5-2021

Determining the Effectiveness of Wildlife Exits Along a South Texas Highway

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DETERMINING THE EFFECTIVENESS OF WILDLIFE EXITS

ALONG A SOUTH TEXAS HIGHWAY

A Thesis

by

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Submitted to the Graduate College of
The University of Texas Rio Grande Valley
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2021

Major Subject: Biology

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May 2021

ABSTRACT

Sheikh, Zarina N., Determining the Effectiveness of Wildlife Exits Along a South Texas Highway. Master of Science (MS), May 2021, 80 pp., 6 tables, 15 figures, references, 95 titles, 2 appendices.

Movement is a key component of survival for many species, often causing wildlife to cross heavily trafficked highways, resulting in road mortalities. In Cameron County, Texas, ten wildlife exits (WE) were installed along State Highway 100 in conjunction with existing mitigation structures to provide species such as the U.S. endangered ocelot with a safe option to escape the right-of-way (ROW). The objectives of this study were to determine effectiveness and species usage, as well as to estimate the percentage of wildlife that crossed back into the habitat via a WE. Results of this study showed that all six target species used a WE to return to the habitat. Approximately 43% of bobcats observed, a surrogate species for the ocelot, used a WE to escape the ROW. Information on the effectiveness of these novel structures will be useful in the development of future WE to optimize placement and design.

DEDICATION

The completion of my thesis would not have been possible without the guidance of God and my strong faith in Him. There is no way I would have made it a single day, let alone through the two most challenging years of my academic career, without His direction, love, and support. My deepest gratitude goes to Him for forever being my source of inspiration and comfort.

I also dedicate this work to my incredible circle of humans that I am honored to call my family, especially my mother, de Borah Sheikh, who has encouraged me through my daily struggles and is always pushing me to persevere; my brother, Saleem Sheikh, who listened to me practice my presentations and study for exams regardless of what time it was; my sisters, Shaila and Shazia Sheikh, who were an endless motivation and brightened my days with hilarious sister talk; and my sweet orange kitty, Little Fat Guy, who fueled my fascination to study ocelots. Thank you all from the bottom of my heart for your love and for being my rock-solid support system.

ACKNOWLEDGMENTS

I would like to thank Dr. Richard J. Kline for his assistance throughout this process and for providing me the opportunity to work on this ocelot monitoring project. I would also like to acknowledge Dr. John H. Young, Jr. and the Texas Department of Transportation, Pharr District for funding this project, as well as Dr. Christopher Gabler for his help with my statistical analysis. For providing land access and ocelot mortality data, I would like to recognize the U.S. Fish and Wildlife Service.

Additionally, I want to thank individual members of the Kline lab for their assistance and support during my time on this project: Kevin Ryer for his help with study design and formulating my objectives, T. Miles Hopkins for his patience in working through my analysis and answering my questions regardless of how repetitive they were; Thomas Yamashita for his help with analysis and teaching me how to make presentable maps in ArcGIS; and Anna Rivera Roy for providing background information about this project when I initially joined and for being the only one willing to discuss true crime with me. A special thanks goes to my fellow graduate and undergraduate students including Adam Sanjar, Bradley Beer, Victoria Rodriguez, and Alexa Campos for helping with fieldwork and sorting countless photos. Lastly, I want to give a shout-out to OFF!® for literally saving my skin on every field day.

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CHAPTER I

INTRODUCTION

Roads and highways have significant impacts on wildlife and the environment in the form of habitat disturbances and wildlife-vehicle collisions (WVC) (Cain et al. 2003, Forman and Alexander 1998). As wildlife spread into previously unoccupied areas, interactions with humans are becoming frequent, inhibiting wildlife viability along busy highways (Soulsbury and White 2015, Grilo et al. 2008, Kindall and Manen 2007).

Roadways comprise an estimated network of 6.4 million miles stretched across the United States (U.S. Department of Transportation 2018), presenting a variety of threats to wildlife populations through habitat fragmentation and a loss of suitable habitat. In areas where linear infrastructures create a barrier for wildlife, reductions in gene flow can result, separating species into smaller populations (Ascensão et al. 2013). Roads can have additional, indirect effects on wildlife behavior, particularly on species that require territories or cover large distances (Clevenger and Kociolek 2013, Leblond et al. 2013).

Whether it is establishing territory, finding a mate, or simply seeking out a reliable food source, movement is a key component of survival for many species (Holderegger and Di Giulio 2010, Sawaya et al. 2014, Clevenger et al. 2001). Roads and highways can influence wildlife negatively in a variety of ways, often causing habitat fragmentation, noise disruptions, loss of suitable habitat, and wildlife road mortalities. Vegetation maintenance that is associated with many of these road structures can create barriers that may affect species differently (Andis et al. 2017, D'Amico et al. 2015). This combination of interrupted habitat and wildlife dispersal across roadways often results in road mortalities from WVC (Sawaya et al. 2014, Grilo et al. 2008). Although wildlife-vehicle mortalities do not affect the population viability for more abundant species, they can greatly impact threatened or endangered species with small population sizes and low reproductive rates (Gilhooly et al. 2019, Glista et al. 2008), such as the U.S. endangered ocelot (*Leopardis pardalis*). The consequences of a lack of landscape connectivity in south Texas have lead to decreases in ocelot population size, a loss of genetic diversity via inbreeding (Janečka et al. 2007), and an increase in road mortalities (Ascensao et al. 2013, Haines et al. 2005).

Mitigation Structures

Wildlife-vehicle collisions are responsible for an estimated 5% of vehicle-related accidents that are reported across the U.S. each year (Wilkins et al. 2019). These collisions present a direct threat to human safety, domestic pets, and wildlife species of concern that encounter busy roads or highways that intersect their habitat. Wildlife mitigation structures are currently used in the U.S. and abroad in a variety of forms designed to promote habitat connectivity and facilitate successful passages for wildlife across taxa as well as to reduce wildlife road mortalities. Commonly used mitigation structures built to reduce wildlife-vehicle collisions are underpasses, overpasses, continuous fencing, wildlife guards (WG), jump-outs, and gates (McDonald and St. Clair. 2004). The purpose of these structures is to create safer crossing zones for wildlife that encounter roads and highways. Placement and spacing of crossings are key to effective mitigation as well as identification of road mortality hotspots where wildlife access the roadway (Bissonette and Adair 2008).

Over the past few decades, studies have shown that fencing, wildlife crossing structures (WCS), and other mitigation structures along highways are potential solutions to improving habitat connectivity and acting as a filter to reduce road permeability that typically results in WVC (Cain et al. 2003), with varying levels of success. Wildlife crossing structures are meant to provide wildlife that approach a highway a form of safe passage across it, limiting the overall number of WVC that occur (Andis et al. 2017). Simpson et al. (2009) investigated WCS effectiveness for ungulates and found that underpasses and overpasses served as a successful means of connectivity for deer. Use of WCS by carnivores has also been documented where Florida panthers, bobcats, and black bears used WCS to travel across highways that separated their home ranges (Foster and Humphrey 1995).

Other forms of mitigation structures such as WG, fencing, and jump-outs modify movements of wildlife of varying sizes and with different patterns of behavior. Wildlife guards, fencing, and jump-outs have all demonstrated success in reducing wildlife road mortalities and providing habitat connectivity for wildlife (McCollister et al. 2010, Clevenger and Waltho 2000, Gagnon et al. 2011). Fencing in Europe was found to be effective at mitigating the effects of roads on stone martens (Ascensao et al. 2013), suggesting that even partial fencing may aid in the reduction of road mortalities. Jump-outs and earthen escape ramps in Utah have reportedly reduced deer mortalities along roadways (Bissonette and Hammer 2000). Additionally, WG in Montana were successful in preventing deer from entering the roadway, although they were less successful at keeping carnivores like bears and coyotes from accessing the road (Allen et al. 2013).

For larger mammals such as deer and elk, mitigation structures have been constructed to aid wildlife in leaving the area between the road and continuous fencing that separates the road from the habitat, called the right-of-way (ROW). This mitigation exists in the form of earthen jump-outs (Bissonette and Hammer 2000), escapes, and other one-way gates (Jackson and Griffin 2000) to create areas where wildlife can escape the ROW. VerCauteren et al. (2009) installed guards and bump gates for white tailed deer to prevent entry into fenced areas with mixed results. While bump gates demonstrated some success, deer-resistant guards were less effective and were not expected to provide long-term deterrence of deer (Ver Cauteren et al. 2009). Specifications are needed for these structures for roadside use, as gates and escapes do not take ungulate behavior into consideration (Bissonette and Hammer 2000). Deer are prey animals that are typically hesitant to pass through narrow or constricting structures that could make them vulnerable to predators. Consequently, these studies have produced a mixture of results that need continued testing to measure their effectiveness.

Factors Affecting Wildlife Activity

Various factors can influence wildlife activity along roadways including canopy cover, amount of traffic, distances between crossing points, and seasonality. Consideration of structural and landscape attributes is important when determining placement of mitigation structures (Clevenger and Waltho 2000), as well as the target species being studied. Clevenger and Waltho (2000) investigated factors that influence the success of wildlife underpasses in Banff National Park, Alberta, Canada, revealing that carnivores responded differently than ungulates and exhibited greater impacts by landscape as opposed to structural differences. For some carnivores, structural characteristics can play an important role in the species presence at WCS. A study by Clevenger and Waltho (2005) found that constricted structures that were narrower and longer in length had higher black bear and cougar crossing rates. Design and dimensions of mitigation structures should reflect what is known about travel routes, behavior, and biology of all target species under consideration in order to construct an effective structure (Foster and Humphrey 1995). Data on factors affecting success could help shape future wildlife structure appearance and structural specifications to maximize use by target species, especially with regard to predators.

Sections of highways with suitable habitat are likely to contain greater species diversity and could benefit the most from the implementation of mitigation structures. Also, areas with high wildlife traffic can change throughout the year in regions that witness both migratory and resident populations where adaptation to mitigation structure use is expected to differ (Simpson et al. 2016).

