



Federal Highway 2, "The Valley". Photo: Mirna Manteca

Recommendations to mitigate the impacts of Mexico's Federal Highway 2, on the wildlife of the Sky Islands

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ABSTRACT

Between 2016 and 2019 the impacts caused by Federal Highway 2, section **Ímuris – Sonora-Chihuahua State Limits**, on the Sonoran wildlife were monitored. This highway is one of the main barriers for ecological connectivity in the **Sky Islands**, a region considered of high biological diversity because of the convergence of the Sonoran Desert, the Chihuahuan Desert, the Western Sierra Madre and the Rocky Mountains. This road specifically affects diverse species and fragments the habitat of threatened or endangered mammals (NOM-059 SEMARNAT 2019) that have a wide range of distribution such as black bear (*Ursus americanus*), ocelot (*Leopardus pardalis*) and jaguar (*Panthera onca*).

In 2016, 2018 and January 2019, we carried out sampling efforts every two weeks to document wildlife roadkill, registering a total of **330 individuals of 43 species, seven of them listed in some category of protection**. The most frequently registered species were coyote (*Canis latrans*), *Mephitis* skunks, gray fox (*Urocyon cinereoargenteus*), *Sylvilagus* rabbits, *Lepus* hares and coachwhip snake (*Masticophis flagellum*). In addition to the regular monitoring, we registered a **female black bear roadkill in September 2018, 25 km northeast of Ímuris, Sonora**.

We subsequently analyzed the data and identified **27 critical sites** along the Ímuris – Sonora-Chihuahua State Limits section (Sky Islands stretch), of which 14 are located in the Sierra Azul-El Pinito wildlife corridor and the Cocóspera River valley, six in the grasslands between the cities of Cananea and Agua Prieta and the remaining seven in the Sierra Peloncillo wildlife corridor.

In 2017, we registered 707 highway drainages and bridges which we classified by type, size and potential use by wildlife. In 2018, we placed a total of 24 camera traps in a selection of these drainages in two wildlife corridors: **Sierra Azul-El Pinito**, located approximately 20 kms northeast of Ímuris near the Area Designated Voluntarily for Conservation (ADVC) Rancho El Aribabi, and **Sierra Peloncillo**, located 60 km east of Agua Prieta, dividing the ADVC Los Ojos. To date, **our cameras have registered 18 species using drainages to cross the road** including cougars (*Puma concolor*) and several small and medium mammals.

To reduce wildlife roadkill and restore habitat connectivity, we recommend the construction of wildlife crossings, inductive fencing, construction of escape ramps and clearing of drainages. Our studies allow us to determine the most suitable areas to establish these mitigation measures in order to reduce the impact of this road on the regional wildlife.



INTRODUCTION

The expansion and construction of new roads is commonly perceived as an indisputable symbol of development and progress. By connecting important sites or reducing travel time between them, road infrastructure naturally provides a benefit to society and economy. However, we rarely realize that the road system also represents a major barrier for wildlife movement.

By fragmenting ecosystems, limiting the access to resources and changing animal behavior patterns, roads are a strong threat to both individual species and entire ecosystems.



Bear (*Ursus americanus*) roadkill, east of Ímuris, September 2018.
Photo: Soy Cobre

Fragmentation tends to create small and isolated animal populations from larger and better-connected populations. These subpopulations have a higher probability of extinction than larger ones (Primack, 1998). Some of them are so reduced that the reproductive processes are altered, resulting in local extinctions. Additionally, species recovery efforts from small populations are interrupted as the recolonization process is hampered by road barriers.

Some additional negative effects caused by roads are: wildlife mortality due to collisions with vehicles, changes in reproductive patterns, changes in dispersal and migration patterns, air and soil pollution, dispersal of invasive exotic plants, among others.

In Sonora, these factors affect populations of threatened and endangered species such as black bear (*Ursus americanus*), ocelot (*Leopardus pardalis*), American badger (*Taxidea taxus*) and jaguar (*Panthera onca*).

Concerned about these impacts on the Sonoran ecosystems, several Citizen Organizations along with academics and landowners, have collaborated since 2016 to collect technical and scientific information of Federal Highway 2's effect on wildlife, specifically the section from the city of Ímuris, Sonora, to the Chihuahua State Limits. Since 2010, this highway began a process of roadway expansion and construction of additional lanes in different sections.



This report compiles collaborative work of Wildland Network, Sky Island Alliance and Ecology for the Conservation of the Great Desert (EcoGrande), A.C. Its objective is to present the results of the research of our organizations. Also, we include a series of recommendations to mitigate the effects of habitat fragmentation and roadkill.

Study Area

The Ímuris – Sonora-Chihuahua State Limits section of Federal Highway 2, located in the northeast of Sonora near the United States borderline, covers 243 kms and crosses four municipalities. Starting at the lowest part (800 m.a.s.l) is the municipality of Ímuris, continues northeast through the municipalities of Cananea, Naco and Agua Prieta (1,900 m.a.s.l.). The most common and representative climate in the area is temperate semi-dry with low rainfall and high temperatures. The Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO) classifies this region as belonging to the Sonoran biogeographic province, Northern Chihuahuan Plateau and portions of the Western Sierra Madre (CONABIO, 1997).

Ímuris – Sonora-Chihuahua State Limits section of Federal Highway 2



In the region, arid shrubs dominate; however, the altitude differences and the influence of the Western Sierra Madre ecosystems originate a diverse plant composition from temperate to cold climate. As a result, the area has pine and oak forests and grasslands that emerge between wide extensions of plains and gentle hills that, depending on the altitude gradient, can be covered with grasslands or desert scrub. The highest parts lead to the famous Sky Islands where diverse biotic influences converge such as the Chihuahuan and Sonoran deserts, the Western Sierra Madre and the Rocky Mountains due to their latitudinal location. For this reason, the region that crosses the Ímuris – Sonora-Chihuahua State Limits section of Federal Highway 2 is considered of high biological diversity and a priority for conservation (Turner et al., 2005).



White-tailed deer (*Odocoileus virginianus*). Photo: Wildlands Network

In this region there are a great variety of ecosystems that promote a wide variety of wildlife. For example, the Madrean forest is the typical habitat for the white-tailed deer (*Odocoileus virginianus*) in northwest of Mexico, the oak-pine areas are the best habitat for the white-nosed coati (*Nasua narica*) and the black bear (*Ursus americanus*). Other mammals that can be considered indicators of the conservation status of the community are yellow-nosed cotton rat (*Sigmodon ochrognathus*), Southern pocket gopher (*Thomomys umbrinus*), Mexican fox squirrel (*Sciurus nayaritensis*), Bailey's pocket mouse (*Perognathus baileyi*), Eastern cottontail (*Sylvilagus floridanus*) and Neotropical otter (*Lontra longicaudis*). Some notable species are the wild cats that have been registered in the area: jaguar (*Panthera onca*), cougar (*Puma concolor*), ocelot (*Leopardus pardalis*) and bobcat (*Lynx rufus*). This region was also the backdrop for the first reintroduction of the Mexican wolf (*Canis lupus baileyi*) to the state of Sonora in 2011 (Lara et al., 2015).

METHODOLOGY

Roadkill Monitoring

Wildlife needs wide, connected landscapes to find resources like food, water and shelter. For species like wolf, bear or jaguar, to travel from one mountain range to another is the human equivalent of walking from the kitchen to the bathroom in our homes. Although roads are



dangerous places, wildlife try to cross them in order to access the resources they need. Many individuals die trying.

In order to find out which wildlife species are dying on Federal Highway 2, we conducted roadkill inventories every two weeks in both 2016 and 2018, from Ímuris to Cananea and from Cananea to the Sonora-Chihuahua State Limits. We carried out the samplings by driving a car at an average speed of 50 km/h. The copilot was the main observer of the road in order to attain the most possible registries. When we found roadkill, we made sure that there was a safe place to park, get out of the car and register the data.



American badger (*Taxidea taxus*), between Cananea and Agua Prieta.
Photo: Sky Island Alliance-Wildlands Network

For each roadkill incident we registered geographical coordinates, photographs, date, time and identification of the animal at a species level when possible. We complemented the samplings of roadkill with registries of live fauna that were observed both on the road and 50 m to either side of it.

Identification of species

We carried out the procedure of species identification *in situ* where the corpse was found. However, it was not possible to identify all the individuals down to a species level due to the degree of decomposition they presented and because they lost their shape by being constantly crushed by vehicles.

We registered photographs and data of each observation in the free app **iNaturalist** using a smartphone. iNaturalist is a social network, database and citizen science platform where scientists and general public can record observations of fauna, flora and fungi. Roadkill records were subjected to an additional round of identification and confirmation by specialists and dedicated iNaturalist volunteers. All records are publicly available on the platform within the project led by the Sky Island Alliance organization called Sky Island Nature Watch as well as in the project ***Registro de Fauna Atropellada en Carreteras Mexicanas***.



Data analysis

We analyzed roadkill data using the program ArcGIS where the road line was divided into sections of 100 m and each was assigned a value equivalent to the number of registries made in said section. A moving average was calculated for each section using the formula: $x_1 + 0.5*(a_1 + a_2) + 0.25*(b_1 + b_2)$. The following table represents the formula applied in the ArcGIS. Each cell is equivalent to a 100 m section of road.

b_1	a_1	x	a_2	b_2
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In this manner, the observations of individual corpses are translated into a visualization of “hot spots” or important areas where there is a higher incidence of roadkill, which helps us to prioritize sections of the road where we should focus mitigation efforts.

Inventory of drainages and bridges

Drainages and bridges are structures that allow roads to follow a uniform line despite topography while allowing water to flow underneath thus reducing the impact of rivers, streams and temporary flooding on their surfaces. Despite the fact that most of the existing road networks were built before we knew with certainty the impact they have on ecosystems, some of the drainage structures are used by wildlife to cross under roads.

We made an inventory of each drainage and bridge in the Ímuris – Sonora-Chihuahua State Limits section through observations on both sides of the road. We registered the geographic coordinates, width and height of each structure as well as the description of their shape.

We created a database with the following elements:

- Numerical identification of each drainage
- Latitude and longitude
- Altitude



Evaluation of drainages. Photo: EcoGrande



- Name designated by the Mexican Secretariat of Communications and Transportation (SCT)
- Chaining (numbering in kilometers according to the road signs)
- Approximate distance, in meters, between the kilometers where the drainage is located
- Type of drainage structure
- Shape
- Type of construction material
- Height and width
- Drainage opening area in square meters
- Size and classification of the structure (classification according to its recommended dimensions for different sizes of wildlife)
- Wildlife crossing potential
- Elements and observations on the problem in the design and maintenance of drainages
- Visual percentage from one end to the other of each structure

With this database, a shapefile was created to be used in any Geographic Information Systems project and to be able to analyze obtained data.

Structure size

We registered this variable on field, classifying drainages into three categories according to their dimension, in order to segregate the kind of wildlife that could use them to cross the road. When, describing the suitability of the large and medium structures, we not only considered them to accommodate wildlife of one size category, but also of any smaller categories. The categories are:

- Drainages suitable for small animals (1)
- Drainages suitable for medium animals (2)
- Drainages suitable for large animals (3)






The category of drainages suitable for small wildlife includes structures *San Antonio bridge. Photo: EcoGrande* whose opening area does not exceed 1.2m². If it did exceed this number but their height was less than 1.2 m they were still considered for small animals. The category of drainages suitable for



medium animals includes structures with an opening area between 1.2 m² and 6.30 m². The category of drainages suitable for large animals includes structures with more than 6.30 m².

