallery forest, and marshes. This place is home to 69 species of mammals out of which 16 species are considered endemic and 10 under protection (Instituto de Biología UNAM 2019). Most species are of terrestrial habits with only three strictly arboreal, and some other scansorial (Ceballos and Miranda 2000). The search for run over animals on several highways on the coast of Jalisco, including Highway 200, showed that the majority were mammals (57 %; Lara-Gómez 2008). The most frequent roadkills were opossums (*Didelphis virginiana*) and armadillos (*Dasypus novemcinctus*) with both covering 30 % of the records, followed by skunks (*Mephitis macroura*), raccoons (*Procyon lotor*), coatis (*Nasua narica*) and grey foxes (*Urocyon cinereoargenteus*; Lara-Gómez 2008).

No mitigation measures were built along this highway, but there are several bridges crossing the various streams and rivers of the area for topographic reasons. Even it has been observed that the use of a wildlife crossing structure does not necessarily equate to its effectiveness to maintain the connectivity on the landscape, several studies have demonstrated that a broad range of species use the structures, and the optimal design and placement of crossing structures is often species-specific and that crossing rates depend on both landscape and structural features (Van der Grift *et al.* 2013). Streams are important natural features that serve as biological corridors for most species. Many mammal species move through the landscape along riparian corridors and crossing structures along waterways will likely be optimal for them (Clevenger *et al.* 2002). Measuring the rate of use by wildlife is an important first step in almost every evaluation of wildlife crossing structures. In many studies, monitoring is limited to registering passing animals at the crossing structures, without measurements at control sites. Essential variables are often not measured, which hinders the interpretation of data and makes it impossible to compare the functioning of multiple structures (Van der Grift and Van der Ree 2015).

The present study objective assesses the use by mammals of some of the actual crossing structures along Federal Highway 200 to determine their potential role to facilitate the movement of medium and large size mammals between the coast and the upland area, in the influence area of Chamela-Cuixmala Biosphere Reserve. This study will serve as reference for further road projects and their mitigation efforts to maintain mammal connectivity in the area.

The study area is in the municipality of La Huerta, Jalisco, México, within the influence zone of the Chamela-Cuixmala Biosphere Reserve (CCBR), in the surroundings of Careyes residential area. We chose a 7 km segment of Federal Highway 200 connecting Melaque-Puerto Vallarta with Careyes as the center and monitored all existing crossing structures, consisting of 2 bridges, and 1 concrete culvert (Figure 1). The highway is paved and has two-way lanes and a width of 8 m. Each bridge was a concrete structure of *ca.* 15 m in length, 8 m wide and had a height of *ca.* 5 m (Figure 1A-B). The concrete arch culvert was of *ca.* 8 m length, 1 wide, 1.5 m high located 5 km south of the Careyes stream with rocky ground cover (Figure 1C). The terrain is rugged and hilly with seasonally dry streambeds, known locally as *arroyos*, separating the prominent hills. Streams are ephemeral, and during the dry season free water is found only in scattered, isolated pools in the *arroyos*. The study site has a dry tropical climate exhibiting a marked seasonality in precipitation, with 85 % of the 748 mm average annual rainfall occurring from June to November, and a prolonged drought from mid-February to late May (Bullock 1986). The dominant vegetation type is tropical dry deciduous forest, with semideciduous forest in the larger *arroyos* (Lott 1993).

Photo-trapping (Mixmart HC-800A) was used to record mammal crossings beneath the highway on the Careyitos and Careyes streams and a natural drain going through 1 concrete culvert. We set 5 camera trap stations in total. Two camera trap stations on each stream, located one under each bridge where the stream crosses the highway and one upstream further away from the highway (300 m in the Careyitos stream, and 1,000 m for Careyes stream); another in the entrance of the arch culvert. Structures were surveyed for approximately 5 months (November 2020 to April 2021), covering most of the dry season, when stream beds are dry, and mammals can walk freely without water hindering their motion. Cameras were programmed with a 16 MP resolution, high sensitivity in the motion sensor, to fire 3 shots for each triggering event with a one-minute delay.