Additionally, there is evidence that habitat corridors are actively used by predators as well as their prey. Gloyne and Clevenger (2001) investigated the use of WCS by cougars along 45 km of the Trans-Canada Highway in Alberta, Canada. They detected a positive correlation between mule deer and cougars utilizing these corridors and found that cougars appeared to be making the most passages through areas with the highest habitat quality (Gloyne and Clevenger 2001). Similar studies have found overlap of predators and their prey (Ford and Clevenger 2010, Dickson et al. 2005), but do not suggest that predator behavior at WCS is affected by prey movement. These findings support the idea that WCS are serving their intended purpose for predators, lending an optimistic view to the implementation of similar structures along other highways.

Measuring Effectiveness of Mitigation Structures

A common method of determining the effectiveness of a mitigation structure is to examine the number of crossing events for species that are observed using these structures (Grilo et al. 2008, Andis et al. 2017). Crossing events allow the behavior of an individual to be recorded and categorized to better understand the performance of a mitigation structure. Some of the ways of measuring effectiveness include road mortality surveys, monitoring telemetry movements, and camera trapping. Monitoring wildlife activity via cameras is a common method of documenting species interactions and passage rates given that camera trapping is effective for wildlife that are elusive, largely nocturnal, or maintain low population densities in a given area (Heilbrun et al. 2006). Camera monitoring is effective for various types of mitigation structures including fence ends (Huijser et al. 2016), WCS (Simpson et al. 2016, Grilo et al. 2008 Huijser et al. 2016), and WG (Allen et al. 2013)**.**

Ocelots in South Texas

Since a variety of mammals require suitable habitat that can stretch across vast ranges, they represent wildlife that would typically use crossing structures and benefit from effective mitigation (Ford and Clevenger 2010). An ideal candidate to study is the ocelot, because this species is endangered in the United States and would allow the consequences of roadways to be viewed through a conservation lens by estimating effective population sizes of highly fragmented populations (Janečka et al. 2007). Though the ocelot's range previously extended all the way to Arkansas, loss of its preferred thornscrub habitat has caused populations to dwindle, limiting the ocelot's range in the United States to southern Texas (Janečka et al. 2007).

In south Texas, mitigation efforts are underway to conserve the two remaining U.S. populations of the ocelot, a medium-sized carnivore that has been federally listed as endangered throughout its range in the United States since 1982 (USFWS 1982). Currently, these ocelot populations are known from Willacy and Cameron Counties in south Texas (Horne et al. 2009, Lombardi et al. 2020, Janečka et al. 2007), which are separated from the larger Mexico population by roads and highways as well as areas of urban and agricultural development

(Lehnen et al. 2021). Ocelots are sensitive to changes in their preferred habitat which can amplify through the implementation of linear infrastructure and human development. As a result, one of the causes of ocelot mortality are collisions with vehicles along roads and highways that intersect areas of optimal habitat in which ocelots are known to occur (Wilkins et al. 2019, Haines et al. 2005). Due to the rarity of ocelots and their similarities in ecology, bobcats have often been used as a surrogate species for ocelots when considering responses to mitigation structures (Grigione and Mrykalo 2004, Hewitt et al. 1998, Schmidt et al. 2020). This is largely due to their similarities in habitat, diet, body size, behavior, and overlapping home ranges (Booth-Binczik et al. 2013, Cain et al. 2003, Horne et al. 2009). Various forms of mitigation structures for ocelots and other mesocarnivores in this area are being studied with the aim of reducing the number of highway entries that often result in road mortalities. Presently, an estimated 80 individual ocelots comprise the two isolated populations that inhabit areas of south Texas (Horne et al. 2009, Haines et al. 2005). Ocelots are typically solitary, feeding on small mammals, birds, and other vertebrates (Trolle and Kéry 2003). One of the primary reasons behind the decline of these carnivores is due to loss of its critical habitat in regions where these felids are found. Ocelots require dense habitat and often show a preference for areas with >75% canopy cover (Horne et al. 2009, Satter et al. 2018). As a result, they are restricted to areas that offer this amount of vegetation, making them more sensitive to environmental changes and alterations to existing habitat.

An important consideration when building mitigation structures with regard to ocelot conservation is the surrounding habitat. Cain et al. 2003 examined the effect that mitigation has had on bobcat mortalities and suggested that maintaining preferred habitat near highways may increase mortalities. Though favorable habitat is ideal for the persistence of ocelots, the presence of prime habitat bordering the highway could prove to have negative impacts on individuals. Examination of novel wildlife exits has the potential to reduce road mortality, and their effectiveness on State Highway 100 was considered by looking at bobcat activity.

Wildlife Exits

In September 2016, the Texas Department of Transportation (TxDOT) began construction of mitigation structures on State Highway (SH) 100 in Cameron County, Texas. Mitigation structures were constructed in response to three ocelot mortalities that occurred along SH 100 between 2010-2014 (Environmental Affairs Division 2015). The mitigation structures installed included wildlife crossings, WG, wing walls (WW), gates, and continuous fencing; all conservation measures were aimed at reducing ocelot road mortalities, as well as non-target species (Final Bi-annual Summary Report 2018). Importantly, no jump-outs or other avenues of exiting the ROW through the fencing were created.

Camera monitoring of structures on SH 100 showed successful use of WCS, however, wildlife were reportedly circumventing WG and fence gaps and entering roadways (Rivera Roy 2020). These entries by wildlife via WG and fence ends (FE) onto the roadway quickly lead to concerns that an ocelot could similarly access the ROW, become trapped between contiguous fencing, and get hit by a vehicle. Wildlife guards do not always serve as adequate barriers to carnivores such as bobcats and coyotes and can sometimes permit wildlife to enter the roadway (Allen et al. 2013). Additionally, fence gaps at intersections may allow wildlife to enter the roadway (Cserkész and Farkas 2015, Huijser et al. 2015) and become trapped in the ROW.

To mitigate this potential problem, TxDOT installed ten wildlife exits (WE) on February 13, 2019, in an effort to give wildlife that crossed onto the road using a WG a safe option to exit the ROW, reducing wildlife road mortalities. Similar solutions for large mammals in the form of wildlife jump-outs and escapes have exhibited low usage and limited success for wildlife traveling along the ROW and searching for an exit off of the road (Huijser et al. 2016). On a highway in Mantua, Utah, comparison of jump-outs and one-way deer gates found that earthen jump-outs were more effective in removing deer from the ROW (Bissonette and Hammer 2000). These structures are typically built for ungulate use and are not intended for small to medium-sized mammals. Wildlife exits are a novel type of mitigation structure in this study area, specifically designed for ocelot use. Since WE are significantly smaller in size and shape to other WCS and jump-outs, it is easier to categorize wildlife usage by counting the number of successful crossing events. As previously constructed mitigation structures do not prevent all roadway entries, this study examined the effectiveness of WE in returning individuals to the habitat that entered the roadway via other mitigation structures.

While offering jump-outs to enable wildlife to leave the roadway is a recommended practice at WCS (Bissonette and Hammer 2000, Huijser et al. 2009), none have been installed in conjunction with structures in Texas. Given that these are the first known WE to be employed on a mitigation project in the state of Texas, this project is unique in that it examines questions on wildlife activity that surface after the implementation of novel mitigation structures. Wildlife exits were installed specifically for the endangered ocelot and other medium-sized carnivores, though the design offers a multitude of wildlife the opportunity for safe passage from the ROW to the habitat side of the chain-link fence.

In this study, two main objectives were assessed to 1) characterize the wildlife community at WE and ROW locations to determine species composition for all target species and 2) to examine the effectiveness of WE by characterizing how wildlife use them and the frequency of use in the intended way.

The first objective was to characterize the wildlife community using the WE and various ROW locations to determine differences in species composition. On roads and highways with wildlife mitigation structures present, wildlife communities occurring along the road can differ in species presence and abundance to adjacent wildlife communities that exist on the habitat side of the fencing. The following hypotheses were tested:

1. Wildlife communities surrounding the WE will be significantly different in terms of canopy cover, side of highway, year and interaction type (exiting the roadway, entering the roadway, walking parallel to the fence, etc.).

2. Wildlife communities around the ROW locations will be the same among all ten sites along SH 100.

3. Species composition and abundance will not significantly differ between wildlife using WE and wildlife detected on cameras placed in the ROW. Interaction type and side of highway will have no influence on wildlife activity across WE or ROW locations.

The second objective of this study examined the effectiveness of WE by identifying the mitigation structures where wildlife enter and exit the roadway, calculating the percentage of wildlife remaining on the road that correctly use a WE to escape the ROW, and estimating the number of wildlife remaining on the road. The hypotheses for this objective were as follows:

1. All target species will find and use a WE to correctly travel from road to habitat. No species will use a WE incorrectly to access the roadway from the habitat side.

2. Bobcats and coyotes will learn to utilize WE correctly over time to escape the roadway and access the habitat. More bobcats will use WE than coyotes to move from road to habitat as a result of size differences.

3. Wildlife exits with high cottontail and rodent usage will exhibit high mesocarnivore activity due to presence of prey.

Study Area

This study occurred along an 11.9 km stretch of State Highway (SH) 100 between Los Fresnos and Laguna Vista in Cameron County, Texas (Fig. 1). The right-of-way on SH 100 has been fenced with continuous geomesh polypropylene fiber (GEO 55) chain-link fencing with ten WE. Bordering the Laguna Atascosa National Wildlife Refuge, the habitat in this area primarily consists of dense Taumaulipan thornscrub, grassland communities, and Gulf coastal prairie, and has a flat topography with elevations ranging from 0-10 m (Watson et al. 2019, Haines et al. 2006, Horne et al. 2009). Vegetation along SH 100 is variable, from dense thornscrub with high canopy cover in some areas to wide stretches of open grassland. The climate in this area is subtropical and semi-arid (Harveson et al. 2004, Jahrsdoerfer and Leslie 1988); annual rainfall throughout the region is 65 cm, with summer temperatures climbing to 35°C and winter temperatures averaging as low as 12°C (NOAA 2021).