In this way, the drainage structures are classified for its use by different groups of wildlife and actions can be performed for each of them separately.

**Dimensional characteristics of the classification of drainages and bridges structures of the
Ímuris – Sonora-Chihuahua State Limits section of Federal Highway 2**

CATEGORY	WILDLIFE TYPE	DRAINAGE HEIGHT	DRAINAGE WIDTH	DRAINAGE OPENING AREA
1 	Small (rodents, reptiles, birds)	0.1 m - 1.2 m	0.1 - 1 m	- 1.2 m ²
2 	Medium (canids, small felines, mustelids)	1.2 m – 2.10 m	1 m – 3 m	1.2 m ² – 6.30 m ²
3 	Large (large felines, artiodactyls, bovines)	≥ 2.10 m	≥ 3 m	≥ 6.30 m ²

Potential use by wildlife

With the objective of evaluating the potential use of drainages and bridges by wildlife, we registered the presence of wildlife on field through sightings, tracks, excreta, scratches, among others. We also evaluate the quality of the habitat surrounding each drainage and bridge by visually rating the immediate physical characteristics of the place. We consider aspects such as the presence of human settlements, clearing of the natural habitat and soil degradation. Additionally, we register the design elements and maintenance conditions of each drainage and bridge.

With the information on wildlife use, quality of the landscape and maintenance conditions, we classify each drainage by its potential use by wildlife as follows (the colors correspond to the symbols used in the maps included):

1. **High (Green):** If there is any direct sighting and clear evidence of tracks, recent excreta and presence of wildlife. If the surrounding landscape is of good quality for wildlife, for example, without human settlements or infrastructure that could disturb them. If the drainage does not present accumulation of sediment or no visibility from one side to the other problems.



2. **Moderate (Yellow):** If there is clear evidence of tracks and excreta but not of recent use. Also, if the landscape has low use of anthropogenic activities. If the drainage does not present accumulation of sediment or no visibility from one side to the other problems.

3. **Low (Red):** If there is evidence of lesser identifiable tracks and/or excreta but are not recent. If there are human settlements around or infrastructure that disturbs or drives wildlife away. If the drainage does not present accumulation of sediment or no visibility from one side to the other problems.

4. **Null (Black):** If there is no evidence of tracks and/or excreta. There are human settlements around and the habitat is transformed by human activity, displacing wildlife.

With this classification of potential use of drainages by wildlife, we identify the drainages or drainage areas that require attention and also those that have a significant potential to be adapted as wildlife crossings.

Monitoring wildlife using drainages as Wildlife Crossings

Camera traps installation

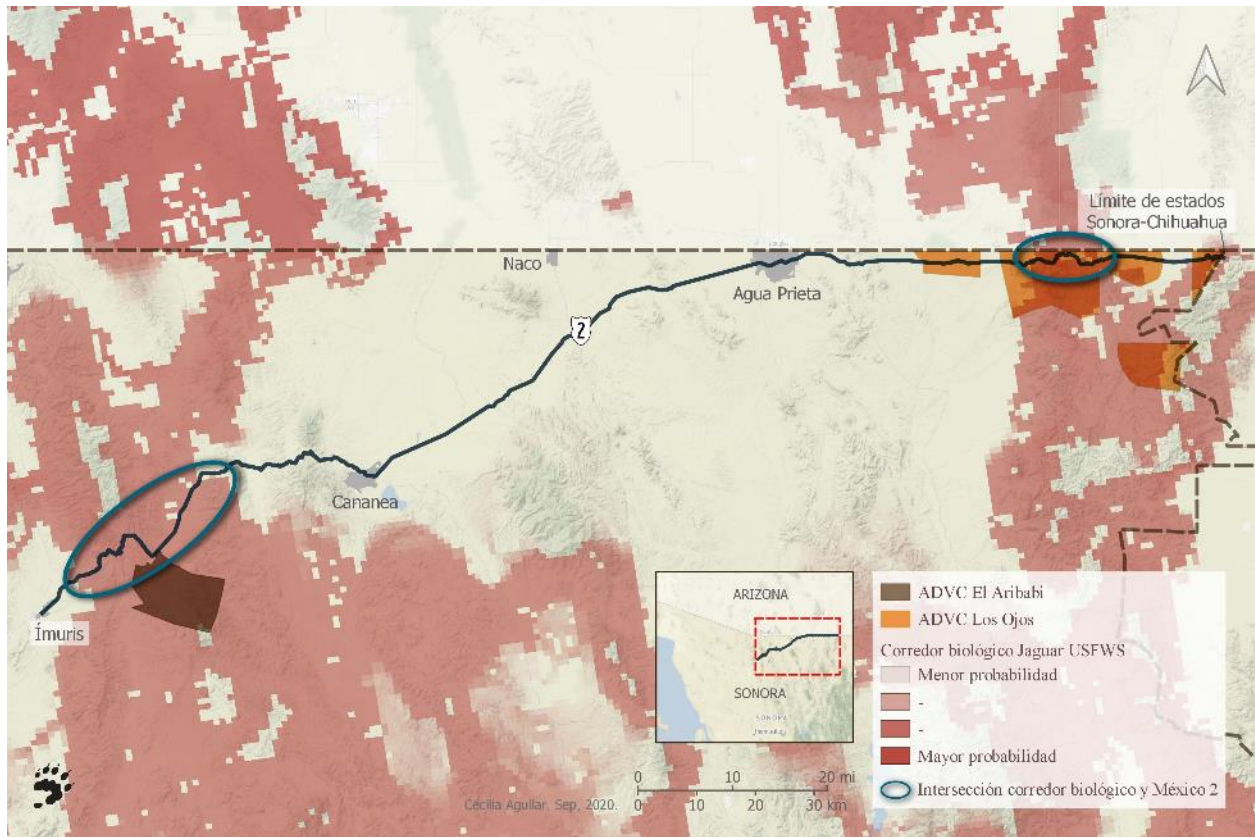
To help determine important areas for drainage monitoring and construction of wildlife crossings we also used digital models of habitat and connectivity of three species in the area: jaguar (Stoner et al., 2015), black bear (Delfín-Alfonso et al., 2012) and Mexican wolf (Martínez-Meyer, et al. 2017), as well as roadkill information obtained by Sky Island Alliance in 2016 and 2018 located on the iNaturalist platform.

With the objective of determining which wildlife use the existing drainages to safely cross the road, we decided to install camera traps (cameras adapted to operate outdoors, continuously and for long periods; they have a motion sensor that activates the shutter, capturing photos of animals, people and objects moving in front of them).

We began the installation of camera traps in August 2018 with the placement of 24 cameras in drainages along two wildlife corridors that cross Federal Highway 2: **Sierra Azul-El Pinito**, approximately 20 km northeast of Ímuris, near the ADVC Rancho El Aribabi, and **Sierra Peloncillo**, 60 km east of Agua Prieta, dividing the ADVC Los Ojos.



Intersection of the jaguar wildlife corridor with Federal Highway 2



First, we selected the drainages with a high potential of use by wildlife through the classification described above. Then, we examined the area in detail to locate the camera in a strategic location where the entrance of the drainage could be noticed allowing us to capture the individuals that use the drainage to cross the road.

We placed the cameras in trees with screws, safe boxes and locks with metal wire to prevent them from being stolen, however, some drainages did not have nearby trees, so we decided to fix them on their ceilings or walls using a drill, anchors and screws. We changed batteries and memory cards every two months.



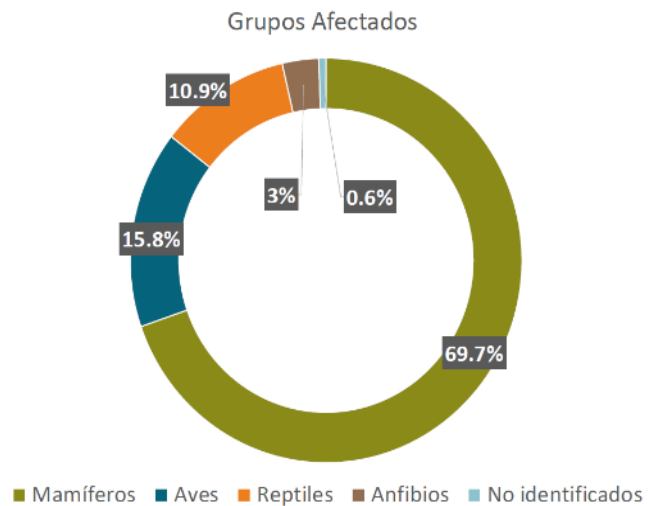
Personnel placing camera traps. Photo: Wildlands Network



RESULTS

Monitoring wildlife roadkill

We registered a total of 330 individuals of 43 species, seven of them listed in the NOM-059-SEMARNAT (Table 2). We accumulated 36 registries of listed wildlife, which represent 10.9% of the total numbers of roadkill. The species most commonly registered were the coyote (*Canis latrans*) with 44 individuals, skunks of the genus *Mephitis* with 41 individuals, gray fox (*Urocyon cinereoargenteus*) with 14 individuals, rabbits of the genus *Sylvilagus* with 17 individuals, hares of the genus *Lepus* with 27 individuals and coachwhip snake (*Masticophis flagellum*) with 14 individuals in the threatened category.



Coyote (*Canis latrans*) between Cananea and Agua Prieta. Photo: Sky Island Alliance-Wildlands Network

The group with the highest number of roadkill individuals is mammals with 230 registries (69.7%) followed by birds with 52 (15.8%), reptiles with 36 (10.9%) and amphibians with 10 (3%). Two individuals could not be identified (0.6%).