Once retrieved from the memory cards, the photographs were stored and processed using Camera Base 1.7 (Tobler 2010). We excluded all the non-mammal pictures. We identified the photographed species using Ceballos and Miranda (2000). We considered independent events those consecutive photographs of the same species separated for at least 1 hr (Tobler *et al.* 2008). We used independent photographic events to approximate the abundance of each species (Ramesh and Downs 2015). To calculate the sampling effort per station, we obtained the number of camera days that each camera station functioned, counting the number of days from activation to the last photograph taken. We considered a camera night to be a period of 24 hr during which the camera was operating. Total sampling effort for each structure was obtained by adding the number of camera days that each camera station operated on each station (Ramesh and Downs 2015). For each target species, capture rate was calculated as an estimate of relative abundance: Capture rate = number of detections / number of camera trap nights *100 (Glen *et al.* 2014).

We performed all the data analyses with the independent events obtained as a proxy for species abundance for each station and then by stream (Careyes and Careyitos) comparing bridge stations against upstream stations. We did asymptotic diversity profiles, based on statistical estimation of the true Hill number for q = ^{0}D (species richness, Sobs), ^{1}D (Shannon´s exponential index, e^{H}) and ^{2}D (inverse Simpson´s index, 1 / D) for the different bridge and upstream stations using iNext software (Chao *et al.* 2016). We estimated diversities for standardized samples with a common sample size or sample completeness. Hill numbers, or the effective number of species, are increasingly used to characterize the taxonomic, phylogenetic, or functional diversity of an integrated assemblage curves. It is based on sampling theory that smoothly link rarefaction (interpolation) and prediction (extrapolation) and standard-

