EVALUATING STRUCTURE CLASS AND CONSTRUCTION EFFECTS ON WILDLIFE USE OF ROAD UNDERPASSES

by

Joshua D. Renner, AWB®, B.S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Wildlife Ecology
August 2020

Committee Members:

M. Clay Green, Chair

Thomas R. Simpson

Floyd W. Weckerly

FAIR USE AND AUTHOR’S PERMISSION STATEMENT

Fair Use

Duplication Permission

ACKNOWLEDGEMENTS

Without the guidance of my chair, Dr. Clay Green, and the vast knowledge of he and my committee members, Dr. Butch Weckerly and Dr. Randy Simpson, none of this would be possible.

I would like to thank Dr. John H. Young and the Texas Department of Transportation for the financial support, advice, and dedication to my work here and many like it across the state.

I also owe a large debt of gratitude to my colleagues, many volunteers, undergraduates and good friends that helped me pull this off: Josh Harrison, Ryan & Jamie Chase, Travis Randolph, Mark Pearson, Ember Bower, Gayle Theil, Kevin Legrow, Tania Pena, Kris Phuong, Will Thompson, Townsend, and Michelle Adcock.

The unwavering support from my wife, Brittany, and the rest of my family was the most important of all.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Road ecology, the study of ecological impacts of roads, has become a major area of research. Road ecology involves the study of a variety of road effects such as soil erosion, hydrological effects, soil chemistry alterations, direct road mortality, and consequences to wildlife at the local and population level. This study aims to assess wildlife interactions between two classes of road underpasses (bridges and culverts) and looks into the effect of road construction in the area during the observation period. Six road underpasses were monitored on a 24 km stretch of bifurcated highway US 281, 4 km south of George West, Texas, within the South Texas Brush Country near the Bordas Scarp. Two types of established underpasses were monitored: bridge (n=3) and culvert (n=3). Camera arrays were installed at each underpass to maximize the detection of wildlife utilizing or interacting within the corridors of the underpass as well as the surrounding road-effect zone habitat. Linear mixed-effects models were used to analyze the effects of construction disturbance and underpass class between the two data sets where time intervals between independent captures responded to pre- and post-disturbance and bridge and culvert classes, respectively. Between the dates monitored, 10 June 2017 to 6 July 2019, a total of 2,111 independent captures events were observed, 950 prior to the disturbance and 1,161 afterwards from the two disturbed bridge stations. Between the dates monitored 10 June 2017 to 23 May 2018, a total of 4,940 independent captures events were observed, 2,301 under bridge structures and 2,639 under culverts at 6 monitored stations. Our findings suggest that neither disturbance under bridges nor structure type affected use by the wildlife population detected using these underpasses; however, we did see differential use among species. Post-construction monitoring studies, such as this one, can shed light on the effectiveness of these road underpasses as mitigation measures and can also provide information about how an existing road could be altered to achieve similar results.

I. EVALUATING STRUCTURE TYPE AND CONSTRUCTION EFFECTS ON WILDLIFE USE OF ROAD UNDERPASSES

Introduction

The first federally funded road building scheme in the United States was devised and implemented in the early 1800s (Bensen 1997), producing the 1000-km Cumberland Road, which was built to connect the major waterways of the Potomac and the Ohio River, allowing better access for people into the frontier west. Two hundred years later, the United States has over 6.5 million kilometers of roads; Texas' landscape alone contains over 500,000 km of that total (FHWA 2015). Road ecology, the study of ecological impacts of roads, has become a major area of research. Road ecology involves the study of a variety of road effects such as soil erosion, hydrological effects, soil chemistry alterations, direct road mortality, and consequences to wildlife at the local and population level (Forman and Alexander 1998, Forman and Deblinger 2000). Forman and Deblinger (2000) coined the term Road-effect Zone in an attempt to define the expansive ecological area under the influence of roads. Forman and Alexander (1998) estimated that 20% of the United States landmass could be ecologically impacted by these road-effect zones.

Direct impacts to wildlife include fragmentation of habitat as well as road mortality (Kroll 2015). A highway study in Canada conducted from 2008 to 2011 observed 7 taxa (snakes, turtles, frogs, toads, birds, mammals, and unknown) affected by road mortality; their estimated mean kills/km/day ranged seasonally from 0.85 to 2.12 road kills/km/day (Garrah et al. 2015). The well-studied Florida Panther (*Puma concolor coryi)* is an example of how roads fragment habitat and divide an already diminishing population. The Florida Panther has a large adult home-range and research (Schwab and

Zandbergen 2011) suggests that females shape their home ranges to fit the road in what is called the Cage Effect. The Cage Effect is responsible for habitat fragmentation and segregation of sexes that can affect breeding in a small population because these cats do not establish home ranges that are near or cross large roadways.

In addition to effects on wildlife populations, wildlife-vehicle collisions have a large impact on the economy. In 1995, $1.1 billion in damages were estimated for vehicle repair bills from wildlife collisions with only deer species in the United States (*Odocoileus spp.,* Conover et al. 1995). One of the mitigation strategies designed to reduce both habitat fragmentation and road collision is the engineering of roads permeable to wildlife where permeability is described as a design to make a road that does not create a barrier to wildlife movement. (Clevenger and Waltho 2000, Bissonette 2002, Kroll 2015). In a cost-benefit analysis, Huijser et. al. (2009) compared the average wildlife-vehicle collision cost of deer, elk and moose, to the average costs of varying strategies that would mitigate wildlife-vehicle collisions. They estimated elevated roadways and road tunnels as 100% effective where effectiveness was the estimated reduction in ungulate-vehicle collisions after implementation (Huijser et al. 2009). These structures, such as culverts and span bridges, allow wildlife to either cross over or under roadways. Different structures can be designed and placed in different habitats to target species of particular interest. Surrounding landscape, resources, and available road easement will likely dictate the design and breadth of a crossing.