Though part of the land that encompasses the study area is managed by the U.S. Fish and Wildlife Service, some areas are privately-owned and used for agriculture or ranchlands. The area is home to many species that are unique to south Texas, including the state-threatened Texas tortoise, and endangered species like the Aplomado falcon and the ocelot. Numerous species in this area face threats of population decline, primarily due to a loss of habitat. Future development is expected to continue throughout the Lower Rio Grande Valley, likely further fragmenting the remaining habitat in this area.

CHAPTER II

METHODS

Although designed with the endangered ocelot in mind, the dimensions of the WE are suitable for use across a wide range of species (Fig. 2). Six medium-duty PVC coated T-posts measuring four feet high were driven 12 inches into the ground and secured to each exit with T-post clips to provide support. The material used for the exit fencing was 2" x 3" mesh 16 gauge black PVC coated welded wire, from which two side panels were cut to dimensions of 2' x 4.5' long and secured using hog rings along the roadside of the existing chain-link fence. The height of the exits was 24 inches tall with the opening measured at 18 inches wide (Fig. 2). The WE were funnel-shaped and narrowed to a final width of approximately five inches across, extending to a depth of 33 inches when measured from the chain-link fence.

Data Collection

Camera monitoring was carried out year-round and occurred from February 2019 to November 2020. For the purposes of this study, a total of 20 Reconyx HyperFire 2™ series cameras were set up across the ten WE. At each WE, two cameras were installed 2-3 m from the exits, one on the roadside of the continuous fencing and one on the habitat side, each facing perpendicular to the exit (Fig. 3).

All cameras were checked monthly at which point memory cards were replaced and batteries were changed as needed. Cameras were programmed to take a set of three pictures at one-second intervals each time the camera was triggered by motion. On field days when pictures were collected, surrounding vegetation was cleared out to an approximate distance of three meters around each exit to reduce excessive camera triggers and to clearly view species interactions in each photo. The distance of this arc was chosen to discourage unwanted human interest in the cameras, as well as to limit the visual alterations made to the habitat's natural appearance that could repel wildlife entry from the roadside (Brown and Gehrt 2009). In addition, a densitometer was used to measure the amount of canopy cover at each WE. A WE was closed once either a bobcat or coyote was observed using it to incorrectly access the roadway, due to the concern that an ocelot may do the same.

In addition to the cameras that were set up at each WE, ten cameras were placed in the ROW on both the north and south side of SH 100 to capture wildlife walking along the highway (Fig. 1). Using ArcMap 10.6.1, ROW locations were selected by identifying unmonitored gaps of chain-link fencing exceeding 500 m to the nearest mitigation structure. From these gaps, cameras were placed on the roadside of the fencing, approximately three meters away and facing perpendicular to the fence (Fig. 4). The primary goal was to capture animal activity occurring along the road that was not being recorded on cameras next to a monitored opening in the fence. Surrounding vegetation was cleared 2-3 m around each ROW camera.

Along with the ten WE, this project currently monitors five WCS, 16 WG, four FE, 16 gates, and three WW, all of which were constructed to prevent wildlife road access in order to reduce wildlife road mortalities along SH 100 (Fig. 5). Similar to WE data collection, these mitigation structures were checked every two weeks during which memory cards were replaced and batteries were changed as needed. Total entries onto the road and exits into the habitat at every monitored WCS, WG, gate, and WW were counted for each of the target species from

February 2019 to November 2020 to determine the number of individuals remaining on the roadway.

Data Management

Each WE camera was checked once per month, at which point pictures were downloaded, visually analyzed, and sorted into corresponding species folders. All pictures were renamed according to the date and time that the photo was captured using the software programs Renamer and Special Renamer (Sanderson and Harris 2013). Additionally, DataOrganize was used to catalog pictures and highlight any organization errors that were missed during the sorting process.

All recorded species were identified to the lowest taxonomic level (Table 1). For the purposes of this study, only mammals larger than rodents were assigned an interaction. Interactions were not assigned to humans, rodents, birds, and most herpetofauna with the exception of species of concern, including the Texas tortoise and the Texas indigo snake, and primarily ground-dwelling birds such as the northern bobwhite and greater roadrunner. However, given the low numbers of these species as well as their ability to permeate the continuous chain-link fencing along SH 100, they were excluded from analysis. Due to their size, larger animals such as white-tailed deer, nilgai, and javelina were unable to use WE and were also excluded from analysis. Although eastern cottontails occasionally traveled directly through the WE fencing, this species was included in analysis due to their availability as a prey item for mesopredators (Booth-Binczik et al. 2013). Rodents in this area were small enough to permeate both the chain-link and WE fencing and were consequently analyzed in relation to mesocarnivore presence by counting independent events. Additionally, all domestic animals except for domestic cats were excluded from analysis. The purpose of these constraints was to encompass only the species that were expected to benefit the most from the installation of the WE.

Once classified by species, a second reviewer further sorted the pictures by the number of individuals observed in each picture. Finally, individual interaction categories were assigned depending on how the individual interacted with the WE, where "A" designated a successful crossing from one side of the fence to the other, "B" was an entry and exit on the same side of the fence, and "P" was assigned to interactions where an individual moved parallel to an exit and did not attempt to use it (Fig. 6). Potential directions included "H" which designated the habitat side of the fence, "R" indicated a direction on the road, and "F" was a wildlife crossing made via a hole or gap in the exit's mesh fencing. Figure 6 illustrates the categories for the possible interactions that occurred. Similarly, pictures from all other mitigation structures were sorted by species, number of individuals, and categorized by interaction type (Fig. 7).

Data Analysis

In order to avoid counting the same animal as multiple individuals, a time frame of 30 minutes was established to determine independent interaction events (O'Brien et al. 2003). If multiple interactions of an individual of the same species occurred at a WE under this time frame, it was considered the same individual and counted as a single event. For example, if an animal was documented crossing onto the road and then captured within 30 minutes using a mitigation structure to travel back into the habitat, it was considered the same individual unless overwhelmingly evident (by means of markings, injuries, size, etc.) that there were two distinct individuals.

Characterization of the Wildlife Community at Wildlife Exits and Right-of-Way Locations

To accurately assess the wildlife community using the WE, the total number of individuals for each type of interaction for all target species were counted (Table 2). Sampling periods for the WE ranged from February 2019 to November 2020, while data collection for ROW cameras was carried out from December 2019 through December 2020. All datasets were analyzed using Microsoft Excel and PRIMER-e v7 with PERMANOVA+ (PRIMER-E, Albany, Auckland, NZ) where recorded species were listed as variables and each site as a sample. Four factors were considered for the species community analyses including canopy cover, side of highway, year, and interaction type.

To determine the level of transformation needed, visual examinations of shade plots were conducted (Clarke et al. 2013). A fourth root transformation was used for all permutational multivariate analysis of variance (PERMANOVA) analyses. A Bray-Curtis similarity matrix was applied to the transformed data with a dummy variable of one to compare the relationship between the sites that were sampled. A dendrogram (Fig. 8) and a bootstrapped metric multidimensional scaling plot (mMDS) (Fig. 9) were created to visualize the differences in the wildlife communities. A PERMANOVA was used to compare the wildlife communities and interactions among WE and species observed at ROW locations by interaction type. All factors included in the PERMANOVA model were fixed.

Post hoc pair-wise PERMANOVA tests were used to further test combinations of each level within a factor to determine the source of the differences. A similarity percentages (SIMPER) analysis set at a cut-off of 95% was used to identify species that were responsible for any patterns of variation observed between WE and ROW sites. Univariate diversity measures and indices were determined for total number of species recorded (S), total number of individuals observed (N), Pielou's evenness (J'), and Shannon diversity (H'). Shade plots and histograms were used to determine that a log transformation was needed for all species diversity analyses. An analysis of variance (ANOVA) was run to determine any significant differences among the groups and a post hoc pair-wise Tukey test was used to determine differences between groups.

Use of Wildlife Exits

To determine where wildlife was entering and exiting the roadway outside of WE, the total number of individuals for each target species were counted for all entries (H-R) and exits (R-H) at any WG, gate, or WW within 200 m of an exit (Table 3). This distance was chosen given the average walking speed per hour of a bobcat is approximately 400 meters per hour (Elizalde-Arellano et al. 2012), and the 30-minute photo capture interval for individual identification events. Using ArcMap 10.6.1, a 200 m buffer around each WE was created to identify mitigation structures that were included within this range. Wildlife guard crossing counts were drawn from eight WG that were adjacent to the ten WE. In this analysis, additional species including cottontails, armadillos, and raccoons were excluded due to their ability to permeate the continuous chain-link fencing along SH 100 by burrowing or climbing directly over the fence. These species were found to be impacted the least by the installation of the WE and often did not use them in the manner they were intended, to travel from the road to the habitat.

To calculate the number of individuals that remained on the roadway on SH 100 for each species, four categories of individual interactions were created: 1) “Mit H-R”, which encompassed all entries onto the roadway made via a WG, gate, or WW, 2) “Mit R-H”, included all exits from the road into the habitat made via a WG, gate, or WW, 3) “WE R-H”, which considered all road to habitat crossings through a WE, and 4) “WE H-R”, indicated habitat to road access through a WE. Total entries onto the road were determined by adding all Mit H-R and all WE H-R movements:

Total entries onto road = (Mit H-R) + (WE H-R)

The number of individuals remaining on the road after all Mit R-H escapes was calculated by taking the difference of all Mit R-H from the total entries:

Remaining on road = [(Mit H-R) + (WE H-R)] – (Mit R-H)

Percentages of individuals that left via a WE were calculated for each of the target species using the following formula:

$$\text{Left road via WE (\%)} = \frac{\text{(WE R-H)}}{\text{(WE R-H)} + [\text{(Mit H-R + WE H-R)} - \text{Mit R-H}]} \times 100$$

To determine the number of individuals of each species that were not recorded leaving the highway via a monitored mitigation structure within the 200 m buffer around each WE (the total unaccounted for), all "WE R-H" was removed from the "remaining on road" count:

Unaccounted for = [[(Mit H-R) + (WE H-R)] – (Mit R-H)] – (WE R-H)

Finally, data was examined to determine if bobcat and coyote use in the road to habitat direction increased during the study period. The total R-H events for each of these species across all ten WE were counted per 30-day period from February 2019 to November 2020 to identify when each species initially began to use the WE. Patterns in mesocarnivore usage of WE as well as the total number of WE accessed was also determined. Additionally, mesocarnivore activity patterns at WE as a function of time of day were reported for all bobcat and coyote interactions between February 2019 and November 2020 to determine peak activity times over the span of 24 hours.