Affected species protected by the Official Mexican Standard (NOM-059-SEMARNAT)

COMMON NAME	SCIENTIFIC NAME	NUMBER OF ROADKILL	NOM-059-SEMARNAT CATEGORY
Coachwhip Snake	<i>Masticophis flagellum</i>	14	Threatened
Western diamondback rattlesnake	<i>Crotalus atrox</i>	6	Special Protection
American badger	<i>Taxidea taxus</i>	11	Threatened
Western box turtle	<i>Terrapene ornata</i>	1	Special Protection
Montezuma quail	<i>Cyrtonix montezumae</i>	1	Special Protection
Garter Snake	<i>Thamnophis sp</i>	2	Threatened
Cooper’s hawk	<i>Accipiter cooperii</i>	1	Special Protection

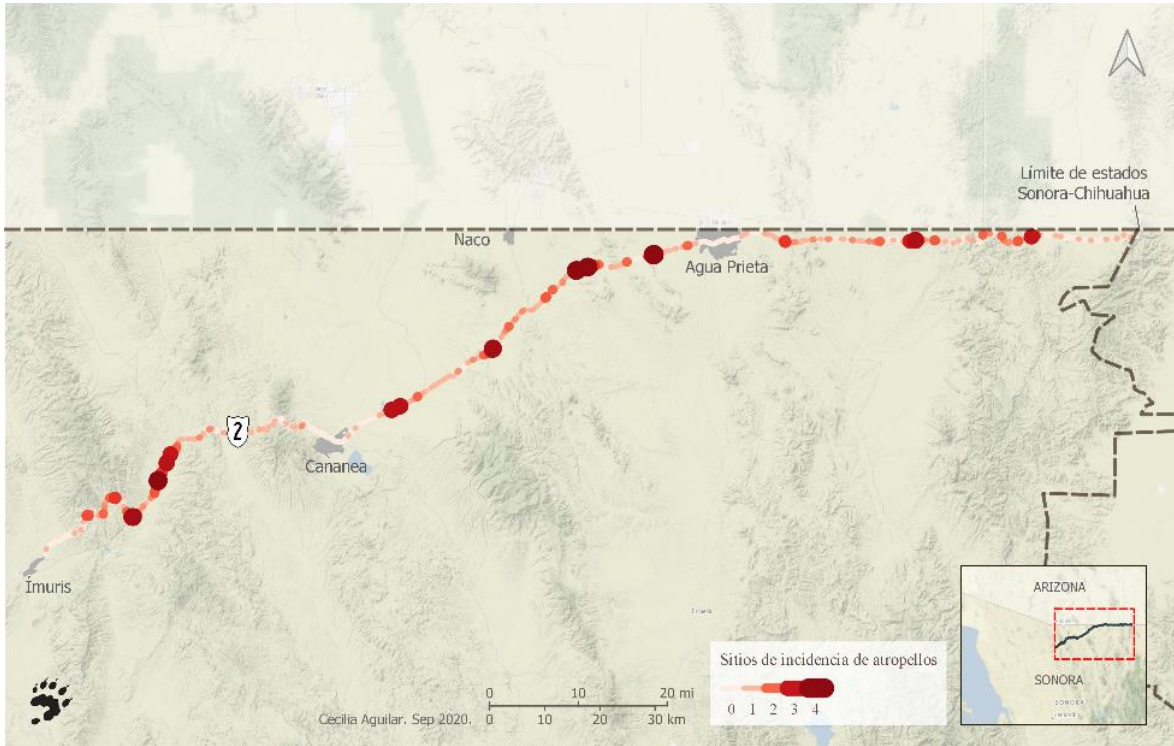
Critically Important Areas or “Hotspots”

We were able to identify at least 27 sites that are critically important areas along the Ímuris – Sonora-Chihuahua State Limits section, of which 14 are found in the wildlife corridor Sierra Azul-El Pinito, six in the grasslands between Cananea and Agua Prieta and the remaining seven in the wildlife corridor Sierra Peloncillo. Likewise, we identified 29 sites of medium importance along the entire section. It is worth mentioning that many of these sites are on straight sections of the road where drivers tend to increase speed.

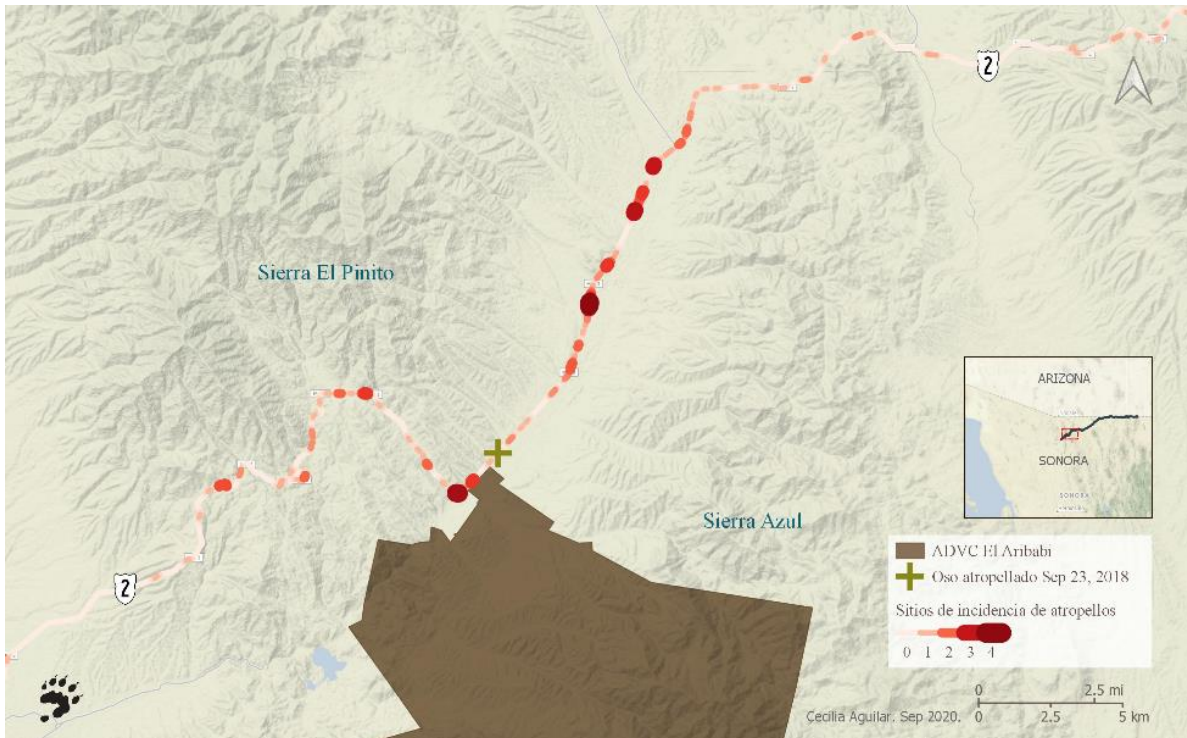
The specific points with highest scores are near bodies of water such as the Cocóspera River, tributary streams of the San Pedro River, cattle dams and the streams of San Bernardino and El Verde. This matches with studies that suggest that variables such as high volume of traffic and proximity of the road to bodies of water are associated with high mortality rates and groupings of roadkill (Filius et al., 2020).



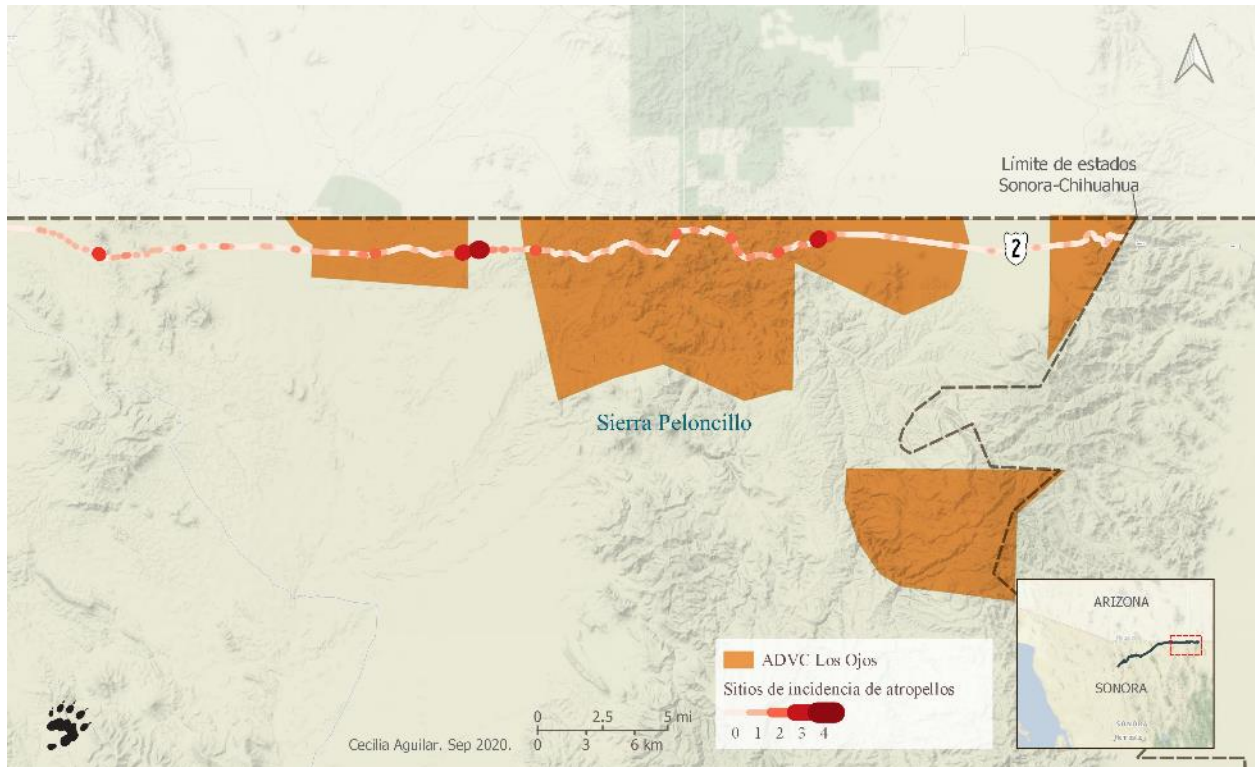
Areas with the highest incidence of roadkill



Areas with the highest incidence of roadkill in the Sierra Azul-El Pinito wildlife corridor



Areas with the highest incidence of roadkill in the Sierra Peloncillo wildlife corridor

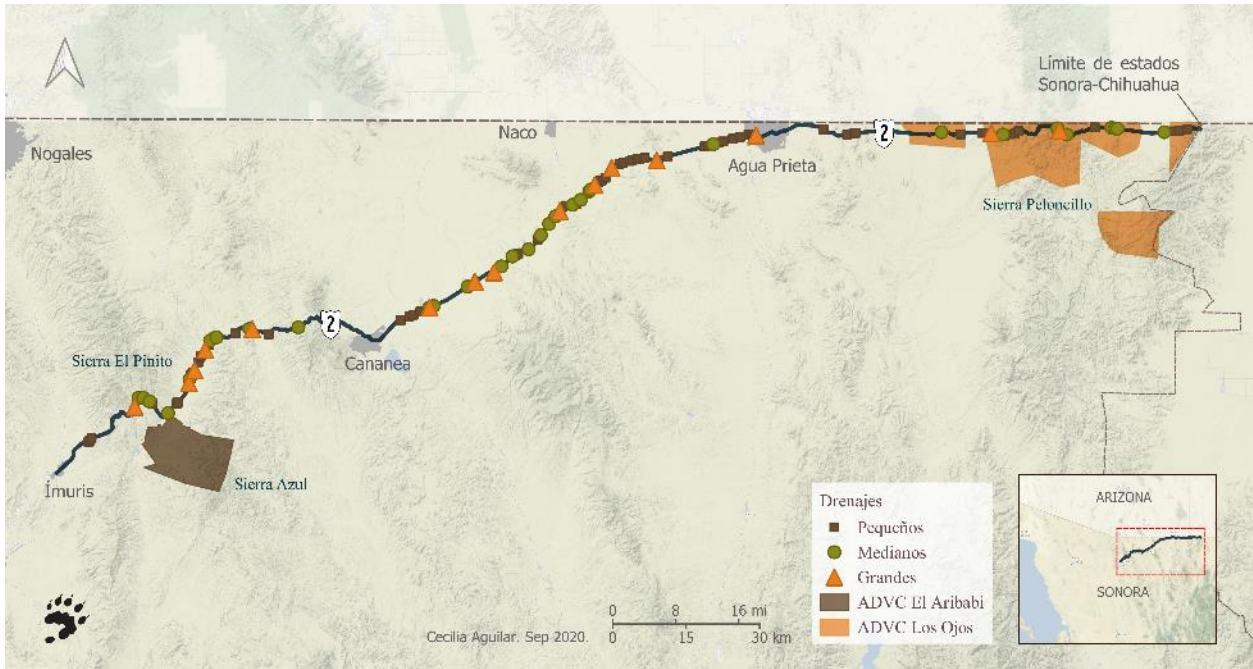


Drainages and bridges

In general, the drainages in the Ímuris – Sonora-Chihuahua State Limits section of Federal Highway 2 are in good condition; however, it is clear that they require constant maintenance. Of a total of 707 drainages, 374 (53%) present problems of accumulation of sediment, garbage or other elements that obstruct the water flow and the crossing of wildlife. We classified the drainages into three categories according to their size, however, 27 (4%) of them were not included in any of these categories because they were under construction and it was not possible for us to document their dimensions.