This study aims to assess wildlife use of two classes of road underpasses (bridges and culverts) and examine the effects of road construction (e.g. clearing of vegetation) on crossing use by wildlife during the observation period. This study hopes to add information about how structures, once intended for drainage, can be used by wildlife and how these classes of structures may be used differentially along the same road in proximity.

Study Site & Experimental Design

Six road underpasses were monitored on a 24 km stretch of bifurcated highway US 281 beginning 4 km south of George West, Texas, within the South Texas Brush Country near the Bordas Scarp. (Figure 1) This area was chosen due to the number of potential crossing structures near each other along the same road with similar habitat structure. The area is best described as flat to rolling terrain with elevations not exceeding 305 m above sea level. Annual rainfall ranges from 41-89 cm with little precipitation in winter. The surrounding landscape is a patchwork of agricultural lands and native pasture with Mesquite-Granjeno (*Prosopis glandulosa - Celtis pallida*) series on uplands, Mesquite-Huisache (*Prosopis glandulosa – Acacia farnesiana*) series on poorly-drained soils, Cenizo (*Leucophyllum frutescens*) series near the Bordas Scarp, and a combination of Texas Ebony-Anacua (*Ebenopsis ebano – Ehretia anacua*) and Sugarberry-Elm (*Celtis laevigata - Ulmus* sp.) series in riparian habitat. (Diamond, et al. 1987) Given the drainage nature of the road underpasses, habitat surrounding the entrances to the crossings have a higher proportion of riparian series species.

Two classes of established underpasses were monitored: bridge (n=3) and culvert (n=3). Stations US281 4, US281 11, & US 281 14 (Fig. 1) were the monitored bridges, and stations US281 6, US281 7, and US281 13 (Fig 1) were the monitored culverts. Table 1 lists the stations as well as equipped cameras and measurable crossing dimensions. Bridge height was not measured because it varied greatly as the terrain rolled underneath these structures. In most locations bridge height was over 4 m. Camera arrays were installed at each underpass station to maximize the detection of wildlife utilizing or traversing the underpass as well as the surrounding road-effect zone habitat. (Smith et. al. 2017, O'Connor et. al. 2017) A total of 25 Reconyx Hyperfire PC900 Professional camera (Reconyx, Holmen, WI) traps were placed across the underpasses: 4 traps at each culvert (one trap facing the interior and one trap facing the exterior of the crossing on each side) with one trap observing a culvert with an open median, and 4 traps under each bridge (near game paths and areas with tracks present). Because US Highway 281 was oriented north-south, the wildlife crossing corridors were oriented east-west. Cameras were labeled and organized by station and direction. For example, 6ET would note a camera as being located at station US281 6 on the east side of the road facing towards the structure.

Camera mounting differed across stations to maximize detection within and among the underpass structure and surrounding corridor. Table 1 shows the camera mounts across all stations. Camera mounting definitions were as follows:

Sign Post: Post-hole diggers were used to dig holes approximately 38cm deep. A u-post was then driven in approximately 0.6m from ground level and secured with concrete. Reconyx HyperFire Camera series security enclosures were then attached to opposite sides of the u-post with carriage bolts and nuts. Cameras were then placed in the security enclosures and the post was manipulated to best capture the terrain. A Python lock (Master Lock, Oak Creek, WI) was then used to secure the security enclosures to one another.

Concrete Mount: Security enclosures were bolted directly into the concrete of the bridge or culvert at an approx. 90^{o} angle, washer spacers were used to adjust angle to best fit the cameras view of the wildlife crossing corridor.

Swivel Kit: Reconyx Heavy Duty Swivel mounts were bolted directly to the concrete of the bridge or culvert using lag screws. Screws were then secured with metal epoxy. Security enclosures were then attached to the swivel mounts and aimed for optimal coverage of the wildlife crossing corridor. A Python Lock (Master Lock, Oak Creek, WI) was used to secure the enclosure to the swivel mount.

At minimum, cameras took 1 picture per second for 3 seconds after each thermal motion trigger. Photographs were analyzed using Reconyx MapView Professional. This system allows for the documentation of species, count, and directionality, as well as taking measures of temperature, time, date, and moon phase for further analysis. Successful captures included directional movement in relation to labeled cameras on either side of the crossing. All crossings were monitored for 2 years, from June 2017 to July 2019.