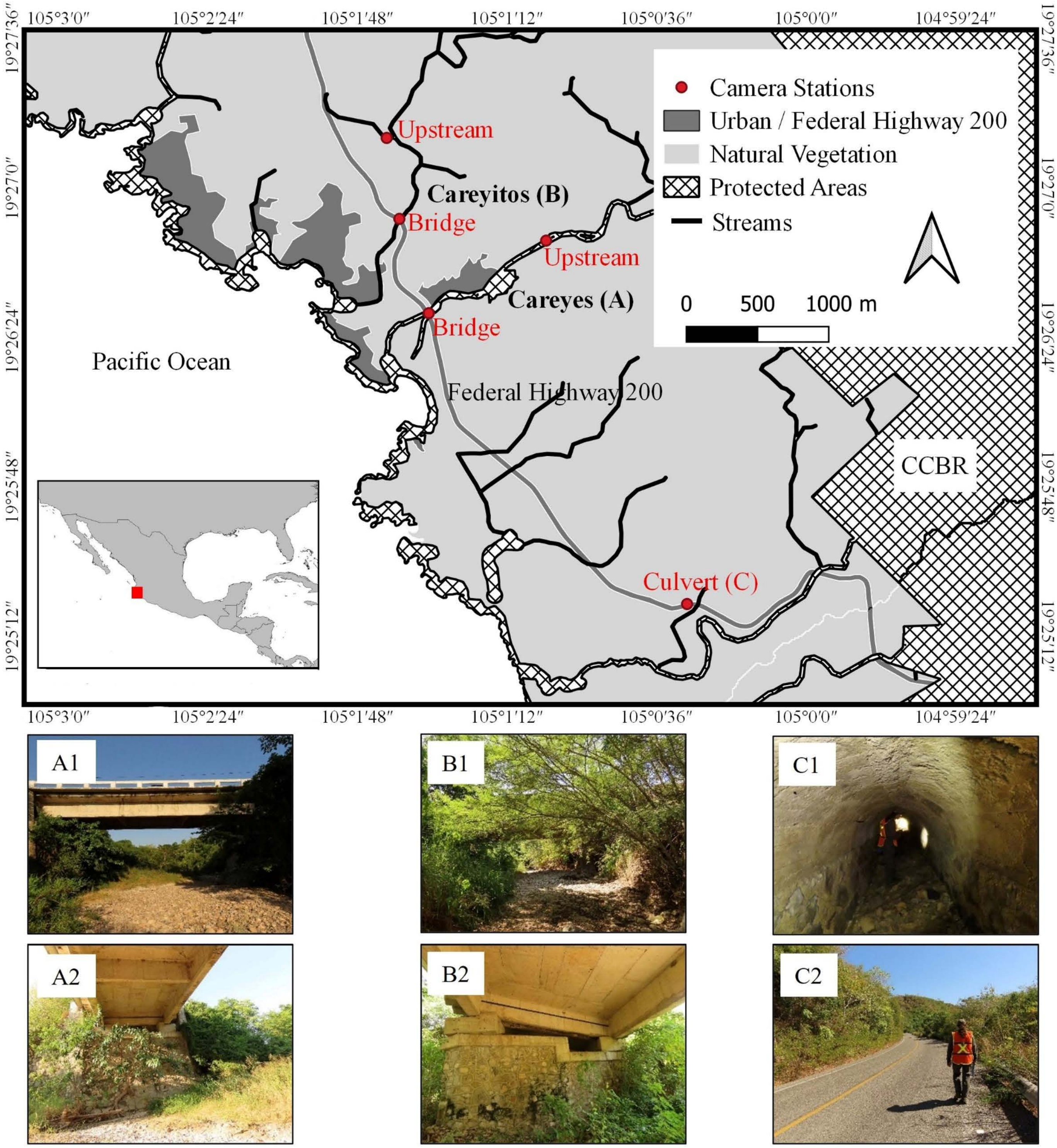

Figure 1. Location of surveyed drainage structures along Federal Highway 200, Jalisco, México. In map: Careyes (B1) and Careyitos (B2) streams with their bridges and their upstream cameras (U1 and U2) and concrete culvert with close-ups of the different streams and structures. A1) Careyes bridge viewed from stream and A2) under bridge; B1) Careyitos stream and B2) under bridge; C1) concrete culvert, C2) culverts location from highway at the end of the curve. All crossing structures crossed the whole width of the highways 8 m. Chamela-Cuixmala Biosphere Reserve and other protected areas appear with a grid, urban areas and highway in dark grey, streams in black, camera stations in red.

izes samples based on sample size or sample completeness and facilitate the comparison of biodiversity data (Chao *et al.* 2014). We did rank-abundance graphics for beta diversity and community structure to see how species changed in terms of photographic events recorded for each station.

With an effort of 736 camera / nights we recorded a total of 421 mammal records, of which 252 were crossings beneath Federal Highway 200, 241 through both bridges (158 for Careyes and 83 for Careyitos) and 11 through the culvert crossings (Table 1). A total of 14 mammal species were recorded, of which 3 are species under protection (NOM-059-SEMARNAT-2010; SEMARNAT 2010): the ocelots (*Leopardus pardalis*) and the jaguarundi (*Herpailurus yagouaroundi*) both considered endangered (P), and the pygmy

Table 1. Mammal species recorded crossings beneath Federal Highway 200 at Careyes and Careyitos bridges together with a nearby culvert in Jalisco, México. Each bridge had an upstream camera station on the same streams for comparison.

				Careyes		Careyitos		
Family	**Species**	**Endemic**	**NOM-059-SEMARNAT-2010**	**Bridge**	**Upstream**	**Bridge**	**Upstream**	**Culvert**
Didelphidae	*Didelphis virginiana*			8	11	54	20	
Canidae	*Canis familiaris**			1	1			
	Canis latrans					1		
	Urocyon cinereoargenteus			1	4	3		
Procyonidae	*Nasua narica*			2	8	5	14	6
	Procyon lotor			9		1	1	
Mephitidae	*Spilogale pygmaea*	X	A		1			
Felidae	*Felis catus**			2				
	Herpailurus yagouaroundi		A					1
	Leopardus pardalis		P	5	19	2	46	2
	Puma concolor				7		9	
Leporidae	*Sylvilagus cunicularius*	X					1	
Cervidae	*Odocoileus virginianus*			77	7	14	5	
Tayassuidae	*Dicotyles angulatus*			53	0	3	15	2
Total records	421			158	58	83	111	11
* Invasive species								

skunk (*Spilogale pygmaea*) as threatened (A). When comparing bridges with the upstream cameras and their diversity profiles (q0 - q2) we found no significant difference (as confidence intervals overlap) speaking of species richness (q0 = 8.99 - 9.99). Nevertheless, differences appear (q1 - q2) where diversity values are lower under the bridge (3.47 - 3.84) than farther upstream (5.3 - 7.49; Figure 2). When comparing bridges against the culvert we found that the bridges allow far more species (q0 = 9.9 average) than the culvert (q0 = 4.23 average). Also, species composition (species related to their relative abundance) varied between the bridge and upstream camera stations (Figure 3). In general terms, species with the highest number of records using bridges were white-tailed deer (*Odocoileus virginianus*, 91), opossums (*Didelphis virginiana*, 62) and peccaries (*Dicotyles angulatus*, 56). While in upstream cameras, highest number of records were for ocelots (65), opossums (31), coatis (22), pumas (16), white-tailed deer (12), and peccaries (15) though not present in one upstream station (Tables 1 and 2).