CHAPTER III

RESULTS

Characterization of the Wildlife Community at Wildlife Exits and Right-of-Way Locations

Of the 12 species that were expected to use WE to travel from the road to the habitat, ten of them used WE in the R-H direction (Fig. 10) from February 2019 through the time of the first WE closure on April 13, 2020. At the end of the data collection period in November 2020, four of the ten WE had been closed due to bobcats and coyotes using them in the unintended direction of habitat to road.

Of the four factors that were tested in the full PERMANOVA model, canopy cover, side of highway, and year did not produce significant differences in WE activity across the ten sites. Results showed that only interaction type was significantly different across all wildlife communities surrounding the ten WE from February 2019 to November 2020 (d.f. = 3, pseudo-F = 3.7373, $p = 0.0001$, permutations = 9924) (Fig. 9). The four interaction types included in the test were road to habitat (R-H), habitat to road (H-R), parallel on the road (P-R), and parallel on the habitat (P-H). The PERMANOVA test did not detect any significant differences among the wildlife communities near the ten ROW sites on SH 100 ($p = 0.759$). PERMANOVA results testing differences in species composition between WE and ROW sites showed that interaction type had a significant effect (d.f. = 4, pseudo-F = 4.0898, $p = 0.0001$, permutations = 9937) (Fig. 9). The same four interactions at WE were analyzed, adding parallels along the ROW as a fifth level within the factor of “interaction type”. A bootstrapped mMDS plot produced with a 95% confidence region revealed significant differences between the groups. Post hoc pair-wise comparisons between P-H and all four of the other interaction types were significant: P-H and R-H ($t = 2.39$, $p = 0.005$, permutations = 9946), P-H and H-R ($t = 2.81$, $p = 0.0003$, permutations = 9951), P-H and P-R ($t = 2.18$, $p = 0.0037$, permutations = 9942), and P-H and ROW ($t = 2.75$, $p = 0.0001$, permutations = 9962). Additionally, individual comparisons between ROW and all of the other interaction types were also significantly different: ROW and R-H ($t = 1.69$, $p = 0.0245$, permutations = 9948), ROW and H-R ($t = 2.39$, $p = 0.0008$, permutations = 9943), and ROW and P-R ($t = 1.86$, $p = 0.0173$, permutations = 9938). Finally, R-H and H-R were found to be significantly different ($t = 1.70$, $p = 0.0167$, permutations = 9957). Although “side of highway” was also tested as a factor, it did not yield significant results ($p = 0.573$).

Results from the SIMPER analysis showed that the primary species responsible for the average dissimilarity between P-H and all other groups was the nine-banded armadillo (≤ 24.7%) (Table 4 of SIMPER results). Eastern cottontails (≤ 20.7%) and Virginia opossums (≤ 15%) followed armadillos in overall percentage of species contributions to the dissimilarities observed. Furthermore, cottontails were the primary species driving differences between R-H and H-R, contributing approximately 22.9% to the dissimilarity between this group (Table 4 of SIMPER results). Coyotes and bobcats showed their highest contribution to average dissimilarity between R-H and H-R, with coyotes contributing 11.4% and bobcats contributing 10.8% to the average dissimilarity in this group. The primary species responsible for the average dissimilarity for all ROW sites grouped with R-H, H-R, and P-R were eastern cottontails (≤ 29%) (Table 4). Between ROW and P-H, the principal species responsible for dissimilarity was the nine-banded armadillo (≤ 22.2%). Among mesocarnivores, bobcats contributed the most to the dissimilarities seen between ROW and R-H, comprising approximately 11.6%. In contrast, coyotes had the highest contribution to dissimilarities between ROW and H-R, providing around 12.1% to the average dissimilarity in this group.

Averages of diversity indices (± standard error) for all interaction types were calculated (Fig. 11). The average number of species were recorded for R-H (4.9 ± 0.31), H-R (2.8 ± 0.39), P-H (7.3 ± 0.42), P-R (4.6 ± 0.62), and ROW (4.5 ± 0.31). For average number of individuals, the results were reported for R-H (10.5 ± 1.00), H-R (6.47 ± 0.84), P-H (20.1 ± 1.88), P-R (9.31 ± 1.30), and ROW (8.95 ± 0.57). Evenness across each interaction type was calculated for R-H (0.90 ± 0.01), H-R (0.73 ± 0.09), P-H (0.92 ± 0.02), P-R (0.79 ± 0.09), and ROW (0.91 ± 0.01). Lastly, Shannon diversity values were averaged for all R-H (1.41 ± 0.07), H-R (0.78 ± 0.13), P-H (1.83 ± 0.09), P-R (1.25 ± 0.17), and ROW (1.35 ± 0.06) sites. After the averages for each of the five interaction types was calculated, an ANOVA further highlighted significant differences between R-H, H-R, P-H, P-R, and ROW interactions. The average number of species was significant across all interaction types ($F = 14.34$, $p < 0.00001$). Results of the post hoc Tukey test showed significant pair-wise comparisons of average number of species for interactions between R-H and H-R ($p = 0.0092$), R-H and P-H ($p = 0.0022$), H-R and P-H ($p < 0.00001$), H-R and P-R ($p = 0.0347$), P-H and P-R ($p = 0.0005$), and P-H and ROW ($p = 0.0003$). Results comparing differences in averages of number of individuals across interaction types was significant ($F = 17.91$, $p < 0.00001$). Pair-wise comparisons showed significant differences between four groups: R-H and P-H ($p < 0.0001$), H-R and P-H ($p < 0.00001$), P-H and P-R ($p < 0.00001$), and P-H and ROW ($p < 0.00001$). Average Shannon diversity comparing species richness and relative abundance showed significant differences between interaction types ($F = 9.752$, $p < 0.00001$). Specifically, pair-wise differences were found to be significant between R-

H and H-R ($p = 0.0037$), H-R and P-H ($p < 0.00001$), H-R and P-R ($p = 0.0422$), H-R and ROW ($p = 0.0108$), P-H and P-R ($p = 0.0176$), and P-H and ROW ($p = 0.0461$). There were no significant differences between the average evenness across all five interaction types.

Use of Wildlife Exits

All six target species were observed using the WE to travel from R-H and H-R from February 2019 through the end of the data collection period in November 2020 (Table 3). The species were black-tailed jackrabbits, bobcats, coyotes, domestic cats, striped skunks, and Virginia opossums.

All R-H events at WG, gates, and WW combined resulted in 123 bobcat and 685 coyote events (Table 5). After all of the R-H events were made via a WG, gate, or WW, approximately 38 bobcats and 229 coyotes were observed remaining in the ROW. From these totals, the number of individuals that left the ROW using a WE were calculated. Percentages of successful WE R-H events for all species remaining on the road after all exits via a mitigation structure other than a WE were as follows: bobcats = 43%, jackrabbits = 38%, skunks = 38%, opossums = 37%, domestic cats = 15%, and coyotes = 6% (Fig. 12). Of the initial 123 bobcats that entered the roadway over the course of this study, 29 of those successfully found and used a WE to cross back into the habitat. In contrast, only 15 of the remaining 229 coyotes on the roadway were recorded traveling from R-H. Jackrabbits and skunks followed bobcats in overall percentage of successful exits from the ROW via a WE, both of which had 38% of their respective species exiting from the road. Opossums and domestic cats were the next two species that used a WE to escape the ROW.

Species density maps for all target species showed that nearly 90% of all wildlife traffic in the R-H direction occurred in the section of SH 100 between WE02 and WE07 (Fig. 13).

Wildlife exits that represented the least R-H activity were WE08, WE09, and WE10, contributing less than 5% of the total traffic. Approximately 83% of wildlife traffic in the H-R direction occurred between WE04 and WE07, with all other WE sites exhibiting low activity levels in this direction.

Bobcat and Coyote Activity

Bobcat and coyote use of WE increased over time for crossing events observed in the road to habitat direction. Two bobcats used WE within the first 30 days of the installation of the WE to move from R-H, with both species correctly using WE after approximately six months post-installation (Fig. 14). Of all complete crossing events made across all ten WE in either direction, 69% of bobcats and 75% of coyotes were observed using WE to correctly travel from R-H (Table 3). Bobcats used six of the ten WE and coyotes used eight of them. Furthermore, there was substantial overlap with coyotes using all WE that bobcats used, with the exception of WE04. Bobcat and coyote activity decreased nearly a year and half into this study due to WE closure from unintended H-R use (Fig. 14).

Bobcat activity in the R-H direction showed that approximately 83% of successful crossings were concentrated around WE04, WE05, and WE06 (Fig. 13). For bobcats accessing the road via WE in the H-R direction, WE04 displayed the highest level of activity. When considering coyote activity, R-H crossing events were relatively evenly distributed across all ten WE sites (Fig. 13). Conversely, all H-R attempts for coyotes during this time period were restricted to WE09 and WE10.

Bobcat and coyote activity as a function of time of day was reported for all crossings, attempted entries, and observations captured on camera from February 2019 through November 2020 (Fig. 15). Similar hourly patterns were observed for the two species: bobcat activity reached its peak at 10 pm and then again from the hours of 12 am – 5 am. Comparatively, coyote activity climbed at 10 pm, increasing again from 12 am – 4 am. Although there were no bobcat occurrences at exits between the hours of 10 am and 3 pm throughout this time period, coyotes were recorded near a WE at every hour of the day except 11 am and 3 pm. The total number of coyote observations was nearly double the total number of bobcat observations.