Data were uploaded into Program R (3.6.3; https://www.r-project.org)) using R Studio (1.2.5033; https://rstudio.com) that would be later uploaded for statistical analyses in the R package 'camtrapR' (Niedballa et al. 2016). Camera data were collected and sorted by species/station. We combined the date and time of each record using the function ('DateTimeOriginal') for the purpose of organizing photos into capture events. We generated a record table to sort by station, species, and then date/time ('DateTimeOriginal') to appropriately define a capture event. Capture events were sorted by unique species per station per 60-minute interval (Tobler et. al. 2008). A capture event was counted by species/station within the 60-minute interval. The original intention of the study was to assess the differential use of underpass structures, bridges and culverts over a 2-year period. However, in May 2018, roughly halfway through the study, two stations, both bridges, (US 281 11 and US 281 14) underwent brush and vegetation clearing which created an opportunity to examine wildlife use before and after the disturbance event. Therefore, two data sets were analyzed. First, one data set containing captures from June 2017 to July 2019 for Stations US 281 11 and US 281 14; these stations underwent the clearing event on 23 May 2018 (Figure 2). These data were analyzed to detect the effects of the clearing event on wildlife use and/or wildlife detectability. The second data set was analyzed containing all stations from 10 June 2017 to 23 May 2019. These dates were chosen due to the clearing events at two of the six monitored stations. This analysis was designed to detected differences of wildlife interactions between the two crossing types (bridges and culverts). Linear mixed-effects (LME) models were used to analyze the effects of disturbance and underpass class between the two data sets where time intervals between independent captures responded to pre and post disturbance and bridge and culvert respectively. Data sets focused on medium to large mammals (e.g. meso-carnivores, ungulates) and excluded birds, small mammals, and herpetofauna as they did not use the structures in sufficient sample sizes, or were undetected.

Results

Disturbance Analysis

Between the dates monitored 10 June 2017 to 6 July 2019, a total of 2,111 capture events were observed, 950 prior to the disturbance and 1,161 after the disturbance under bridge Stations 11 and 14. Species observed included armadillo (*Dasypus novemcinctus*), bobcat (*Lynx rufus*), feral cat (*Felis catus*), coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), feral hog (*Sus scrofa*), opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and white-tailed deer (*Odocoileus virginianus*). Table 2 shows species capture totals as well as the numbers of captures pre and post disturbance. Table 3 shows the total captures by species per station.

An LME model comparing the additive effects of species and disturbance where station was a random effect was compared to a model that only analyzed the effect of the disturbance. A chi-squared maximum likelihood test was performed comparing two models, delta.time.hours ~ Disturbance + (1 | Station) to delta.time.hours ~ Disturbance + Species + (1 | Station). The model containing both disturbance and species predictors was best supported ($\chi^2 = 364.53$, df=9, $p < 0.001$, Table 4). To examine differential use by species, 95% confidence intervals were produced from bootstrapping 1,000 iterations from the model of better fit. There were no significant differences in collective wildlife use pre and post disturbance. Species model estimates are based upon the use of Armadillo. (Figure 3) Coyote, striped skunk, and gray fox were not captured post disturbance. Lower capture numbers were detected for armadillo, bobcat, feral hog, opossum, and raccoon post disturbance compared to pre disturbance. White-tailed deer and feral cats were the only species detected in higher numbers after the clearing event occurred at the disturbed bridge stations.

Structure Analysis

Between the dates monitored 10 June 2017 to 23 May 2018, a total of 4,940 capture events were observed, 2,301 under bridge structures and 2,639 under culverts at Stations 4, 6, 7, 11, 13, and 14. Thirteen species were observed included armadillo, bobcat, feral cat, coyote, eastern cottontail (*Sylvilagus* floridanus), gray fox, feral hog, javelina (*Pecari tajacu*), opossum, raccoon, striped skunk, and white-tailed deer. Table 5 shows total captures of species as well as the numbers of captures under each structure type. Table 6 shows total captures by station.

An LME model comparing the additive effects of species and structure where station was a random effect was compared to a model that only analyzed the effect of the structure. A chi-squared maximum likelihood test was performed comparing two models, delta.time.hours ~ Class + (1 | Station) to delta.time.hours ~ Class + Species + (1 | Station). The model containing both the structure class and species predictors was best supported ($\chi^2 = 612.31$, df=11, $p < 0.001$, Table 7). To examine differential use by species, 95% confidence intervals were produced from bootstrapping 1,000 iterations from the model of better fit. There were no significant differences of use across all species between the structure classes. Species model estimates are based upon the use of armadillo. (Figure 4) A large disparity of capture events across structure classes is seen in bobcat, gray fox, feral hog, opossum, and striped skunk. White-tailed deer were detected almost exclusively under bridges.

Discussion

Designing a proper permeable road can mitigate both wildlife-vehicle collisions and prevent or reduce the effects of habitat fragmentation (Clevenger and Waltho 2000, Bissonette 2002, Kroll 2015). Our study revealed that numerous wildlife species frequent these structures that were designed and intended for transportation and drainage purposes, not wildlife. Use of wildlife under bridges is likely heavily underestimated. The camera trap placement under culverts gave a full view of the crossable sections of these structures, whereas, the bridges varied in breadth from 32 to 110 meters not allowing for full coverage under bridges by camera traps. The Reconyx Hyperfire PC900 cameras have an approximate 40° field of view at 30 meters, allowing a maximum breadth coverage of 22 meters. If trap placement covered this maximum and wildlife use was uniform across the length of the bridges, wildlife use under some bridges might be underestimated by up to a factor of 5. However, camera trap placement along or near trails and trackways should provide optimal coverage of usable areas that could have been affected by construction disturbance.