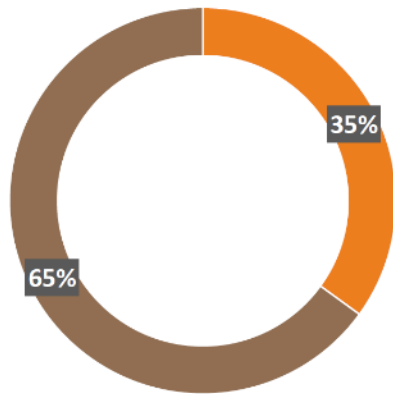
Representation of 20% of the drainages on the Ímuris – Sonora-Chihuahua State Limits section



Small drainages add up to 415 (59%); 268 (65%) of these are clogged with garbage, rocks or other items that obstruct the passage. **Only nine (2%) small drainages have high potential of use by small wildlife.** On the other hand, 260 (63%) drainages are of moderate use. We consider that with the proper and constant maintenance they could be used by small sized wildlife. 146 (35%) of small drainages have low or no use potential and require maintenance.

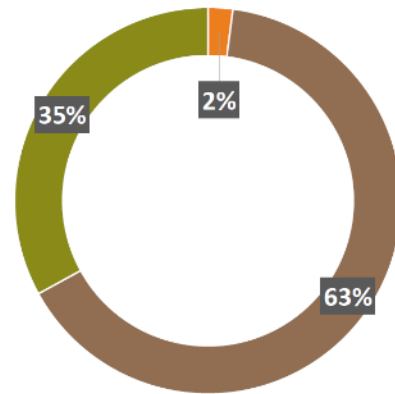
Drenajes Pequeños

Con Problemas de Azolvamiento



Libres Azolvados

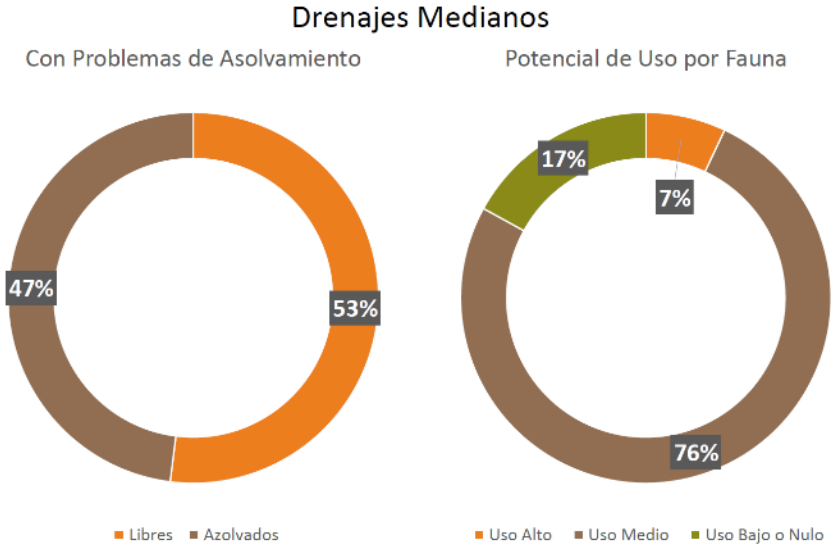
Potencial de Uso por Fauna



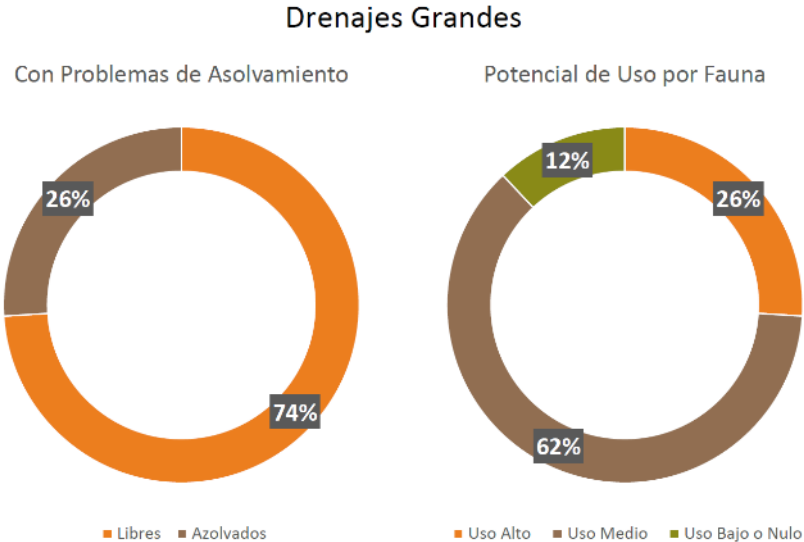
Uso Alto Uso Moderado Uso Bajo o Nulo



Medium size drainages that are considered of great importance for use by medium and small wildlife add up to 176 (25%). We documented accumulation of sediment problems and other obstructions in 83 (47%) of these. **Of the total medium drainages, 13 (7%) have high potential of use by medium and small wildlife**, 134 (76%) have moderate potential and 29 (17%) have low or no potential of use.



Finally, large category drainages—especially bridges—are considered the most important for wildlife crossings. Of the total of drainages in the section, this kind add up to 89 (12%). 23 (26%) drainages presented elements that hinder their potential use as wildlife crossing. **Another 23 (26%) large drainages or bridges have a high potential**, 55 (62%) have moderate potential of use and 11 (12%) have low or no potential of use.

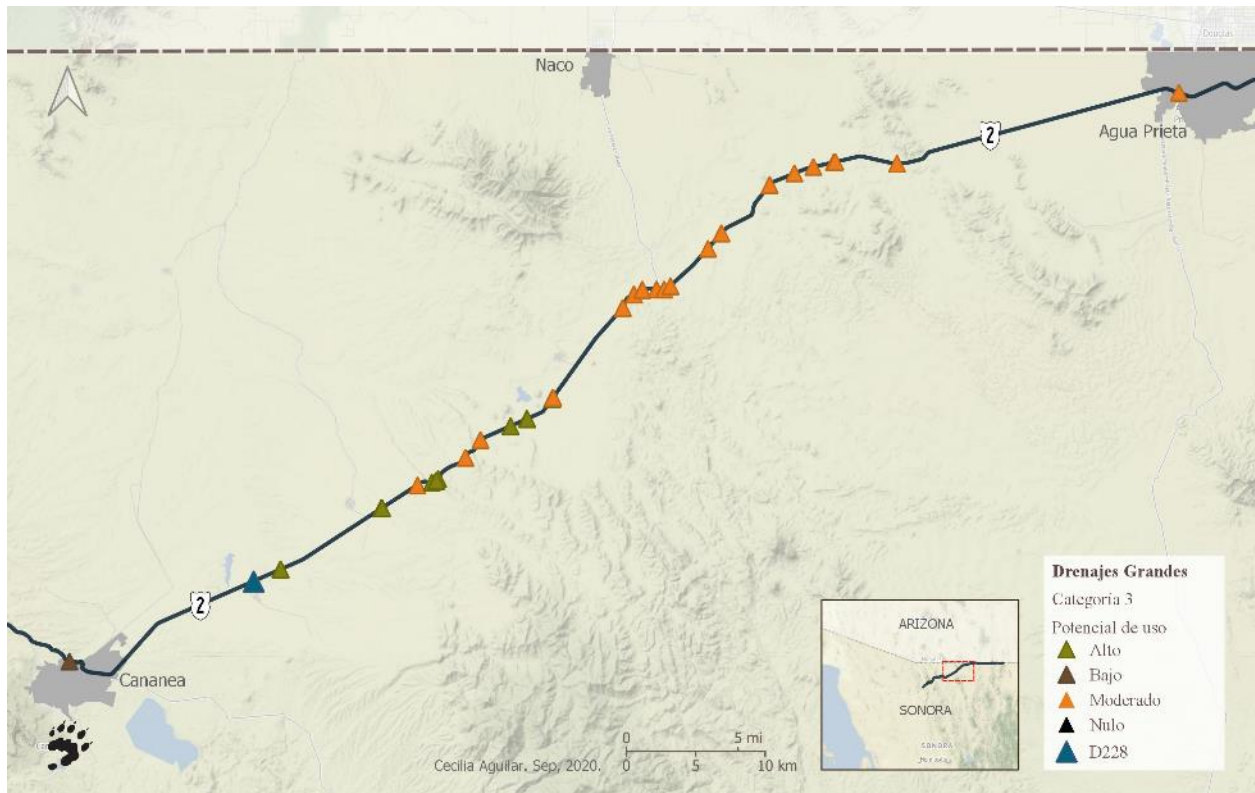


It is important to point out that on kilometer 121 + 500 there is a stream for which no drainage was built on the road. The stream appears to be diverting to drainage D125. It is also important to mention that in the D228 drainage a western tiger salamander (*Ambystoma mavortium*) was registered, a species whose populations have suffered an alarming decline in recent decades mainly because of factors related to the modification of its habitat, pollution of rivers and lakes and introduction of invasive exotic species (PACE, 2018). Salamanders are vulnerable species and indicators of a healthy ecosystem. The presence of this species shows us that we still have time to preserve and connect the region's ecosystems for aquatic species. These sites are indicated in the maps below:

Location of Category 3 (large) Drainages of the Ímuris-Cananea section of Federal Highway 2