Prey Activity

Wildlife exits were observed to have a high number of cottontails and rodents. The average number of cottontails across all ten sites was 433.2 ± 190.3 and the average number of rodents was 318.3 ± 75.42. Cottontail densities were highest at WE03, which also harbored the most coyote activity (58%) of all WE. This exit was followed by relatively equal abundances of cottontails found at WE01 and WE06. Approximately 70% of rodent activity was concentrated between WE05 and WE08, with WE03 contributing an additional 14% (Table 6). Rodent activity was highest at WE06, with nearly 25% of all activity occurring at this one site, followed closely by rodent activity at WE07 (19%). A Spearman correlation was not significant for "rodents x bobcats" $r_s = 0.505$, p (1-tailed = 0.068), as well as for "rodents x coyotes" $r_s = 0.177$, p (1-tailed = 0.310). Furthermore, Spearman correlations for "cottontails x bobcats" $r_s = 0.340$, p (1-tailed = 0.168), and "cottontails x coyotes" $r_s = 0.323$, p (1-tailed = 0.181) were also not significant.

CHAPTER IV

DISCUSSION

Characterization of the Wildlife Community at Wildlife Exits and Right-of-Way Locations

In several studies, WCS have been documented to have variable wildlife activity depending on location (Rodriguez et al. 1996, Glista et al. 2009) and differences in species presence and abundance along a road or highway is often dependent on multiple factors (Cuyckens et al. 2016, Dickson et al. 2005, Leblond et al. 2013) including seasonality (Craveiro et al. 2019), suitable habitat (Grilo et al. 2008), availability of and proximity to water sources (Ng et al. 2004), and vehicle traffic (Chruszcz et. al 2003, Grilo et al. 2008). Although factors such as canopy cover, side of highway, year, and interaction type were all considered, only interaction type produced significantly different results in wildlife communities between these locations in the present study. The first hypothesis that wildlife communities surrounding WE would be different across all ten sites was partially supported, given that interaction type was found to be significant. The hypothesis concerning species composition around ROW locations was also supported, as all sites exhibited similar communities. Finally, species composition and abundance was compared between WE and ROW locations, hypothesizing that wildlife detected on these cameras would be similar. This hypothesis was partially rejected; interaction type displayed significant differences, while the side of the highway was not a significant factor.

Wildlife Exit Communities

The initial hypothesis in this study testing the differences in wildlife communities surrounding each of the WE along SH 100 was partially supported, finding that of the factors considered, interaction type showed significant differences across all ten sites. Research carried out by Van der Grift and Van der Ree (2015) outlines guidelines for evaluating species use of WCS, stating that wildlife communities using WCS should eventually reflect actual species communities in the surrounding area. Further testing of groups of interactions revealed significant dissimilarities between parallel events on the habitat side (P-H) when compared to the other three interaction types, including parallels events on the road (P-R), road to habitat (R-H) crossings, and habitat to road (H-R) crossings. Potential explanations behind these results could be that there are more resources accessible to wildlife on the habitat side of the chain-link fence. A study by Ng et al. (2004) found that sources of water are important factors that have been associated with raccoon presence near WCS that contained water. Additionally, a sense of security in the form of dens, burrows, and trees common in denser habitat does not exist in the ROW area along SH 100. The grassy area is often mowed, leaving no form of cover for species that rely on bushes and canopy cover either to hunt for prey or escape a predator. A study by McDonald and St. Clair (2004) investigated the small mammal communities near crossing structures in Banff National Park, Alberta, Canada and found that translocated rodents had a higher return success across crossing structures with greater vegetative cover. An abundant food source present in denser habitats with high canopy cover is likely to support more carnivores such as ocelots, bobcats, and coyotes (Booth-Binczik et al. 2013, Harveson et al. 2004, Lombardi et al. 2017). For the carnivores in this study area, an abundance of prey such as rodents and the eastern cottontail is key to sustaining small populations of predators, including the endangered ocelot (Booth-Binczik et al. 2013).

Analysis between the R-H and H-R group showed significant differences as well, suggesting that the design and dimensions of the WE could be influencing the type of wildlife activity that is observed. This association was found in a related study that established a relationship between dimensions of a crossing structure and the size of an animal, demonstrating that larger animals tend to utilize larger structures (Mata et al. 2005). Wildlife exits were originally created to allow ocelots that entered the ROW an option to escape into the habitat via a WE, and as a result were designed for wildlife the size of a felid. However, many of the species included in the analysis were small enough to travel in either direction. These species were included in order to evaluate species communities from a predator-prey point of view. Cottontails contributed 23% to the dissimilarity seen between these two groups, the highest of all species observed. A potential reason for these differences, apart from their small size and ease of travel through the WE, could be that the ROW is typically covered in grass. Grasses are a primary source of food for cottontails (Dalke and Sime 1941), which could explain why they access the ROW via a WE more frequently than other species. A similar finding was reported in a study by Feldhamer et al. 1986, where researchers found the presence of forbs and grasses in the ROW provided more incentive for white-tailed deer to enter the roadway.

After reviewing the results of the SIMPER test, a more comprehensive picture of the differences between interaction types was formed. For species contributing to the dissimilarities observed between all of the significant group comparisons, armadillos, cottontails, and opossums were the top three drivers of these differences. These species are among the most abundant of the small mammals within the study area and exhibit high levels of permeability on roads and highways with open sections or gaps in their continuous fencing (Ford and Clevenger 2019, Yanes et al. 1995). Ford and Clevenger (2019) found that fencing designed for larger mammals was an ineffective barrier in preventing ROW access to small mammals. Additionally, species evenness was not significantly different across the four interaction types, suggesting that the relative abundance of different species was similar.

Bobcats and coyotes showed up on the lower end of species contributions for the groups that produced significantly dissimilar results in overall abundance. Predators are often found in lower numbers compared to their prey due to where they fall in the food chain and the amount of energy that is passed up to the next level, which does not support comparable population sizes as their prey (Tucker and Rogers 2014). Coyotes and bobcats in this area showed the highest percentage of contribution between the R-H and H-R group. These observations could also suggest reflections in ocelot behavior for individuals that approach a WE from the road. Given their similarities in behavior and ecology to felids such as bobcats (Grigione and Mrykalo 2004, Booth-Binczik et al. 2013), it is likely that they would respond the same and attempt to use a WE to escape the ROW. Although the WE were designed for felids, coyotes were able to use WE to access the habitat from the roadside. Nearly twice as many coyotes as bobcats were captured on camera across all WE during this study. Of the coyotes that approached the WE from the roadside, several of the attempts did not result in successful crossings. While reviewing pictures, it was apparent that many of the coyotes that managed to completely cross from R-H often struggled to fit through the narrowest section of the WE, whereas this did not appear to physically limit bobcat R-H crossings.

Wildlife Exit and Right-of-Way Communities

The composition of the wildlife community at ROW cameras was observed to be significantly different than the WE communities. Species observed in the ROW are often left traveling in the open with no cover (Ford and Clevenger 2019). Lower levels of wildlife activity were expected on the roadside of the fencing as a result of mitigation structures and fencing (Feldhamer et al. 1986), which have been successful in preventing roadway entries.

Examination of the species contribution for each comparison showed that eastern cottontails were responsible for the highest dissimilarity seen between ROW sites when compared to R-H, H-R, and P-R. Cottontails were the most abundant species observed in this study overall, often crossing through the WE to access the preferred grass in the ROW many times in a single camera trap night (Hudson et al. 2005). Foraging opportunities in the ROW in the form of forbs and grasses are known to draw wildlife such as deer and rabbits onto roadways and can result in mortalities (Clevenger and Kociolek 2013, Huijser et al. 2016, Feldhamer et al. 1986). In contrast, nine-banded armadillos were the primary species responsible for dissimilarities between ROW and P-H. There were only three individual armadillo observations noted for the duration of the data collection period in which an armadillo made a successful crossing via a WE. However, most armadillos were observed walking parallel on the habitat side of the chain-link fencing, with few individuals in any other interaction category. This could potentially be due to the size of the armadillos in relation to the narrowest measurement of the WE (five inches) that may discourage WE usage in either direction. Armadillos typically prefer areas in dense habitat where they can burrow, rather than open areas with less cover that may increase predator detection (Platt et al. 2003). This may offer insight into the lower numbers of armadillos in the ROW when compared to those observed traveling in the P-H direction near WE.

Focusing on bobcat and coyote presence revealed dissimilarities between ROW and R-H. More bobcats were observed exiting from the roadway via WE than were observed at ROW sites. If ocelots behave similarly to bobcats when they enter the ROW, this finding suggests that ocelots are likely to use a WE as an option to escape. Conversely, coyotes contributed the most to dissimilarities between ROW and H-R. There were 19 coyotes observed in the ROW and only five that crossed in the H-R direction during this time period. Further work should consider bobcats and coyotes that attempt to enter a WE, but do not successfully cross. Grilo et al. (2008) found that additional factors such as enhanced vegetative cover near the entrance and placement of structures in suitable habitat encouraged carnivore usage along two highways in southern Portugal.

With the exception of species evenness, which did not differ significantly between interaction types, all interaction types showed significant differences in average number of species, individuals, and for average species richness and relative abundance (Shannon diversity) recorded for WE and ROW. For each of these diversity measurements, there were patterns of significance for two separate pairings of interaction groups: P-H and P-R, and P-H and H-R. These results for the average number of species, individuals, and relative abundances traveling parallel on the habitat side of the fence when compared to the number of species traveling along the roadway indicated that these groups are distinctly different. This is consistent with the findings of Shilling et al. (2012) that reported a lower number of species traveling in the ROW. This suggests that the barrier chain-link fencing is doing its part in preventing wildlife access onto SH 100. Furthermore, these averages are different when comparing P-H activity to H-R crossings. Since WE are designed to be narrower on the habitat side to discourage entries from this direction, it was expected that there would be fewer species and individuals crossing from H-R than there would be in the surrounding habitat. Although many prey animals are reluctant to travel through constricted areas (Bissonette and Hammer 2000, Clevenger and Waltho 2005), predators exhibit less discomfort in narrow spaces and show a preference for constricted structures (Clevenger and Waltho 2005). Wildlife exits on SH 100 have more size constrictions for wildlife that attempt to enter from the habitat side, an issue that is nonexistent for wildlife that only walk parallel to a WE and do not attempt to enter it.