Intuitively, larger numbers of white-tailed deer crossed under bridges than culverts because the dimensions of culverts exclude species of their size. Bobcats were present throughout all stations monitored. Previous research (Young et. al. 2019) suggested that bobcats avoid roads and their home range has little overlap with road habitat. In this study, camera traps captured a large number of incidences of bobcats in road habitats hunting under bridges and day-bedding in culverts. Station US281 13, which detected 380 bobcat-incidents, is one station where day-bedding was seen often. Station US281 13 also captured the greatest totals of striped skunk, gray fox, and opossum incidents, as well as a large total of raccoon and armadillo incidents. White-tailed deer were captured performing a wide array of behaviors under bridges such as browsing and bedding. Javelina were captured at the northern three stations, while feral hogs were captured only at the southernmost station. This coincides with previous research which found that home ranges of javelina and feral hogs tend to not overlap in 50% and 75% core areas (Ilse & Hellgren 1995). These results show that underpasses were used at similar rates by the wildlife population using these structures as a whole, although the two classes of underpasses were likely used differently by different suites of species. Future research in this area should investigate home-range overlap and landscape habitat features as those would add to the knowledge of how a wildlife population would interact with these road crossings.

This study also suggests that disturbance under bridges does not affect use by all underpass-friendly species of wildlife. However, differential use by species was detected. There was a decrease in detection following the construction disturbance for all species except for white-tailed deer and feral cats. With the presence of vegetative structure, cameras were placed facing game trails and likely passages of large and small mammals. After the clearing event, cameras were not moved from their previous locations. With the removal of such vegetative structure, detectability of small mammals was likely reduced as rapid growing grass species took place of large trees, and sparse underbrush. Moll et. al. (2020) established that the effect on larger species' detectability, such as white-tailed deer, is less profound than smaller species such raccoon and opossum when obstructive vegetation grows in the camera's field of view. The higher number of captures of white-tailed deer after disturbance could be due to the artificial moving of the edge habitat. Tall dense grasses gave white-tailed deer ample areas to bed down and for fawns to hide while adjacent woodlands gave ready access to browse (Rohm et. al. 2007). Coyote captures are low across all stations and bobcat captures decreased at these stations post disturbance. The apparent lower use of bridges by predators may have led to the higher frequency of use by white-tailed deer. Further research should be done in the area looking into the predator-prey relationships along this corridor as well as the aforementioned landscape habitat features that can shed more light on how land use changes affect the crossing corridors.

Ecological Implications

The overall design of a road is dictated by many factors, from taxpayer dollars dictating the budget to the engineering required to build a road across a landscape requiring a huge interdisciplinary effort. Any road will degrade habitat, manipulate wildlife movement, and likely kill wildlife regardless of the design; however, proper implementation of mitigation strategies can be used to lessen the severity. The goal of a permeable road is to create a safe travel corridor for people and wildlife. This study shows wildlife use across varying structures and investigates the potential effects of road maintenance construction on these wildlife corridors. The goals of a wildlife crossing should consider target species as well as other members of the wildlife community. For this landscape, white-tailed deer benefit from the presence of bridges while many mesocarnivores were shown to interact with smaller culvert structures as well as the bridges. Land-use changes within and among road easements can alter the proportion of species use by either attracting or repelling. Weller (2015) emphasized the importance of a pre-construction review, a well monitored clearing and construction phase, early implementation of mitigation structures, and adequate education as important features of building a cost-effective, high functioning road for both the public and wildlife. Post-construction monitoring studies, such as this one, can shed light on the effectiveness of these mitigation measures and can also provide information about how an existing road could be altered to achieve similar results.

Table 1. Monitored stations, structure class, dimensions, and method of camera installation. Stations were monitored with camera traps from June 2017 to July 2019 in Live Oak County, Texas.

Station	Class	Height	Width	Camera	Camera Mount
US 281 4	Bridge	N/A	97m		
				ET	Sign Post
				EA	Sign Post
				WT	Sign Post
				WA	Sign Post
US 281 6	Culvert	1.83m	1.83m		
				ET	Sign Post
				EA	Concrete Mount
				WT	Sign Post
				WA	Sign Post
US 281 7	Culvert	0.76m	1.53m		
				ET	Sign Post
				EA	Swivel Kit
				WT	Swivel Kit
				WA	Swivel Kit
US 281 11	Bridge	N/A	110m		
				ET	Sign Post
				EA	Sign Post
				WT	Sign Post
				WA	Sign Post
US 281 13	Culvert	1.53m	1.83m		
				ET	Swivel Kit
				EA	Swivel Kit
				WT	Concrete Mount
				WA	Concrete Mount
US 281 14	Bridge	N/A	32m		
				ET	Sign Post
				EA	Sign Post
				WT	Sign Post
				WA	Sign Post

Table 2. Species accounts pre disturbance and post disturbance across stations US 281 11 and 14 monitored by camera trap from June 2017 to July 2019 in Live Oak County, Texas. Disturbance occurred 23 May 2018.

Species	Pre	Post	Total
Armadillo	40	5	45
Bobcat	30	11	41
Cat (Feral)	21	40	61
Coyote	5	0	5
Gray Fox	1	0	1
Hog (Feral)	52	17	69
Opossum	74	4	78
Raccoon	41	18	59
Striped Skunk	3	0	3
White-tailed Deer	683	1066	1749
Total	950	1161	2111

Table 3. Species account by station across bridge structures pre and post disturbance across stations US 281 11 and 14 monitored by camera trap from June 2017 to July 2019 in Live Oak County, Texas.