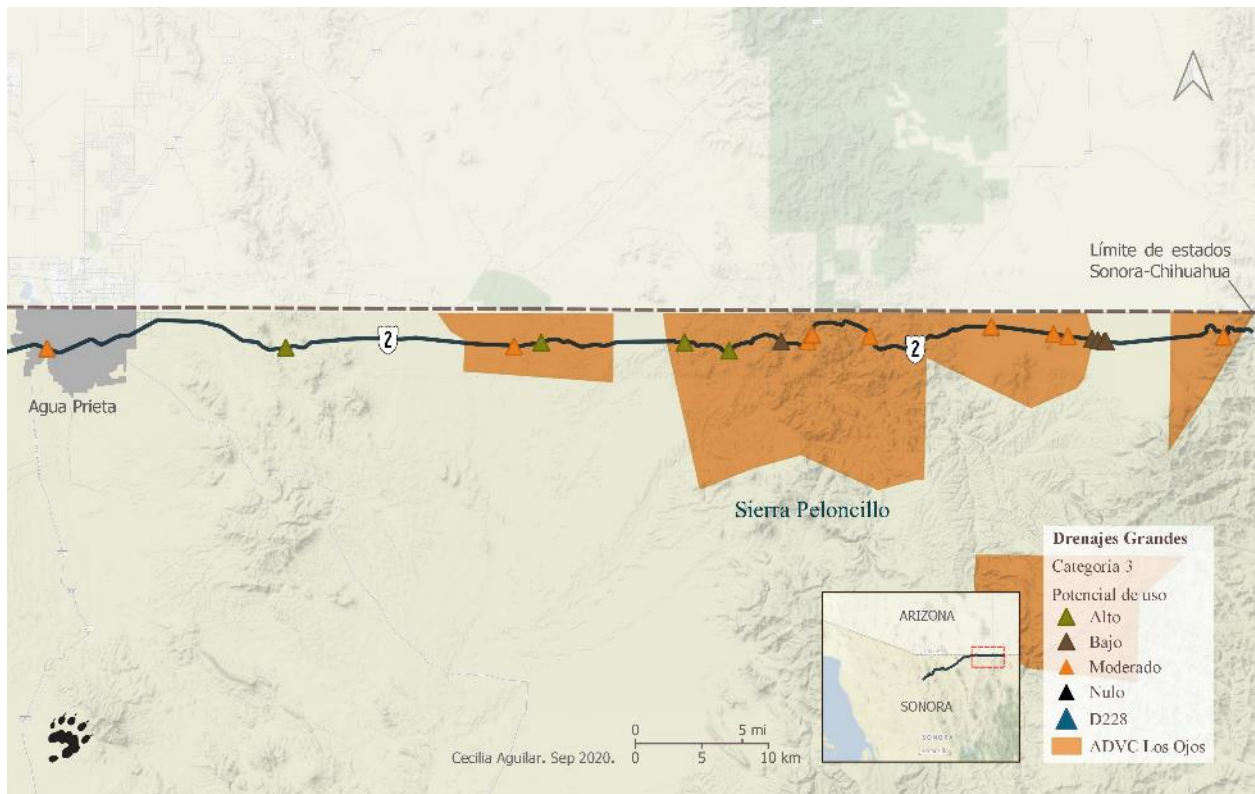
Location of Category 3 (large) Drainages of the Cananea-Agua Prieta section of Federal Highway 2



Western tiger salamander (*Ambystoma mavortium*) recorded in the D228 drain. Photo: EcoGrande



Location of Category 3 (large) Drainages of the Agua Prieta – Sonora-Chihuahua State Limits section of Federal Highway 2



Monitoring of Wildlife using drainages

We registered a total of 18 species using the drainages at both sites where we placed camera traps, having the Sierra Azul-El Pinito wildlife corridor the greater diversity with 18 species while in Sierra Peloncillo we registered 17 species total. Most of the recorded species were small to medium size except the cougar and white-tailed deer, which were the largest.



Collared peccaries (Pecari tajacu) using a drainage to cross. Photo: Wildlands Network



Species using drainages in the Federal Highway 2 in two wildlife corridors: Sierra Azul-El Pinito and Sierra Peloncillo

Nombre común	Especie	S. Azul - El Pinito	S. Peloncillo
Zorrillo Listado	<i>Mephitis mephitis</i>	✓	✓
Zorrillo Encapuchado	<i>Mephitis macroura</i>	✓	✓
Zorrillo espalda blanca	<i>Conepatus leuconotus</i>	✓	✓
Zorrillo moteado	<i>Spilogale gracilis</i>	✓	✓
Tlacuache	<i>Didelphis virginiana</i>	✓	✓
Cacomixtle	<i>Bassariscus astutus</i>	✓	✓
Mapache	<i>Procyon lotor</i>	✓	
Coatí/Chulo	<i>Nasua narica</i>	✓	✓
Liebre cola blanca	<i>Lepus alleni</i>	✓	✓
Conejo Serrano	<i>Sylvilagus floridanus</i>	✓	✓
Ardilla de roca	<i>Otospermophilus variegatus</i>	✓	✓
Venado cola blanca	<i>Odocoileus virginianus</i>	✓	✓
Pecarí	<i>Pecari tajacu</i>	✓	✓
Coyote	<i>Canis latrans</i>	✓	✓
Gato montes	<i>Lynx rufus</i>	✓	✓
Puma	<i>Puma concolor</i>	✓	✓
Zorra gris	<i>Urocyon cinereoargenteus</i>	✓	✓
Rata	<i>Rata sin identificar</i>	✓	✓

To this day, 15 cameras have been stolen: eight in Sierra Azul-El Pinito and seven in Sierra Peloncillo because bridges and drainages are places frequented by people. However, we were able to obtain species records from most of the cameras before they were stolen.



CONCLUSIONS

We estimate that at least 2,000 vertebrates become roadkill each year on the Federal Highway 2 section Ímuris – Sonora-Chihuahua State Limits.

It is evident that the road infrastructure studied was not designed taking into account ecosystem connectivity or wildlife movement, and that currently it does not allow the region’s species to cross it freely.

Despite this fact, some species—such as coatis—seem to have adapted their behavior to take advantage of drainages and bridges as wildlife crossings. Others, like black bears, show no signs of having adapted.

This became evident in September 2018, when a bear was run over in the Sierra Azul-El Pinito wildlife corridor, approximately one kilometer from the entrance to the ADVC Rancho El Aribabi. The bear was less than a hundred meters from two good size bridges under which it could have crossed the road yet chose not to use them, with fatal consequences. It is important to point out that



Coati (Nasua narica) using a drainage to cross the road. Photo: Wildlands Network-Sky Island Alliance

throughout the study we did not obtain any record of bears using drainages or bridges; this seems to agree with studies of wildlife crossings made in Banff, Canada, that suggest that black bears, like wolves, prefer to use upper wildlife crossings or viaducts to cross roads (Clevenger, et al. 2009).

The black bear population of northern Sonora and Chihuahua is relatively small and genetically dependent on the most robust populations of black bear in the United States. Federal Highway 2 divides these populations and puts the genetic health of the Mexican black bear at risk.

The loss of protected species such as black bears, badgers or rattlesnakes is a tragedy that requires immediate mitigation actions. Also, the region is in the extreme north of the jaguar’s



range and in 2019, just over 2 km from the Federal Highway 2 –in the Sierra Peloncillo–, the northernmost photographic record of this species in Mexico, was obtained (Ragan, 2020).

Even though the photographic records we obtained indicate that the existing drainages can function as wildlife underpasses for medium and small species, the lack of maintenance reduces their potential use; that is why it is necessary for them to be cleaned more frequently and, as much as possible, to be modernized with curbs that allow their use by small wildlife during flood episodes.

Recommendations for sections of critical importance

With the results of this study, we determined that the areas of **critical importance** that require implementation of mitigation measures are the Sierra Azul, Sierra El Pinito and Sierra Peloncillo wildlife corridors. The above reinforces the conclusions of the study carried out by Stoner (2015) that pointed out these same two sites as important intersections between Federal Highway 2 and the modeled jaguar corridors.

In addition to this work that already identified Federal Highway 2 as a potential obstacle for the jaguar, it is important to highlight that different studies have identified these two sites as important areas for habitat connectivity of several species classified as **threatened or endangered wildlife** in the NOM-059-SEMARANAT-2010 including the black bear (*Ursus americanus*), jaguar (*Panthera onca*) and Mexican wolf (*Canis lupus baileyi*) (Delfín-Alfonso et al., 2012, Lara Díaz et al., 2015, List et al., 2011, Martínez-Meyer et al., 2017, Theobald et al., 2017), among others.

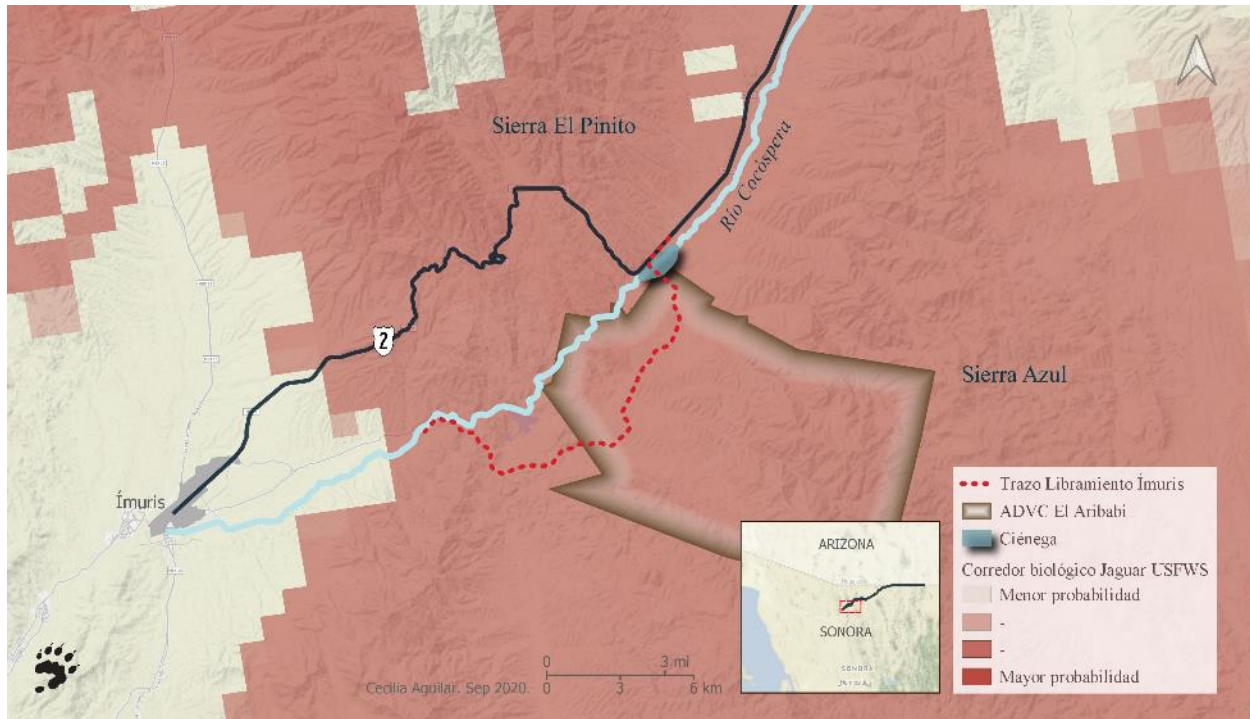
The mitigation measures that we recommend for improving the road permeability in the sections of critical importance are **the construction of wildlife overpasses, adaptation of existing drainages as wildlife underpasses, inductive fencing and installation of escape ramps**.

Sierra Azul and Sierra El Pinito wildlife corridor

Located to the east of Ímuris, this area covers from kilometer 115 to kilometer 145 of Federal Highway 2 in the Ímuris-Cananea section. This is an area of great importance because at this place where the modeled jaguar habitat corridor forms a bottleneck entirely crossed by the road.