As originally hypothesized, the ROW sites were not significantly different across all ten locations. This stretch of highway is largely covered in grass, leaving no presence of canopy cover in the ROW which is necessary for many species that require dense habitat for shelter (McDonald and St. Clair 2004, Brehme et al. 2013, Lehnen et al. 2021). The purpose of installing ROW cameras was to characterize wildlife traveling along the roadway that could potentially use a WE. The average number of species and individuals was significantly different between ROW and P-H, further confirming strong differences in wildlife observed walking along the roadside of the fence and wildlife traveling parallel along the habitat near a WE. These results support the idea that barrier fencing can be an effective method for preventing wildlife from accessing the road (Huijser et al. 2016). The average number of individuals was significantly higher on the habitat side of the road compared to the number captured on cameras placed in the ROW. Restricted road permeability as a result of existing mitigation structures is likely to limit the number of individuals that can access the highway (Myslajek et al. 2020, Yanes et al. 1995). Additional differences in species richness and relative abundance are apparent between H-R and ROW, where more species on average were detected walking parallel along the ROW than using a WE to cross from H-R. This finding provides additional evidence that the size and shape of an animal can influence use at a mitigation structure (Donaldson 2007, Myslajek et al. 2020), potentially limiting the abilities of species using WE in the H-R direction. Comparisons for P-H and ROW were also significant, indicating strong differences in species communities walking parallel on the habitat near a WE as well as parallels in the ROW. With data collection spanning only one year, longer monitoring of the ROW would be needed to examine patterns of seasonality that coincide with landscape changes and species abundance (Clevenger and Waltho 2003).

Use of Wildlife Exits

An effective mitigation strategy typically combines the construction of WCS with a form of wildlife fencing, providing continuous habitat connectivity across highways as well as a means of escape for wildlife that may otherwise get hit by a vehicle (Van der Grift et al. 2013, Rytwinski et al. 2016, Ascensao et al. 2013). One aim of this study was to determine if wildlife would correctly use WE to travel from R-H after entering the roadway via a nearby mitigation structure. Though previous studies investigated wildlife jump-outs and one-way escapes as a form of escape for large mammals (Huijser et al. 2016, Bissonette and Hammer 2000), these studies have reported limited success and moreover, were not designed for mesopredators.

Although WE are not intended for H-R usage, many of the individuals that used WE incorrectly accessed the roadway. A genuine concern after the installation of these exits was that they would potentially create additional points of entry leading to the roadway, which could result in ocelot road mortalities. Incorrect usage has also been observed at WG constructed along highways, exhibiting higher levels of effectiveness for ungulates than carnivores. Allen et al. (2013) found that WG prevented a higher percentage of deer from accessing the roadway than they did for black bears and coyotes. Ideally, all individuals remaining in the ROW should successfully find and use a WE to travel into the habitat, leaving 100% of wildlife that entered and exited the roadway accounted for. However, while all of the target species used WE correctly to travel from R-H, some individuals crossed from H-R via a WE.

Though many forms of mitigation structures such as WG near access roads have been effective in acting as a barrier to wildlife that attempt to enter the roadway (Allen et al. 2013), they do not prevent all wildlife entries onto the road. Similarly, WE do not remove all individuals trapped in the ROW. Of the target species that were analyzed, bobcats showed the highest percentage (43%) of successful R-H crossings through a WE. Interestingly, only six percent of coyotes that remained in the ROW after all other exits through other mitigation structures managed to correctly use a WE to return to the habitat. The larger number of coyotes remaining along the road could be attributed to a few different things. Coyotes are the largest species that were observed using WE during this study and visually struggled in their attempts to use them since the narrow design of the exits was developed for felid use. Ford and Clevenger (2019) found that structural design in culverts can contribute to connectivity, suggesting that openings should be on the habitat side of the fencing due to size limitations for species such as coyotes that have difficulty in crossing fences. The size of an animal combined with its motivation to cross a mitigation structure is thought to contribute to the effectiveness of WG (VerCauteren et al. 2009, Allen et al. 2013). On SH 100, individuals were often seen having trouble using a WE to escape the roadway and would occasionally give up after several attempts at squeezing through the thinnest section. Another possibility could be that a number of these coyotes are actually returning to the habitat via a WG and were not detected on the camera. This can happen when an individual moves past the camera too quickly. While the camera can be triggered during this event, the coyotes are typically moving very fast and may not actually be captured on camera.

As wildlife traffic has been shown to cluster in areas associated with dense habitat, reliable water sources, and a stable food supply (Dickson et al. 2005, Grilo et al. 2008, Ng et al. 2004), species density maps were created to visualize wildlife hotspots on SH 100 near WE. The maps showed that the majority of target species that exited into the habitat via a WE occurred between WE02 and WE07. Nearly all of these WE sites have some degree of canopy cover that is ideal for some species, particularly predators such as ocelots, bobcats, and coyotes (Horne et al. 2009, Harveson et al. 2004). These same factors could also explain the areas between WE04 and WE07 that show the highest levels of wildlife activity at exits in the H-R direction. Prime habitat and resources in these areas are likely able to sustain populations that eventually discover ways of accessing the road by traveling through a WE.

In contrast to the areas displaying high wildlife traffic, the section of SH 100 that encompassed WE08, WE09, and WE10 reflected the least amounts of wildlife activity. This stretch of SH 100 had relatively open habitat that tended to deter medium and large mammals as a result of the vulnerability associated with low canopy cover. However, coyote detections in this area remained until these WE were closed. Canids such as coyotes tend to be more comfortable than felids in open areas throughout regions where all three species co-occur (Lombardi et al. 2020). Although the habitat in this area is largely open, it supports an abundance of rodents which are a primary source of prey for coyotes (Andelt 1985).

Mesocarnivore Activity

A primary goal of this study was to determine if WE would be effective for ocelots and bobcats in this area, as well as how many of the WE would be used. Previous findings suggest there may be a strong learning curve for carnivores that use WCS over time, stressing the importance of long-term monitoring (Clevenger and Waltho 2003, Gagnon et al. 2011, Clevenger and Waltho 2005). This study found that bobcats and coyotes can learn to use WE over time to travel from R-H, but also from H-R. Other studies have speculated in the learning abilities of bears (Sawaya et al. 2014, Huijser et al. 2016), wolves (Clevenger and Waltho 2003), ungulates (Huijser et al. 2016, Gagnon et al. 2011), and other mammals (Jackson and Griffin 2000) to use mitigation structures over time. On SH 100, bobcats learned within the first month to travel from R-H using a WE, while it took coyotes six times longer to learn to correctly use a WE. Overall, the majority of bobcats and coyotes that successfully crossed using a WE performed this crossing in the R-H direction. Since bobcat behavior has been used as a predictor for ocelots (Cain et al. 2003, Horne et al. 2009), these results provide hope that a future ocelot that is trapped in the ROW may use a WE as a means of escape.

Concentrations of activity in the R-H direction differed for bobcats and coyotes across the study area. Bobcat activity was highest in the section of SH 100 between WE04 and WE06. Alternatively, coyote R-H crossing events were more evenly distributed across WE sites. Together bobcats and coyotes used 60-80% of the WE, with twice as many bobcat R-H events as coyote R-H events. One potential reason for the high bobcat R-H use may be due to size differences which allow felids to walk through narrow openings with greater ease than their canid counterparts. Ruediger (2007) suggested that biological criteria may be useful when designing mitigation structures for carnivore use, noting that the size of the structure could influence usage by target species. Though Ruediger (2007) grouped bobcats and coyotes into the same size category, for structures as small as WE, dimensions appear to impact these two species differently. Another explanation may be found when considering habitat types. Bobcat activity was highest in areas near WE that contained some degree of canopy cover, whereas coyotes were detected across habitats with varying levels of canopy cover. Though bobcats can occur in different environments, they generally prefer dense habitats with high canopy cover that is useful for hunting prey (Cain et al. 2003, Horne et al. 2009), while coyotes have broader diet ranges that allow them to hunt or forage in areas that are more open (Lombardi et al. 2020, Andelt et al. 1987). From these initial bobcat results, inferences could be made for ocelots in this area. Ocelots are habitat specialists that show a preference for dense thornscrub (Horne et al. 2009, Satter et al. 2018, Lombardi et al. 2020, Schmidt et al. 2020) and would likely benefit from using WE installed in areas of denser habitat along SH 100.

Interestingly, no bobcats or coyotes used WE07 to cross in either direction. This exit is approximately 60 m away from WE06, which had 13 bobcat R-H crossings and was the most frequently accessed WE for bobcats. These two WE are the closest in proximity to each other, yet they have opposite habitat types, with high canopy cover around WE06 and open habitat surrounding WE07. Type of habitat can be significant for the persistence of carnivore populations across their range (Satter et al. 2019, Horne et al. 2009, Booth-Binczik et al. 2013) and could explain why neither bobcats or coyotes chose to use this WE. Horne et al. 2009 found significant differences in habitat selection for ocelots and bobcats, demonstrating that ocelots consistently selected areas of denser habitat than bobcats. Although canopy cover was not a significant factor in this study, bobcat activity occurred near sites with some of the densest habitat. Continued monitoring is necessary to gather more data that could point towards canopy cover having a significant effect on predator presence in this area.

From the predator-prey perspective, bobcat and coyote presence was compared to WE harboring high concentrations of cottontails, one of the primary sources of prey for mesocarnivores in this area (Booth-Binczik et al. 2013, Andelt et al. 1987, Beasom and Moore 1977, Andelt 1985). Most of the cottontails were detected on cameras at WE03, followed by nearly equal counts at WE01 and WE06. Comparatively, WE03 also had the largest coyote presence of all ten WE, a common predator of the eastern cottontail across its range (Cepek 2004, Andelt et al. 1987). For bobcats, WE05 and WE06 had the highest occurrences of bobcat activity. While WE06 was a popular exit for both bobcats and cottontails, the two species did not compare when considering the overall percentages across all sites. Approximately 33% of bobcats visited this site, whereas only 14% of cottontails did. Bobcats tend to specialize on cottontails as a food source across their range. Tewes et al. (2002) reviewed 54 scientific sources for information on bobcat food habits and found that lagomorphs and rodents were dominant in bobcat diets across the United States. Although the bobcat-cottontail correlations in this study were not statistically significant, a relationship between the two species may still exist, especially as this was the primary pattern observed for the predator-prey dynamic.