Species	Station	Count
Armadillo		
	US281 11	26
	US281 14	19
Bobcat		
	US281 11	36
	US281 14	5
Cat (Feral)		
	US281 11	1
	US281 14	60
Coyote		
	US281 11	5
Gray Fox		
	US281 11	1
Hog (Feral)		
	US281 11	11
	US281 14	58
Opossum		
	US281 11	48
	US281 14	30
Raccoon		
	US281 11	32
	US281 14	27
Striped Skunk		
	US281 11	1
	US281 14	2
White-tailed Deer		
	US281 11	1060
	US281 14	689

Table 4. Chi-squared maximum likelihood results of the model selection for disturbance predictors compared to disturbance and species predictors of the disturbance data. Models used were as follows: 1 - delta.time.hours ~ Disturbance + (1 | Station), 2 - delta.time.hours ~ Disturbance + Species + (1 | Station).

	Df	**AIC**	**BIC**	**logLik**	**deviance**	**Chisq**	**Df**	**P**
1	4	30624	30647	-15308	30616			
2	13	30278	30351	-15126	30252	364.5	9	< 0.001

Table 5. Species accounts across bridge and culvert structures (n=6) across all stations from 10 June 2017 to 23 May 2018 monitored by camera trap from in Live Oak County, Texas.

Species	Bridge	Culvert	Total
Armadillo	162	133	295
Bobcat	95	628	723
Cat (Feral)	23	6	29
Coyote	5	22	27
Eastern Cottontail	5	22	27
Gray Fox	29	154	183
Hog (Feral)	52	0	52
Javelina	212	257	469
Opossum	186	684	870
Raccoon	337	582	919
Striped Skunk	6	148	154
White-tailed Deer	1189	3	1192
Total	2301	2639	4940

Table 6. Species accounts by station across all monitored stations from 10 June 2017 to 23 May 2018 monitored by camera trap in Live Oak County, Texas.

Species	Station	Count	Species	Station	Count
Armadillo			Bobcat		
	US281 4	122		US281 4	65
	US281 6	8		US281 6	124
	US281 7	11		US281 7	124
	US281 11	25		US281 11	28
	US281 13	114		US281 13	380
	US281 14	15		US281 14	2
Cat (Feral)			Coyote		
	US281 4	2		US281 6	8
	US281 6	1		US281 7	7
	US281 7	5		US281 11	5
	US281 14	21		US281 13	7
Eastern Cottontail			Gray Fox		
	US281 4	1		US281 4	28
	US281 6	2		US281 6	10
	US281 7	16		US281 11	1
	US281 11	4		US281 13	144
	US281 13	4			
Hog (Feral)			Javelina		
	US28114	52		US281 4	212
				US281 6	39
				US281 7	218
Opossum			Raccoon		
	US281 4	112		US281 4	296
	US281 6	135		US281 6	38
	US281 7	245		US281 7	268
	US281 11	44		US281 11	21
	US281 13	304		US281 13	276
	US281 14	30		US281 14	20
Striped Skunk			White-tailed Deer		
	US281 4	3		US281 4	506
	US281 6	12		US281 6	2
	US281 7	4		US281 7	1
	US281 11	1		US281 11	455
	US281 13	132		US281 14	228
	US281 14	2			

Table 7. Chi-squared maximum likelihood results of the model selection for structure class predictors compared to structure class and species predictors of the structure data. Models used were as follows: 1 - delta.time.hours ~ Class + (1 | Station), 2 - delta.time.hours ~ Class + Species + (1 | Station).

	Df	**AIC**	**BIC**	**logLik**	**deviance**	**ChiSq**	**Df**	**P**
1	4	67096	67122	-33544	67088			
2	15	66505	66603	-33238	66475	612.31	11	< 0.001