We found differences in species composition and abundance in the same streams between the bridges and the upstream stations. The bridges had a higher ungulate presence while the upstream had more felines (pumas and ocelots). This could be explained by the reluctance of felines towards roads as seen by Conde *et al.* (2010), where jaguar probability of occurrence declines with increasing proximity to roads. If this is true, then ungulates might be closer to the highway as a safer zone for them. This does not mean that predators such as felines do not cross beneath

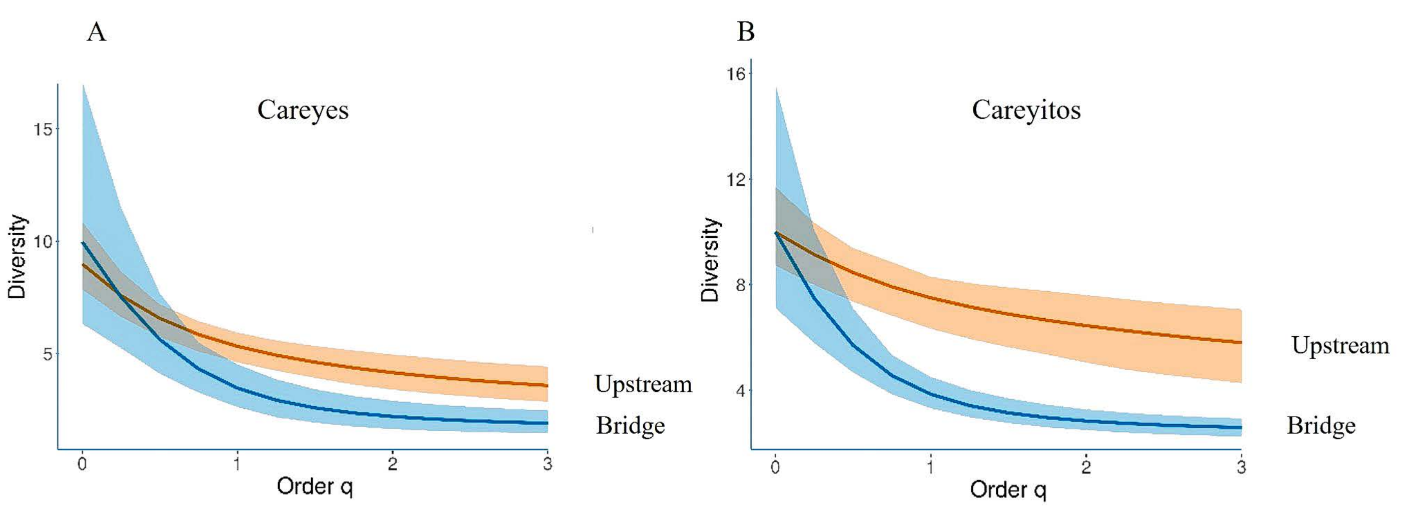

Figure 2. Diversity profile (q0 - q2) of Careyes and Careyitos streams. A) Careyes and B) Careyitos with bridge and upstream diversity profile, respectively. Species richness (q0), inverse Simpson (q1) and Shannon exponential (q2).