In addition to cottontails, rodents comprise a significant portion of the diet for ocelots, bobcats, and coyotes in south Texas (Booth-Binczik et al. 2013, Haines et al. 2005). The majority of rodent activity on SH 100 was concentrated between WE05 and WE08, with WE03 also being a popular site for rodent activity. The WE with the highest level of bobcat R-H activity was at WE06, which was also the site that had the most rodent activity (25%). For coyotes, parallel activity along the habitat at WE03 showed a moderate correlation with rodent activity occurring at WE03. This WE has extensive canopy cover that is likely to support an abundance of mesocarnivore prey. These findings align with previous studies that suggest that the placement of wildlife structures may be even more important than the design (Rodriguez et al. 1996, Cain et al. 2003), especially if suitable habitat is present along distinct sections of roadway.

Similar results were found in a study by McDonald and St. Clair (2004) that observed enhanced vegetative cover as a contributing factor to crossing success in small mammals. Although these small parallels can be drawn between mesocarnivore activity and the presence of cottontail and rodent prey, the potential for WE to create a “prey trap” in which high densities of small mammals are funneled into areas where predators can take advantage of the abundance seems unlikely to result (Dickson et al. 2005). Ford and Clevenger (2010) also found no evidence that predator behavior of large mammals at crossing structures is influenced by prey movement. Interestingly, there were no bobcat or coyote crossings via WE07 even though this exit experienced the second highest rate of rodent activity of all ten WE.

Although promising results that supported the effectiveness of the WE were initially found, given enough time, bobcats and coyotes did learn where the WE were located and began to use them to travel in the unintended direction from H-R. More than half of the H-R bobcat crossings occurred at WE04. Over the course of a few days, the same individual was identified through its spot patterns and inner leg markings (Heilbrun et al. 2003) as repeatedly entering the roadway via a WE and exiting into the habitat using the nearest WG that was around 30 m away. Though WE were initially installed next to guards to provide an immediate option to exit back into the habitat, bobcats and coyotes that are aware of the location of these structures have been observed entering and exiting the ROW with apparent ease. Studies investigating the effectiveness of WG have demonstrated less effectiveness for coyotes, suggesting they could easily walk over the grating given their foot morphology (Allen et al. 2013). These H-R events pose a concern that ocelots could exhibit similar learned behaviors and begin to use WE incorrectly.

Studies suggest that wildlife can become habituated to mitigation structures once they learn of their presence (Simpson et al. 2016, McCollister and Van Manen 2010), particularly resident populations that are likely to use structures more frequently than migratory populations. This could lead to the possibility that habituation may reduce the effectiveness of WE for wildlife that repeatedly approach from the habitat and attempt to cross onto the road. To mitigate this issue once a H-R event was recorded, the WE it occurred at was manually closed in an effort to discourage future crossings made from the habitat side of the chain-link fence. It is worth noting that in some instances, a bobcat or coyote was captured visiting the same WE in the days following the WE's closure with clear interest or attempts to pass through the fencing. Wildlife can learn the locations of crossings and other mitigation structures, increasing the frequency of use (Gagnon et al. 2011, Clevenger and Waltho 2003). In two specific cases, a bobcat approached a closed WE and jumped over the chain-link fence after realizing that it was unable to cross. These instances provide further support that carnivores such as the ocelot are capable of learning the location of WE and will repeatedly return to these sites.

Future Research

Further review of the variables associated with WE is recommended. Results of one study by Clevenger and Waltho (2000) suggested that carnivores and ungulates responded differently to variables associated with WCS. Carnivore use at these structures were better correlated to landscape characteristics such as forest cover and proximity to human activity, whereas ungulates showed a preference for structural attributes such as crossing structure dimensions and openness (Clevenger and Waltho 2000). Wildlife exits monitored in the present study were purposely built and designed for the ocelot. For this reason, landscape characteristics should be considered for future placement of WE on SH 100, emphasizing habitat preferences of felids. Individual identification of bobcats could also provide useful information on the abundance and potential travel routes of these carnivores (Trolle and Kéry 2003, Heilbrun et al. 2006) in areas around SH 100 and nearby highways. Additional research into factors such as canopy cover, seasonality, areas with high mesocarnivore activity, and proximity to other mitigation structures need to be evaluated as these features may influence activity at WE.

Long-term monitoring of wildlife mitigation structures is recommended as it allows an understanding of how species learn to adapt to novel structures over time, as well as the significance of placement and design to species of interest (Gagnon et al. 2011). At the end of this data collection period, all WE had been in place for less than two years. In order to gain a comprehensive understanding of the species communities around different sections of SH 100, monitoring of current sites should continue. Another benefit of long-term monitoring is studying differences in the wildlife community during different seasons. In a study by Elizalde-Arellano et al. (2012), researchers found evidence that bobcats on the Mapimi Biosphere Reserve in Mexico traveled longer distances during the wet season. In addition to considering factors such as seasonality, it is suggested that more WE sites be installed to examine other sections of SH 100 that may highlight prime areas of wildlife activity for target species and their prey. An increase in monitored WE sites offers greater mitigation coverage and additional opportunities for escape from roads and highways in areas where ocelots are more likely to exist.

CHAPTER V

CONCLUSIONS

Future Direction

Overall, WE seem to be being used correctly by most species to escape the ROW. Though it was expected that wildlife would eventually learn to use these exits to travel from H-R, most used it correctly more often and a large number of felids traveled in the intended R-H direction. However, there is a learning component involved that was observed in bobcats and coyotes. Approximately one year into this study, bobcats and coyotes began using WE to access the road more frequently. Land and Lotz (1996) found patterns of learning and use of crossing structures in Florida panthers, suggesting that use of structures is likely to increase as carnivores become aware of their locations. Considerations must be made for the future of ocelot conservation, especially for the two small U.S. populations remaining in south Texas. Ocelots have been recorded in areas near SH 100 and have previously been hit by vehicles on this highway (U.S. Fish & Wildlife Service 2014). If they learn to access the roadway via a WE, this offers concerns about the design of the exits and emphasizes the need for modifications.

At this time, improvements are being proposed for existing and future WE to reduce the ability of animals to use WE to access the road. These modifications include potentially redesigning some of the WE to be fitted with unidirectional doors that should make it possible for animals to travel one way so that they cannot be opened from the habitat side. This one-way door is expected to be transparent in order to provide wildlife with a clear view through the structure, which is expected to make them more willing to travel through it. A possible reduction in the width of WE is also being considered with respect to felid biology and making it more practical for an ocelot to use an exit. Narrowness is not an issue for felids which typically utilize small or constricted spaces to avoid exposed habitats (Clevenger and Waltho 2005). Moreover, additional WE are currently being proposed to be installed in the future near other mitigation structures to provide more options for escape to wildlife trapped in the ROW. Although regular maintenance of the WE mesh has not been necessary, minor repairs or adjustments may be required in time to avoid problems with the integrity of the fencing (Bissonette 2000). Success has also been found in studies that used buried fencing to prevent damage or gaps created by wildlife that burrow or dig under mitigation structures (McCollister and Van Manen 2010). As this study is ongoing, continuous monitoring will compare the new, modified WE to the original design to prevent unintended use.

Future work investigating factors that are expected to influence wildlife activity at WE is recommended to determine elements that may enhance WE usage. The distance to the nearest mitigation structure could influence WE use and would be a valuable factor to explore. Although the purpose of mitigation structures such as WG, gates, and WW are to prevent wildlife from entering the road entirely, activity at WE is expected to vary as these structures are known to be circumvented by wildlife at times. Activity is expected to depend on the distance of each exit to its nearest mitigation structure. Close proximity to nearby mitigation structures will likely result in an increase in WE use as animals that cross onto the road will have more opportunities to exit the ROW using a WE. Similarly, the type of mitigation structure could influence the amount of wildlife activity recorded at the exits, and should also be examined. The effects of long-term monitoring were stressed by Gagnon et al. (2011) who found use of crossing structures by deer increased over time. As species respond differently, long-term monitoring is essential before reliable conclusions can be drawn for these factors (Clevenger and Waltho 2005).

Management Implications

Once a comprehensive understanding of the effectiveness of WE is established, they can be implemented in areas near other mitigation structures to enable wildlife that enter the roadway a way to escape. Overall, researching these structures would provide a broader understanding of the actual effect that WE are having on wildlife that require a form of connectivity between suitable habitat patches. Continuous studies of WE have the potential to bring us closer to answering this question of the efficacy of mitigation structures for ocelots, as well as to advance our knowledge of other wildlife globally that encounter highways and require a safe means of passage. From this information, we can determine the location of mortality hotspots as well as identify the species of greatest risk in a given area and respond accordingly. At the same time, the topic of wildlife mitigation structures along busy roadways provides practical applications to human lives and will benefit society outside of the conservation context. Creating additional mitigation and habitat corridors is expected to further reduce the frequency of human-wildlife conflicts and WVC.

Apart from the knowledge that the immediate results of this study will provide, these findings will be relevant to future researchers and conservationists who strive to bring a solution to the problems that human development and expansion are creating. The value of exploring this topic further will provide greater insight in the fields of wildlife ecology and conservation, broadening our understanding of previously unknown aspects of migration rates, behavior, predator-prey dynamics, and genetic diversity.

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APPENDIX A

APPENDIX A

TABLES

Table 1. All species observed interacting with wildlife exits (WE) and passing by right-of-way (ROW) sites, as well as their respective total individual counts recorded on State Highway (SH) 100 in Cameron County, Texas. All WE data was collected between February 2019 and November 2020 and all ROW data collection was from December 2019 – December 2020. Total interactions for WE include successful crossings from one side of the chain-link fence to the other, entries/exits on the same side of the fence, and parallel interactions in which an individual walked along the fence and did not attempt to use the WE. Directions for species travel included both habitat and roadway usage. All ROW data consisted of individuals walking parallel to the continuous chain-link fencing on the roadside of SH 100.