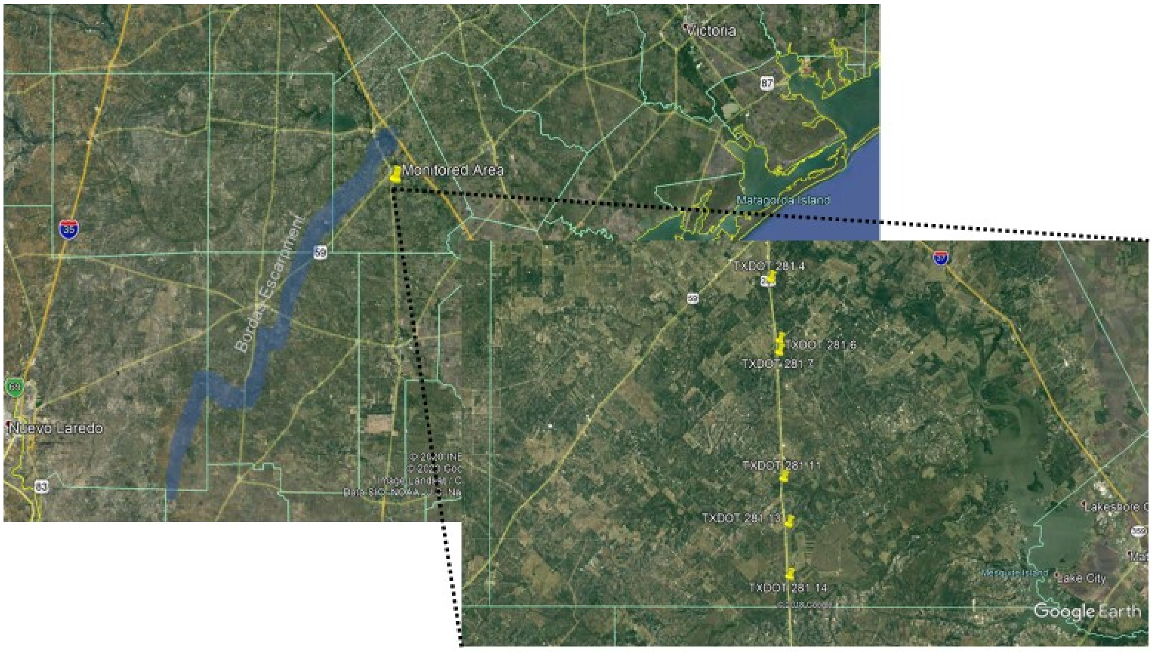
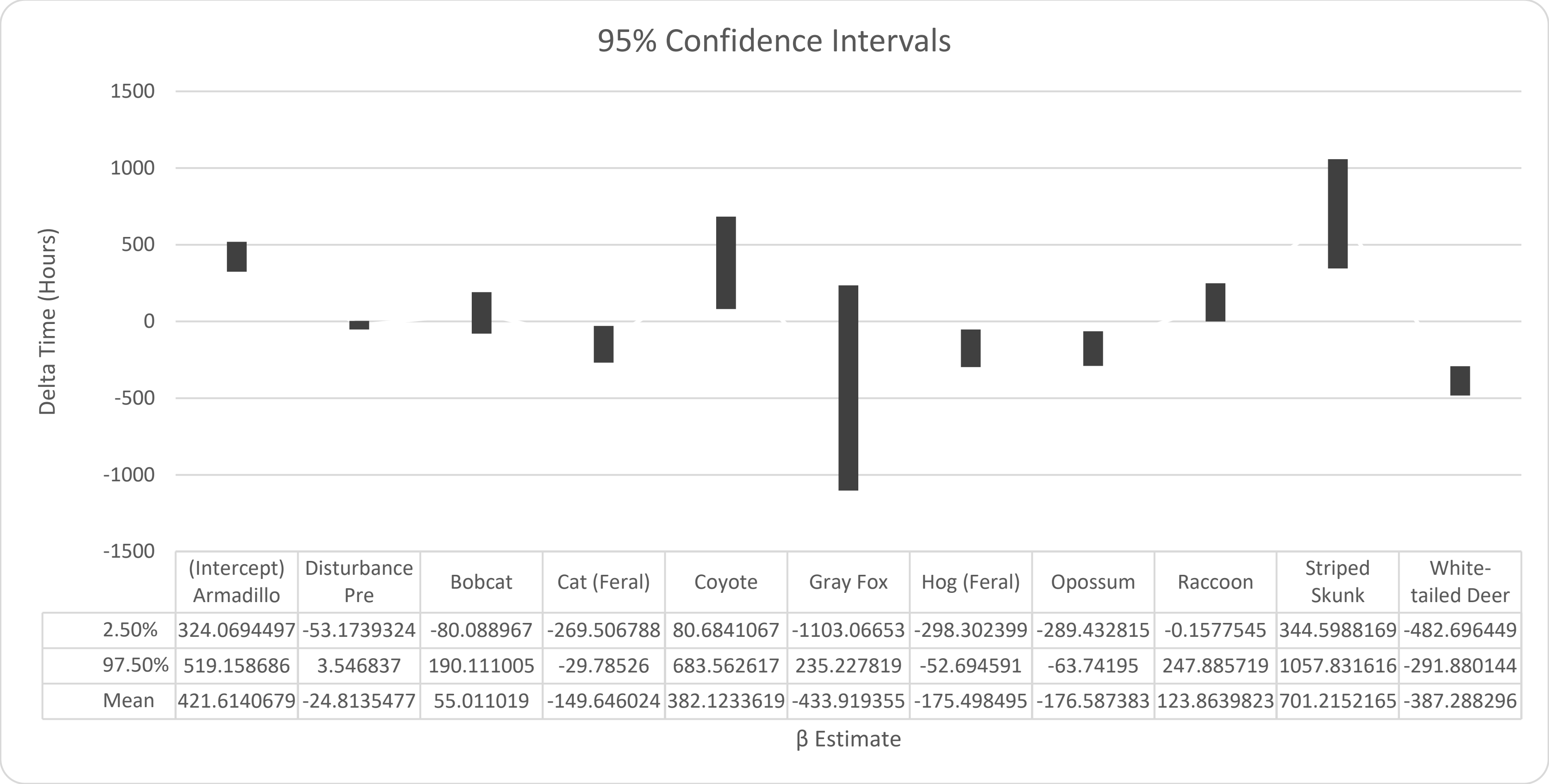


Figure 1. Monitored underpass stations along a 24km section of US Highway 281 and their relative locations in Live Oak County, Texas. US 281 Stations 4, 11, and 13 were bridge structures while US 281 Stations 6, 7, and 13 were culverts. Stations were monitored from June 2017 to July 2019.