Jaguar habitat connectivity model

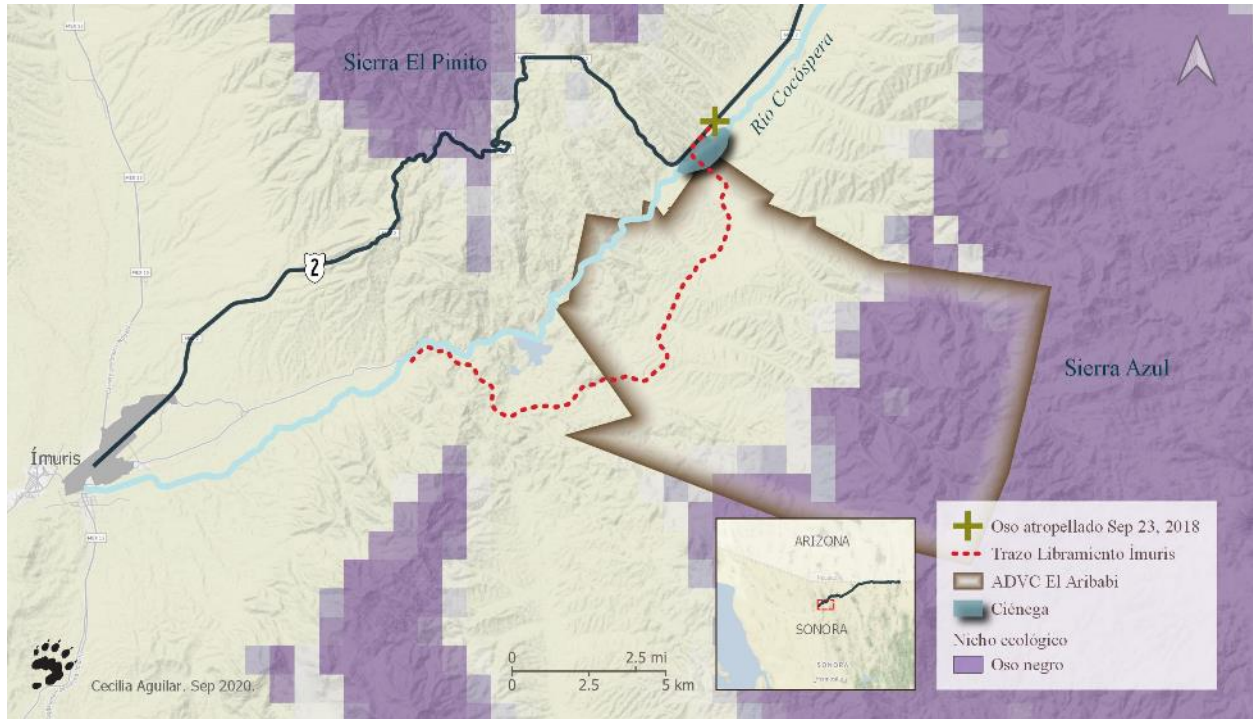


This area is also important for black bear habitat connectivity. As the following map reflects, the Cocóspera River Valley lies between two zones occupied by black bears. Maintaining connectivity between these two areas is important for bears to successfully move between suitable habitats.

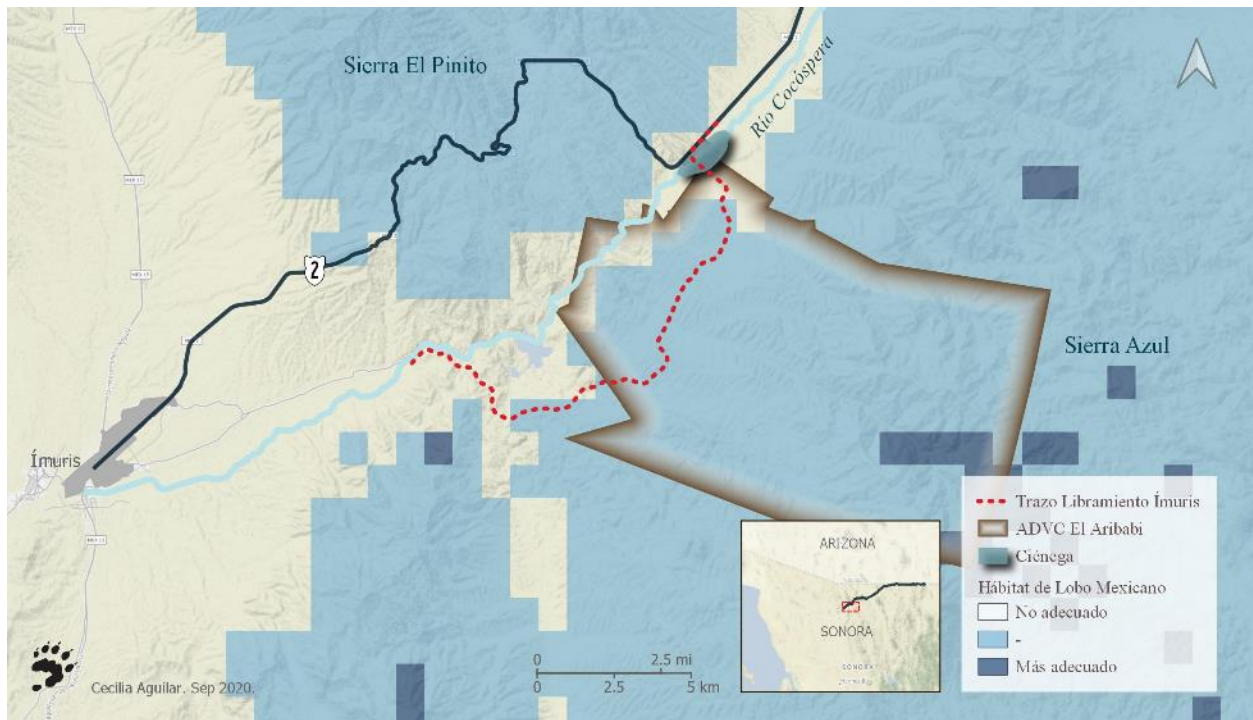
Although recovery efforts for the Mexican wolf (*Canis lupus baileyi*) have been performed in the state of Chihuahua and eastern Sonora, one must take into account that the ADVC Rancho El Aribabi contains suitable habitat for the propagation of this species in the future.



Ecological niche of the black bear



Habitat of the Mexican wolf



For this corridor we highly recommended the construction of two wildlife overpasses in the Cocospera River Valley, **between kilometers 125 and 126 as well as between kilometer 120 and 119**, in order to improve the permeability of black bear, jaguar and ocelot corridors.

Even though there is no standard for the length of inductive fencing on each side of a wildlife crossing, fences are commonly placed at least one mile (1.61 km) in each direction. The number and proximity of hotspots, and drainages that can be used as wildlife crossings in the identified area is such that we recommend building a single 20-kilometer long fenced corridor that goes from **kilometer 115 to kilometer 135** thus avoiding leaving open sections that could reduce its effectiveness, since this section is the one with the highest number of hotspots in the entire study.

We also recommend the adaptation of the drainages between km 115 and km 136 (in the following table) for medium and small species such as collared peccaries and coachwhip snakes. The bridges San Antonio, **km 117 (30.973792, -110.582119)**, and Los Alisos, **km 124 (30.922274, -110.610887)**, are large enough to allow free passage of animals. We recommend adapting Los Alisos bridge as a wildlife crossing by adding a curb and including San Antonio bridge within the fenced section.

Drainages with Lower Wildlife Crossing adaptation potential within the Sierra Azul – Sierra El Pinito corridor

Type of Drain	Kilometer	Coordinates
Bridge	Km 140	30.884944, -110.710361
Drain	Km 137	30.899472, -110.699472
Tunnel	Km 136	30.896944, -110.687111
Bridge	Km 130	30.876361, -110.648222



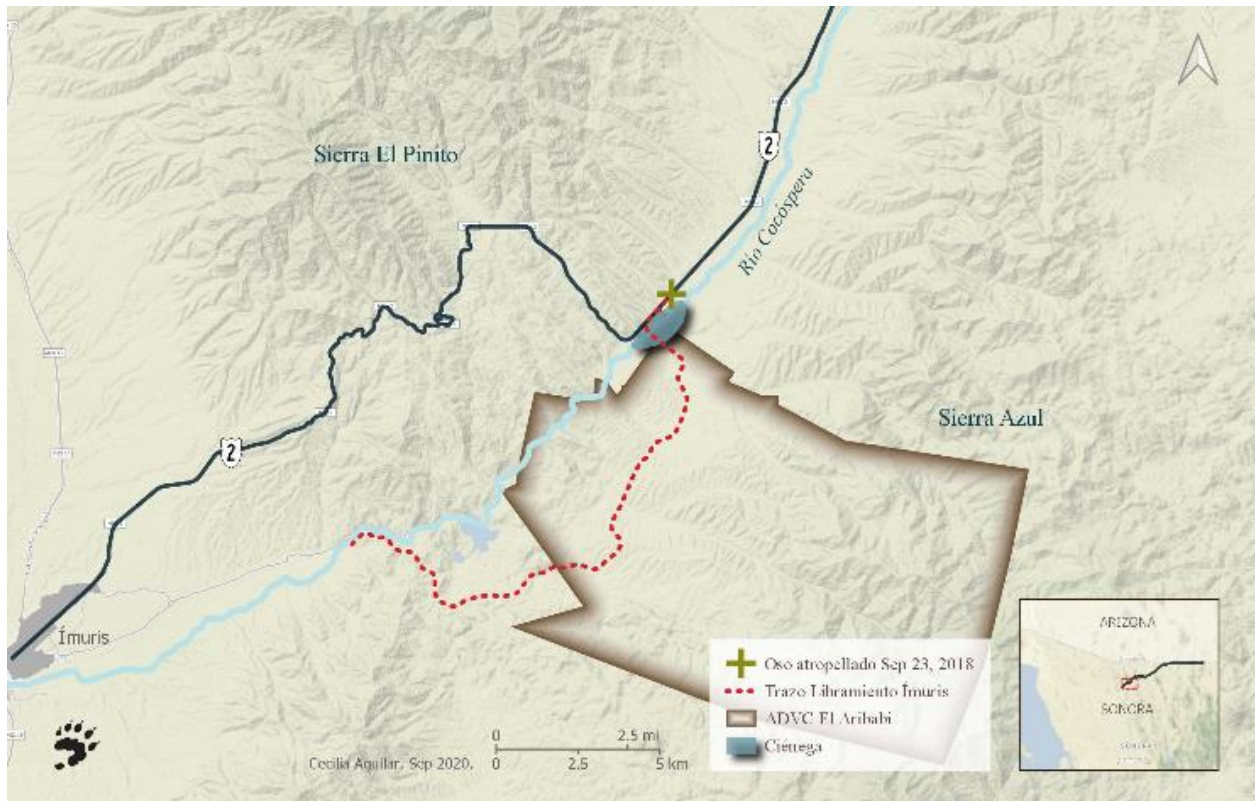


3D model of the viaduct in the possible future highway bypass in the ADVC Rancho El Aribabi. Illustration: P. Capdevielle, S. De la Rosa and Jacalito Films

In the case of the future highway bypass project in Ímuris, it is essential to emphasize that the road should not be built over the Cocóspera River. The infrastructure design of the current line must incorporate a viaduct over the area where remains of a *ciénega* (wetland ecosystem) are identified within the ADVC Rancho El Aribabi. An elevated viaduct will not only function as wildlife crossing but will also allow the restoration of this wetland, which can be a compensation component of the highway project itself.