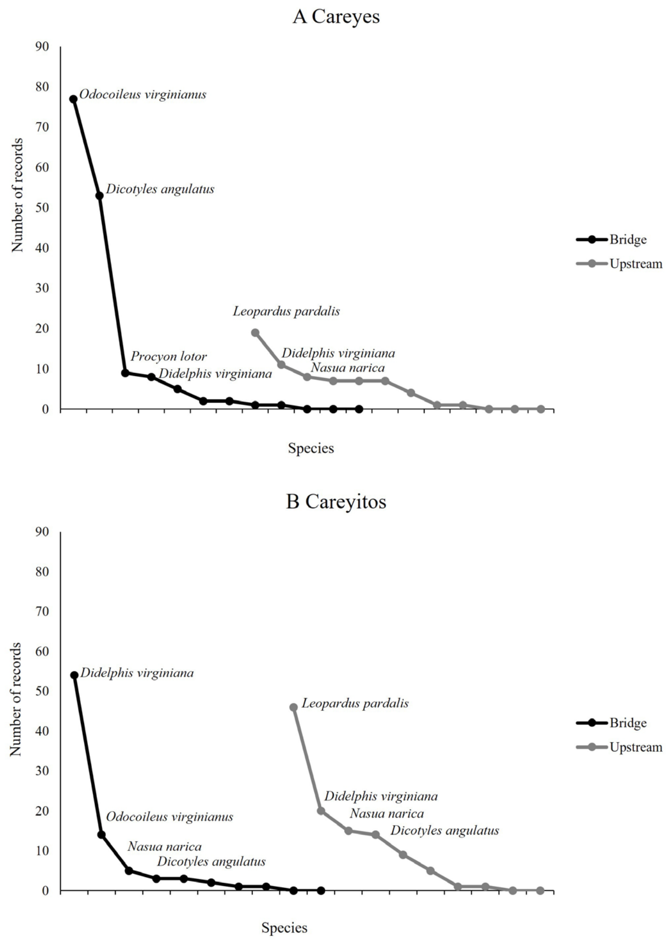

Figure 3. Mammal community assemblage per station in Careyes and Careyitos streams. A) Careyes and B) Careyitos with bridge community in black and upstream community in grey, with most abundant species labeled.

the highway, but they might be doing so in a lesser degree. In the case of ocelots, we have evidence they are going through both bridges and culverts, with bigger species such as pumas and jaguars. Even though we did not have records, there is evidence that these species can use these crossing structures (González-Gallina *et al.* 2018).

We found streams enable connectivity for ungulates across the highway, as we registered both white-tailed deer and collared peccaries of both sexes, adults and offspring crossing beneath the bridges. Till this point, it was unclear if these ungulates would use streams as a way of moving around the landscape. Previous studies by Mandujano *et al.* (2002) found in the CCBR that white-tailed deer preferred hillsides oriented to the north rather than streams and that peccaries formed bigger groups near streams for better protection against predators (5-12 individuals; Mandujano and Martínez-Romero 2002). Jaguars and pumas in the CCBR prefer streams and their associated vegetation (subperennifolia forests) using them to move through the landscape (Núñez-Pérez and Miller 2019).

Contrary to previous reports in México (González-Gallina *et al.* 2018), we recorded highway crossing of peccaries in bridges and culverts, indicating that there is probably some behavioral trait there that prevents them from using such structures in the Yucatán Peninsula. The fact that the González-Gallina *et al.* (2018) study was performed only a short period of time after the construction of the wildlife underpasses could prevented the use of this infrastructure by peccaries, different to what occurs in our study where the highway, the bridges and the culvert have been present more than 40 years. This could indicate that peccaries need a more extended habituation period to use wildlife crossing infrastructure.

Table 2. Capture rate for mammal species recorded crossing Federal Highway 200 through bridges and nearby culvert in Jalisco, México. Each bridge had an upstream camera station on the same streams for comparison.

Species	Careyes		Careyitos		Culvert
	Bridge	Upstream	Bridge	Upstream	
Didelphis virginiana	5.13	8.03	34.39	12.74	
Canis familiaris	0.64	0.73			
Canis latrans			0.64		
Urocyon cinereoargenteus	0.64	2.92	1.91		
Nasua narica	1.28	5.84	3.18	8.92	4.65
Procyon lotor	5.77		0.64	0.64	
Spilogale pygmaea		0.73			
Felis catus	1.28				
Herpailurus yagouaroundi					0.78
Leopardus pardalis	3.21	13.87	1.27	29.3	1.55
Puma concolor		5.11		5.73	
Sylvilagus cunicularius				0.64	
Odocoileus virginianus	49.36	5.11	8.92	3.18	
Dicotyles angulatus	33.97		1.91	9.55	1.55
Sampling effort (number of night traps)	156	137	157	157	129

When building a highway that crosses a stream that exceeds the need for a simple drainage structure, it's common practice to build a bridge. In Chamela, streams are usually ephemeral running with water for just a couple of months a year, which means most of the time they remain perfectly traversable trails across the landscape. Our results showed that at least during the dry season, these structures allow mammals to pass safely below the highway, either along with the riverine vegetation or through the stream bed.

Even though some medium sized mammal species are able to use the culvert, highway drainages cannot substitute bridges or proper wildlife underpasses in terms of mammal species crossings. González-Gallina *et al.* (2018) showed that large wildlife crossing structures allow more species and larger animals to cross through the highway in tropical areas. In order to increase the wildlife crossing capacity of the culverts along the highway, future retrofitting projects should consider increasing the size of these structures to allow more species and individuals to use them, and also prevent flooding during the rainy season, all structures could benefit from drift fencing to funnel wildlife through safe passages.

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