Before

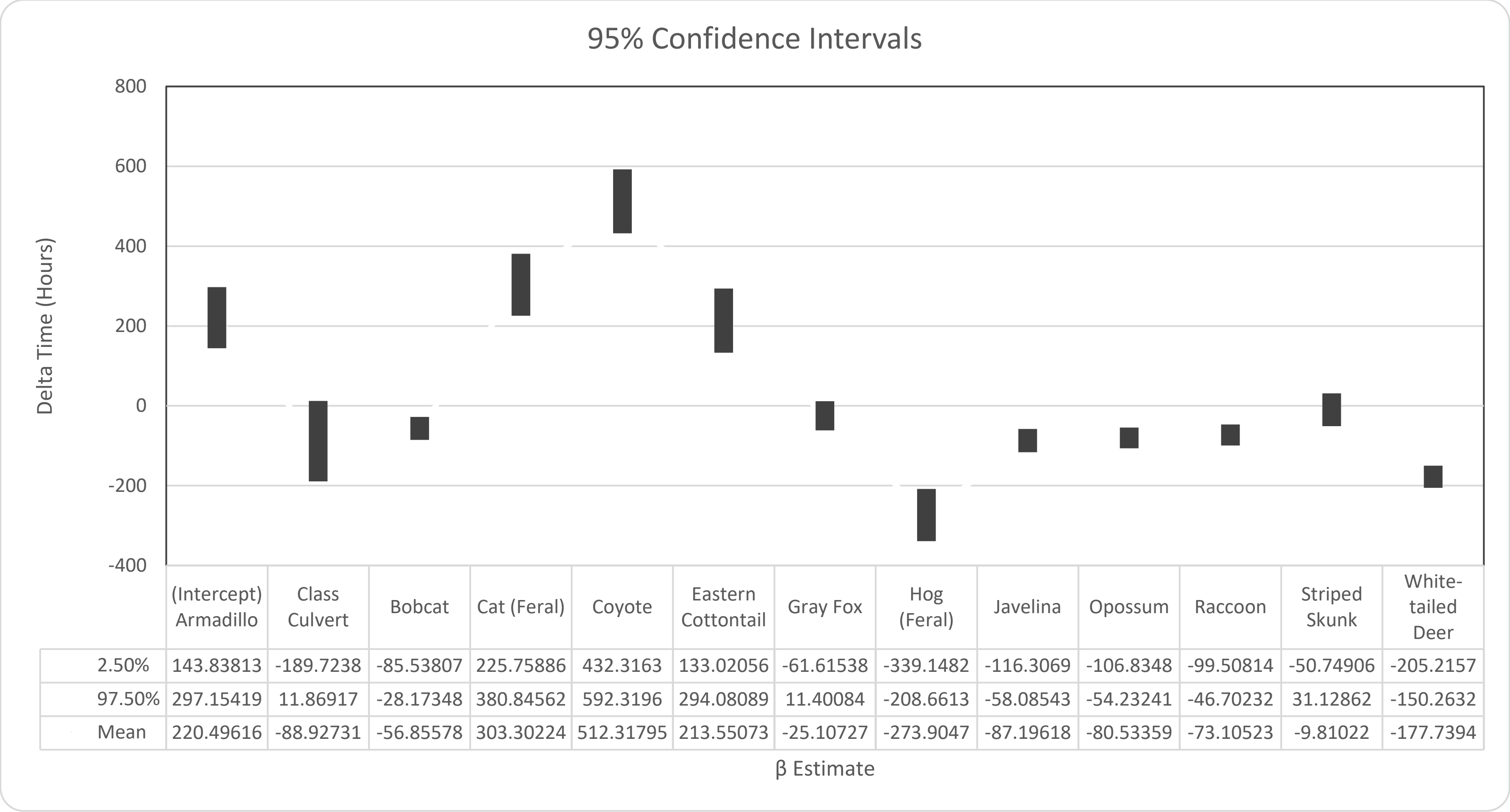
After

Figure 2. Clearing event at Station US 281 11; a similar event occurred at Station US 281 14. All vegetative structure was removed from these stations on 23 May 2018.



	(Intercept) Armadillo	Disturbance Pre	Bobcat	Cat (Feral)	Coyote	Gray Fox	Hog (Feral)	Opossum	Raccoon	Striped Skunk	White-tailed Deer
2.50%	324.0694497	-53.1739324	-80.088967	-269.506788	80.6841067	-1103.06653	-298.302399	-289.432815	-0.1577545	344.5988169	-482.696449
97.50%	519.158686	3.546837	190.111005	-29.78526	683.562617	235.227819	-52.694591	-63.74195	247.885719	1057.831616	-291.880144
Mean	421.6140679	-24.8135477	55.011019	-149.646024	382.1233619	-433.919355	-175.498495	-176.587383	123.8639823	701.2152165	-387.288296

Figure 3. 95% confidence intervals obtained from bootstrapping 1000 iterations of the linear mixed-effect model estimating delta hours responding to additive effects of disturbance and species where armadillo was used as the reference category.