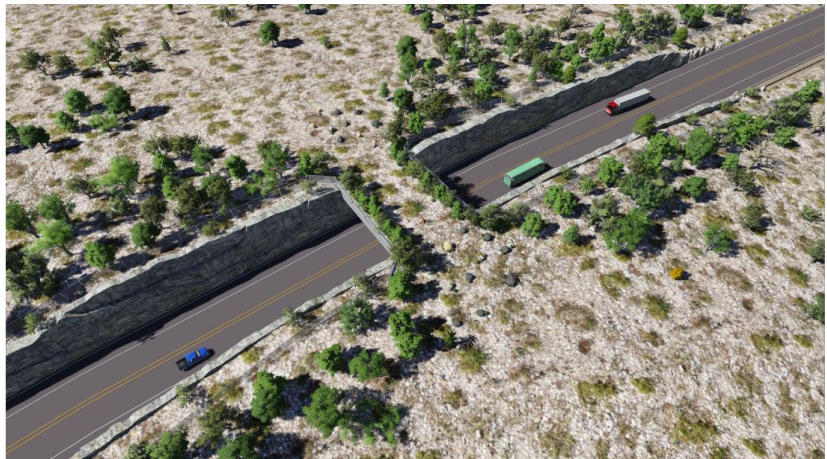


Current line of the Ímuris highway bypass



Sierra Peloncillo wildlife corridor

Located to the east of Agua Prieta, this area includes kilometers 110 to 114 of Federal Highway 2. This section crosses the properties of *Puerta Blanca Livestock Company S. A. de C. V.* and *Los Ojos Calientes Livestock Company S. A. de C. V.* which currently have a certificate issued and endorsed by the Mexican National Commission



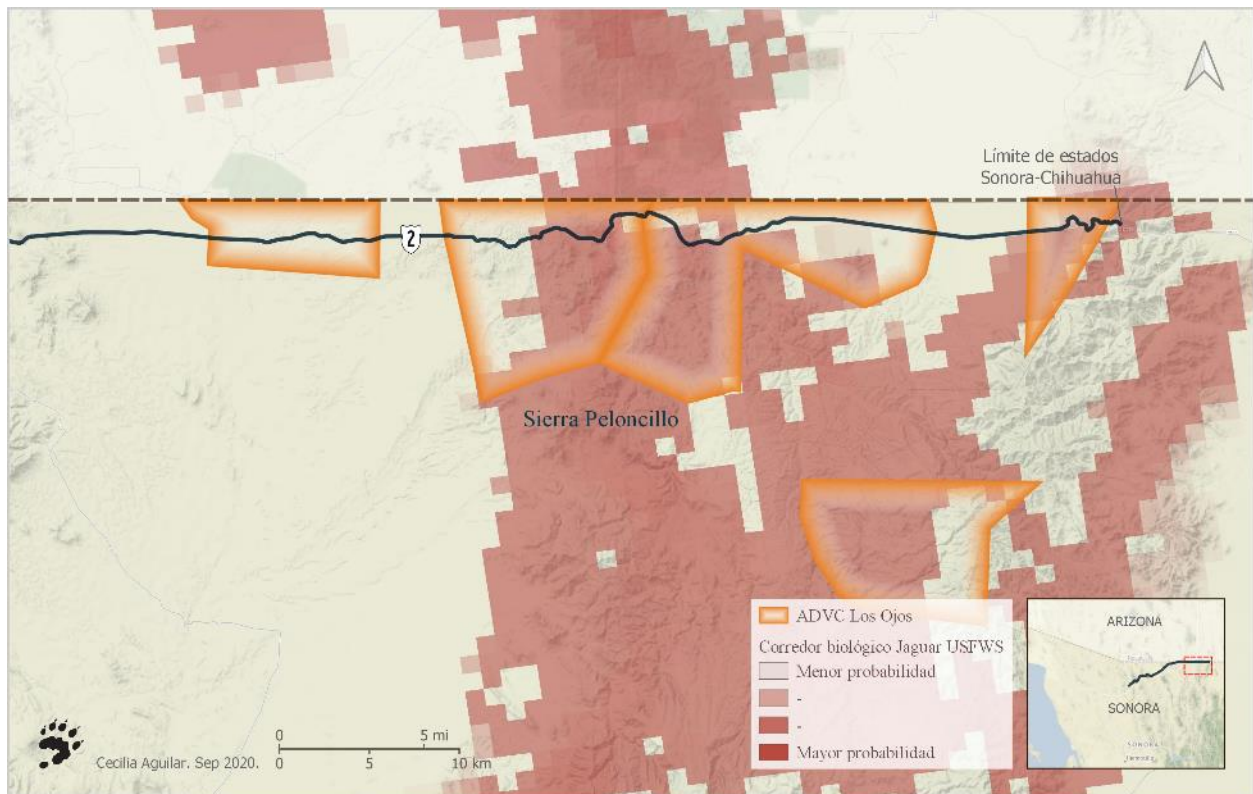
3D model of the possible wildlife crossing in the Sierra Peloncillo wildlife corridor. Source: Pedro Capdevielle

of Protected Natural Areas (**CONANP**) that establishes that this land is an ADVC. In addition to being certified, these properties have been subject to strict ecosystem conservation and restoration management for more than 20 years.

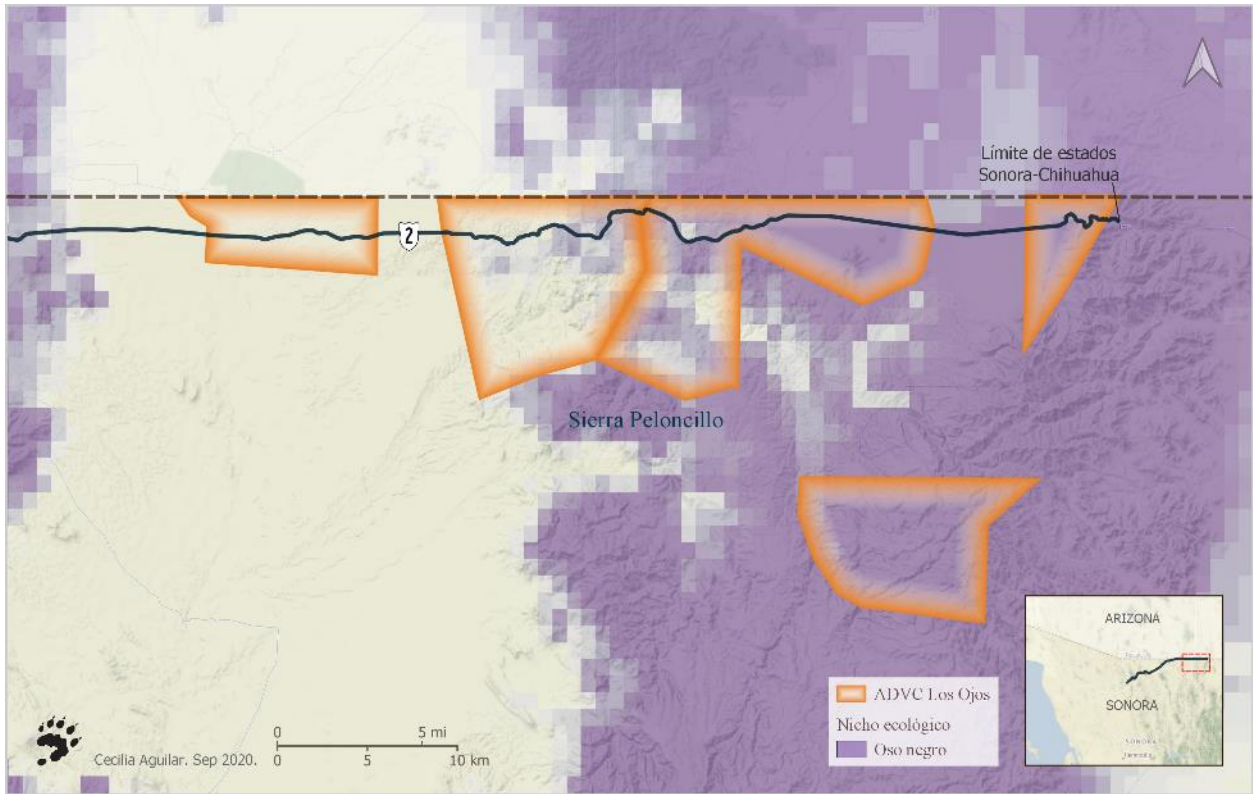


The following maps show that this area is of great importance for priority species since the road crosses jaguar, black bear and Mexican wolf habitat from east to west. These three species need vast landscapes to move in and live. Their habitat is not only cut off by the road but also by the new border wall infrastructure. Animals that manage to cross the current highway from south to north will meet the wall and will be forced to turn south, putting themselves at risk again by having to cross the road one more time.