	(Intercept) Armadillo	Class Culvert	Bobcat	Cat (Feral)	Coyote	Eastern Cottontail	Gray Fox	Hog (Feral)	Javelina	Opossum	Raccoon	Striped Skunk	White-tailed Deer
2.50%	143.83813	-189.7238	-85.53807	225.75886	432.3163	133.02056	-61.61538	-339.1482	-116.3069	-106.8348	-99.50814	-50.74906	-205.2157
97.50%	297.15419	11.86917	-28.17348	380.84562	592.3196	294.08089	11.40084	-208.6613	-58.08543	-54.23241	-46.70232	31.12862	-150.2632
Mean	220.49616	-88.92731	-56.85578	303.30224	512.31795	213.55073	-25.10727	-273.9047	-87.19618	-80.53359	-73.10523	-9.81022	-177.7394

Figure 4. 95% confidence intervals obtained from bootstrapping 1000 iterations of the linear mixed-effect model estimating delta hours responding to additive effects of structure class and species where armadillo was used as the reference category.

LITERATURE CITED

Bensen, J. 1997. The national road. World & I 12:190. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=f6h&AN=9706190307&site=eds-live&scope=site>.

Bissonette, J. A. 2002. Scaling roads and wildlife: The Cinderella principle. Zeitschrift Für Jagdwissenschaft 48:208-214. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=fzh&AN=FZH0174678162&site=eds-live&scope=site>.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborbn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407-414. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=19952218747&site=eds-live&scope=site>.

Clevenger, A. P., and N. Waltho. 2000. Factors Influencing the Effectiveness of Wildlife Underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.2641903&site=eds-live&scope=site>.

Diamond, D. D., Riskind, D. H., & Orzell, S. L. 1987. A framework for plant community classification and conservation in Texas. The Texas Journal of Science. 39:203-221.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology & Systematics 29:207-231. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bai&AN=506080348&site=eds-live&scope=site>.

Forman, R. T. T, and R. D. Deblinger. 2000. The Ecological Road-Effect Zone of a Massachusetts (U.S.A.) Suburban Highway. Conservation Biology :36. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.2641902&site=eds-live&scope=site>.

Garrah, E., R. Danby, E. Eberhardt, G. Cunnington, and S. Mitchell. 2015. Hot Spots and Hot Times: Wildlife Road Mortality in a Regional Conservation Corridor. Environmental Management 56:874-889. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=sur&AN=109236915&site=eds-live&scope=site>.

Huijser, M. P., J. W. Duffield, A. P. Clevenger, R. J. Ament, and P. T. McGowen. 2009. Cost-Benefit Analyses of Mitigation Measures Aimed at Reducing Collisions with Large Ungulates in the United States and Canada: a Decision Support Tool. Ecology and Society 14:15. <https://doaj.org/article/eb159d77ea8a4735aa6babe3f708f069>.

Ilse, L. M., and E. C. Hellgren. 1995. Spatial use and group dynamics of sympatric collared peccaries and feral hogs in southern Texas. Journal of Mammalogy 76:993-1002. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=gft&AN=505914287&site=eds-live&scope=site>.

Kroll, G. 2015. An Environmental History of Roadkill: Road Ecology and the Making of the Permeable Highway. Environmental History 20:4-28. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=sur&AN=101033700&site=eds-live&scope=site>.

Moll, R. J., W. Ortiz-Calo, J. D. Cepek, P. D. Lorch, P. M. Dennis, T. Robison, and R. A. Montgomery. 2020. The effect of camera-trap viewshed obstruction on wildlife detection: implications for inference. Wildlife Research 47:158-165. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edswsc&AN=000521586400007&site=eds-live&scope=site>.

Niedballa, J., R. Sollmann, A. Courtiol, A. Wilting, and P. Jansen. 2016. camtrapR: an R package for efficient camera trap data management. Methods in Ecology & Evolution 7:1457-1462. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=eih&AN=120281894&site=eds-live&scope=site>.

O'Connor, K. M., L. R. Nathan, M. R. Liberati, M. W. Tingley, J. C. Vokoun, and T. A. G. Rittenhouse. 2017. Camera trap arrays improve detection probability of wildlife: Investigating study design considerations using an empirical dataset. PLoS ONE 12:1-12. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=fsr&AN=122569474&site=eds-live&scope=site>.

Rohm, J. H., C. K. Nielsen, and A. Woolf. 2007. Survival of White-Tailed Deer Fawns in Southern Illinois. The Journal of Wildlife Management 71:851. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.4495262&site=eds-live&scope=site>.

Schwab, A. C., and P. A. Zandbergen. 2011. Vehicle-related mortality and road crossing behavior of the Florida panther. Applied Geography 31:859-870. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20113112580&site=eds-live&scope=site http://www.sciencedirect.com/science/journal/01436228>.

Smith, J., S. Legge, A. James, and K. Tuft. 2017. Optimising camera trap deployment design across multiple sites for species inventory surveys. Pacific Conservation Biology 23:43-51. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=sur&AN=122366887&site=eds-live&scope=site>.

Tobler, M. W., S. Carrillo-Percastegui, R. Leite Pitman, R. Mares, and G. Powell. 2008. An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation 11:169-178. <https://doi.org/10.1111/j.1469-1795.2008.00169.x>.

Weller, C. 2015. Construction of Roads and Wildlife Mitigation Measures: Pitfalls and Opportunities. Handbook of Road Ecology :60-64. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edselc&AN=edselc.2-52.0-84977110016&site=eds-live&scope=site>.

Young, J. K., J. Golla, J. P. Draper, D. Broman, T. Blankenship, and R. Heilbrun. 2019. Space use and movement of urban bobcats. Animals 9:275. <http://libproxy.txstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20193238278&site=eds-live&scope=site https://www.mdpi.com/2076-2615/9/5/275/htm>.