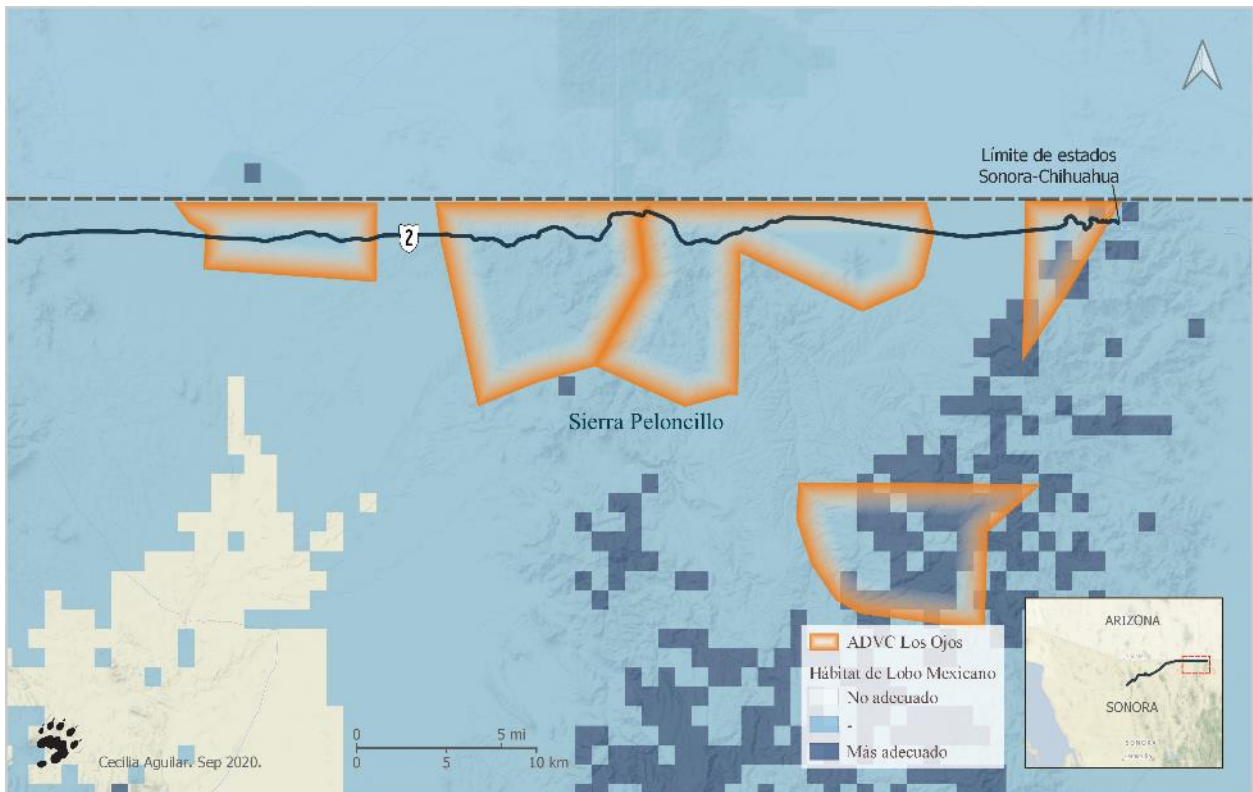
Jaguar habitat connectivity model



Ecological niche of the black bear



Suitable habitat for the Mexican wolf



Due to the reintroduction efforts of the bighorn sheep (*Ovis canadensis*) in New Mexico and the Mexican wolf (*Canis lupus baileyi*) in Chihuahua, it is highly recommended to build a wildlife overpass in **kilometer 115 (31.313431, -109.105041)** to optimize the permeability of the highway along the historical corridors of the two large carnivores present: black bears and jaguars.

The number and proximity of hotspots and drainages that can be used as wildlife crossings in the identified area is such that we recommend building a single 20-kilometer long wildlife corridor that goes from **kilometer 93 to kilometer 113** to avoid leaving open sections that could reduce its effectiveness.

Corridor location for the safe crossing of wildlife



To the west of Sierra Peloncillo lies the El Verde bridge at **km 128 (31.315200, -109.236663)** and the San Bernardino bridge at **km 131 (31.312722, -109.254833)**. Due to the size of these bridges, the importance of streams in the desert landscape and the fact that they are over a hotspot, we recommend retrofitting them as wildlife crossings by installing inductive fences. The proximity of said bridges is such that we recommend the inductive fencing of a single section of 6 kilometers between **km 126 and km 133** to cover both streams with escape ramps. We recommend the adaptation of the drainages within the section, for medium and small species, listed in the following table.



Drainages with Lower Wildlife Crossing adaptation potential within the Sierra Peloncillo corridor

Type of Drain	Kilometers	Coordinates
Bridge	Km 118	31.315083, -109.139514
Tunnel	Km 109	31.315667, -109.056083
Tunnel	Km 109	31.319667, -109.053139
Bridge	Km 104	31.318806, -109.01425

Cananea – Agua Prieta section

The information about the six hotspots identified in the section between Cananea and Agua Prieta is unprecedented in the scientific literature that we consulted. We recommend doing additional studies focused on the impact of the road on small species listed in NOM-059-SEMARNAT such as the western box turtle (*Terrapene ornata*), American badger (*Taxidea taxus*) and rattlesnakes (*Crotalus spp*).

This section of the road possibly requires drainage adaptations in order to function as wildlife crossings for small and medium species, perhaps accompanied by the establishment of fencing with special focus on birds of prey and birds who spend most of the time on the ground such as the Greater roadrunner (*Geococcyx californianus*).

Nonetheless, the results of additional studies will determine specific recommendations for this section.

TECHNICAL SPECIFICATIONS

Below we include a set of technical specifications that should be taken into consideration in the critically important sections.

Inductive fences

The following characteristics for the construction of inductive fences are based on the experience of wildlife crossings located in Arizona, United States, which being adjacent to Sonora, shares much of the same wildlife in the area. This design has been adapted according to a research of the materials available with suppliers of the region.

Mesh

The design considers the use of two types of mesh. The main one made to prevent the crossing of medium and large animals, and the second one, shorter but with a finer weave, placed at the bottom



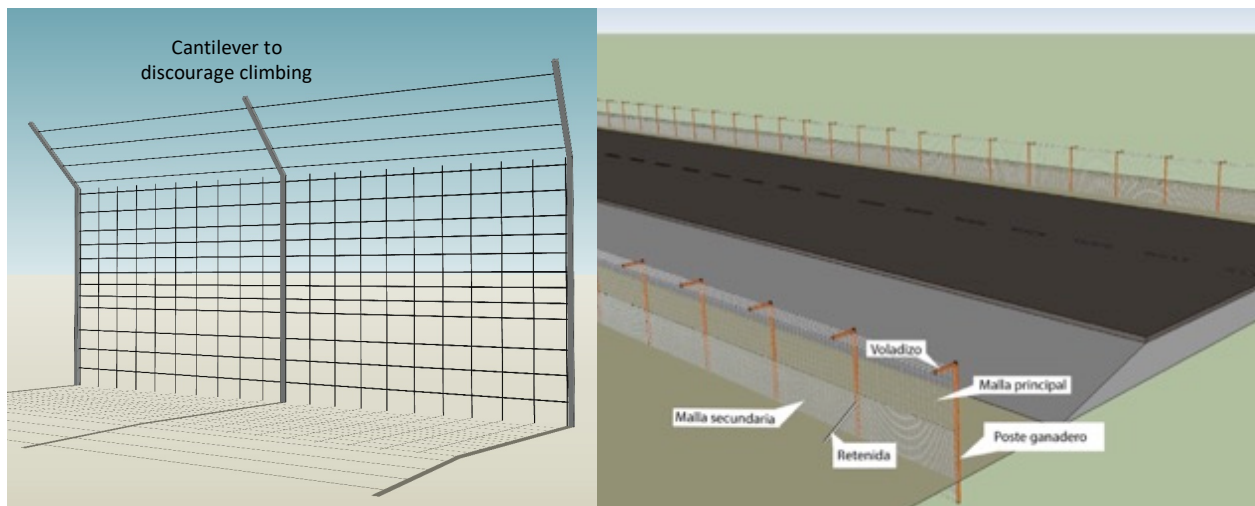
to avoid the crossing of small animals such as turtles, gila monsters, lizards and snakes. The meshes should be attached on the outside of the poles to reduce reparation costs in case of vehicular accidents. The triple torsion mesh is designed to resist the impact of large animals running such as deer. The mesh should be buried to prevent burrowing animals such as badgers and coyotes from digging under it.

Poles

Recommended for use is a 10-foot cattle pole every three meters with steel cables every 50 meters. A 45° metal angle will be placed at the top of each pole to form the cantilever.

Cantilever

An overhang using barbed wire will be placed projecting from the top of the fence, at about 45° and facing away from the road to prevent animals such as bears and felines from climbing the fence and reaching the pavement.



Components of inductive fences. Illustrations: Pedro Capdevielle and Juan Carlos Bravo

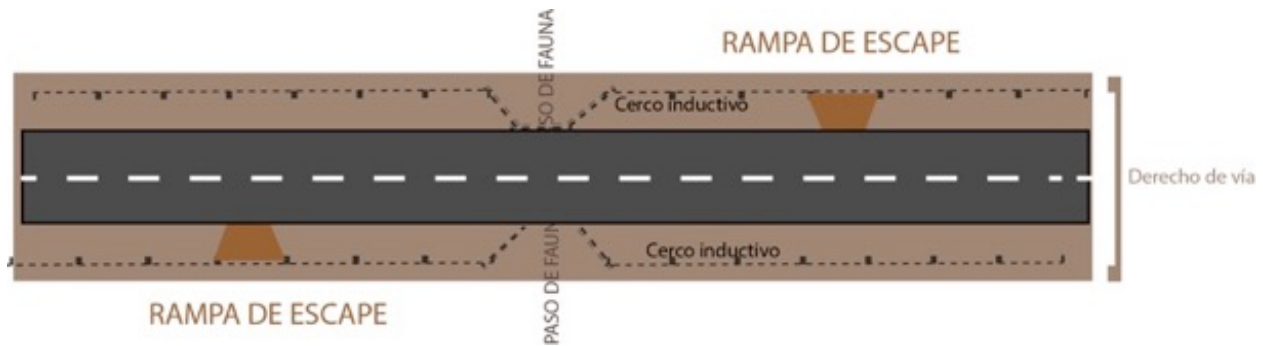
Escape ramps

Escape ramps are simple structures that are an integral part of wildlife crossings. Their function is allowing animals to escape when they somehow manage to enter the corridor formed between the two induction fences on each side of the road. These ramps must not allow animals outside the fence to enter the highway. The experience of wildlife crossings in other countries demonstrates that, even though these fences are built to prevent animals from accessing the body of the road, animals occasionally circumvent the fences through the endpoints or the upper or lower parts of the meshes. Furthermore, the lack of regular maintenance can result in openings or rips caused by vehicular accidents, landslides, vandalism, among other factors. When an animal stays inside the corridor formed by two fences, the risk of hitting a vehicle increases since it cannot easily escape. To minimize the danger of an impact, structures that allow animals



to escape from corridors must be built. Dirt ramps inside the fence can fulfill this function at a low cost.

We recommend building escape ramps at a distance no longer than 2 kilometers between each other, alternated on each side of the road.



Location of escape ramps. Illustration: Juan Carlos Bravo

Wildlife Crossing

To make technical recommendations for upper and lower wildlife crossings it will be necessary to carry out more fieldwork in coordination with transportation authorities and the contractors in charge of each project. Nevertheless, the following preliminary general recommendations can be made to take into account as a starting point for a deeper analysis:

Wildlife underpasses must be at least 7 meters wide by 4 meters high, with natural soil and, in case it is used as drainage, it must have a curb of at least 50 centimeters wide to facilitate the passage of small animals during flood events. The average flood level determines the curb height (Clevenger et al., 2018).

Wildlife overpasses should be at least 20 meters wide and covered with a 30-60 centimeters layer of soil, native vegetation and small bushes. The load calculation of these crossings must consider the weight of the soil when wet during episodes of torrential rains. (Ministry of Agriculture, Food and The Environment, 2016).

At the extremes of both kinds of wildlife crossings, placement of large rocks must be considered to prevent off-road vehicles from using them.



EPILOGUE

This set of recommendations is at the same time a starting point to define specific mitigation projects and a call to authorities to comply with **Article 15 Section IV of the Mexican General Law of Ecological Balance and Environmental Protection** that indicates: *“Whoever carries out works or activities that affect or may affect the environment, is required to prevent, minimize or repair the caused damage, and also assume the costs that such affectation implies. Likewise, those who protect the environment and make sustainable use of natural resources should be encouraged”*.

We consider that Sonora has, at the same time, a unique obligation and opportunity to become a leader in the design and implementation of mitigation infrastructure to promote the conservation of wild species. Also, we hope this report will open up further discussions and research projects with this objective.

Finally, we believe that in addition to the improvement of safety for both—drivers and wildlife—the installation of wildlife crossings on Federal Highway 2 would be an indisputable symbol of development, progress and sustainability in Sonora.

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