Common name	Scientific name	WE total	ROW total
Black-tailed jackrabbit*	*Lepus californicus*	73	4
Bobcat*	*Lynx rufus*	138	8
Coyote*	*Canis latrans*	247	29
Domestic cat*	*Felis catus*	88	15
Domestic dog	*Canis lupus familiaris*	10	5
Domestic sheep	*Ovis aries*	15	3
Eastern cottontail*	*Sylvilagus floridanus*	4332	66
Feral hog	*Sus scrofa*	5	-
Greater roadrunner	*Geococcyx californianus*	10	-
Javelina	*Tayassu tajacu*	25	-
Long-tailed weasel	*Mustela frenata*	59	-
Mexican ground squirrel	*Ictidomys mexicanus*	1	-
Mexican racer	*Coluber constrictor oaxaca*	1	-
Nilgai	*Boselaphus tragocamelus*	12	5
Nine-banded armadillo*	*Dasypus novemcinctus*	1058	18
Northern bobwhite	*Colinus virginianus*	325	123
Northern raccoon*	*Procyon lotor*	266	131
Nutria	*Myocastor coypus*	1	-
Striped skunk*	*Mephitis mephitis*	38	6
Texas coral snake	*Micrurus tener*	1	-
Texas indigo snake	*Drymarchon melanurus erebennus*	2	-
Texas tortoise	*Gopherus berlandieri*	9	-
Virginia opossum*	*Didelphis virginiana*	1687	419
Western diamondback rattlesnake	*Crotalus atrox*	2	-
White-tailed deer	*Odocoileus virginianus*	291	21
Unknown mammal		34	7
Unknown snake		2	-
Unknown		9	-

*Target species included in the overall analysis

Table 2. Total number of interactions at all ten wildlife exits (WE) and ten right-of-way (ROW) locations for all target species recorded on State Highway (SH) 100 in Cameron County, Texas. All WE data was collected between February 2019 and November 2020 and all ROW data collection was from December 2019 – December 2020. Interaction types for WE include successful crossings from the road to the habitat side of the chain-link fence (R-H), crossings from the habitat to the road (H-R), and parallel interactions in which an individual walks past the WE on the road (P-R) or the habitat (P-H) without attempting to use the exit. All ROW data consisted of individuals walking parallel to the continuous chain-link fencing on the roadside of SH 100.

	Interaction Type				
Species	R-H	H-R	P-R	P-H	ROW
Black-tailed jackrabbit	23	23	3	23	4
Bobcat	29	13	16	72	8
Coyote	15	5	10	210	29
Domestic cat	13	3	24	46	15
Eastern cottontail	1159	1189	560	1086	66
Nine-banded armadillo	2	1	16	1036	18
Northern raccoon	50	6	48	151	131
Striped skunk	6	3	2	27	6
Virginia opossum	256	127	289	993	419

Table 3. Total entries and exits of target species at wildlife exits (WE) and all mitigation structures within 200 m of a WE on State Highway 100 in Cameron County, Texas between February 2019 and November 2020. "Mit" categories indicate total crossings made via a wildlife guard, gate, or wing wall. Interaction types include successful crossings from the road to the habitat side of the chain-link fence (R-H) and crossings from the habitat to the road (H-R).

Common name	Scientific name	WE R-H	WE H-R	Mit R-H	Mit H-R
Jackrabbit	*Lepus californicus*	23	23	9	23
Bobcat	*Lynx rufus*	29	13	85	110
Coyote	*Canis latrans*	15	5	456	680
Domestic cat	*Felis catus*	13	3	1000	1069
Striped skunk	*Mephitis mephitis*	6	3	15	22
Virginia opossum	*Didelphis virginiana*	256	127	1522	1828

Table 4. Results of SIMPER dissimilarity analysis for interaction type across all wildlife exits (WE) and right-of-way (ROW) sites along State Highway 100 in Cameron County Texas. Average abundance for each interaction type and percent contributions for each species is reported. Data collection for WE was from February 2019 – November 2020; ROW data collection was from December 2019 – December 2020. Cut-off percentage for SIMPER analysis was set at 95%.

R-H, H-R

Average Dissimilarity = 54.69

Species	R-H Avg Abund	H-R Avg Abund	% Contrib
Cottontail	2.48	2.33	22.9
Opossum	1.77	1.13	17.5
Raccoon	1.44	0.34	16.1
Coyote	0.92	0.25	11.4
Bobcat	0.83	0.42	10.8
Dom. cat	0.54	0.22	7.47
Jackrabbit	0.22	0.32	6.07
Skunk	0.16	0.10	3.98

H-R, P-H

Average Dissimilarity = 62.07

Species	H-R Avg Abund	P-H Avg Abund	% Contrib
Armadillo	0.10	2.76	21.0
Opossum	1.13	2.61	13.8
Cottontail	2.33	2.65	13.7
Raccoon	0.34	1.89	12.9
Coyote	0.25	1.62	10.83
Bobcat	0.42	1.30	8.27
Skunk	0.10	1.04	7.95
Dom. cat	0.22	0.83	6.29
Jackrabbit	0.32	0.56	5.34

P-H, ROW

Average Dissimilarity = 47.09

Species	P-H Avg Abund	ROW Av Abund	% Contrib
Armadillo	2.76	0.42	22.2
Cottontail	2.65	0.71	20.7
Opossum	2.61	2.20	11.5
Bobcat	1.30	0.28	10.3
Skunk	1.04	0.35	8.24
Coyote	1.62	1.05	8.22
Dom. cat	0.83	0.52	7.93
Raccoon	1.89	1.66	5.48
Jackrabbit	0.56	0.14	5.48

H-R, P-R

Average Dissimilarity = 56.82

Species	H-R Avg Abund	P-R Avg Abund	% Contrib
Cottontail	2.33	2.18	23.6
Opossum	1.13	1.61	18.5
Raccoon	0.34	1.17	13.6
Dom. cat	0.22	0.74	10.0
Armadillo	0.10	0.54	8.65
Bobcat	0.42	0.51	8.18
Coyote	0.25	0.58	8.01
Jackrabbit	0.32	0.13	4.99

R-H, P-R

Average Dissimilarity = 43.42

Species	R-H Avg Abund	P-R Avg Abund	% Contrib
Cottontail	2.48	2.18	20.7
Opossum	1.77	1.61	19.2
Bobcat	0.83	0.51	11.6
Dom. cat	0.54	0.74	10.8
Coyote	0.92	0.58	10.1
Raccoon	1.44	1.17	9.24
Armadillo	0.20	0.54	8.99
Skunk	0.16	0.20	4.97

P-R, ROW

Average Dissimilarity = 50.59

Species	P-R Avg Abund	ROW Avg Abund	% Contrib
Cottontail	2.18	0.71	24.0
Opossum	1.61	2.20	17.7
Raccoon	1.17	1.66	11.7
Coyote	0.58	1.05	11.0
Dom. cat	0.74	0.52	10.11
Armadillo	0.54	0.42	9.37
Bobcat	0.51	0.28	7.32
Skunk	0.20	0.35	6.04

R-H, P-H

Average Dissimilarity = 42.96

Species	R-H Avg Abund	P-H Avg Abund	% Contrib
Armadillo	0.20	2.76	24.7
Cottontail	2.48	2.65	14.9
Opossum	1.77	2.61	13.8
Skunk	0.16	1.04	10.0
Coyote	0.92	1.62	8.78
Bobcat	0.83	1.30	8.14
Dom. cat	0.54	0.83	8.14
Jackrabbit	0.22	0.56	6.45
Raccoon	1.44	1.89	5.09

R-H, ROW

Average Dissimilarity = 43.73

Species	R-H Avg Abund	ROW Avg Abund	% Contrib
Cottontail	2.48	0.71	29.0
Opossum	1.77	2.20	15.9
Bobcat	0.83	0.28	11.6
Dom. cat	0.54	0.52	9.70
Coyote	0.92	1.05	8.36
Raccoon	1.44	1.66	7.33
Armadillo	0.20	0.42	7.03
Skunk	0.16	0.35	6.59

P-H, P-R

Average Dissimilarity = 47.33

Species	P-H Avg Abund	P-R Avg Abund	% Contrib
Armadillo	2.76	0.54	20.7
Opossum	2.61	1.61	15.0
Cottontail	2.65	2.18	13.3
Coyote	1.62	0.58	10.9
Bobcat	1.30	0.51	9.37
Skunk	1.04	0.20	8.87
Raccoon	1.89	1.17	8.28
Dom. cat	0.83	0.74	8.23
Jackrabbit	0.56	0.13	5.37

H-R, ROW

Average Dissimilarity = 64.68

Species	H-R Avg Abund	ROW Avg Abund	% Contrib
Cottontail	2.33	0.71	24.0
Raccoon	0.34	1.66	18.4
Opossum	1.13	2.20	16.8
Coyote	0.25	1.05	12.1
Dom. cat	0.22	0.52	7.26
Bobcat	0.42	0.28	6.33
Armadillo	0.10	0.42	5.35
Skunk	0.10	0.35	5.31

Table 5. Wildlife crossing events that occurred across the ten wildlife exits (WE) installed on State Highway 100 in Cameron County, Texas between February 2019 and November 2020. All movement was recorded for individuals that entered or exited a mitigation structure within 200 m of the nearest WE. The “entered road” category was the count of how many individuals entered the roadway using a wildlife guard, gate, wing wall, or wildlife exit. “Mit R-H” indicates all exits into the habitat that were made via a mitigation structure other than a WE. “Remaining on road” was the difference of those that entered the roadway and those that used a structure other than a WE to escape; this was the number of individuals that remained before exits via a WE were counted. Of the total wildlife remaining on the road, the number of individuals that used a WE to escape comprised the “left road via WE” category. “Unaccounted for” counts were the remaining number of individuals that were not recorded leaving the highway via a monitored mitigation structure within the 200 m buffer around each WE.

	Jackrabbit	Bobcat	Coyote	Domestic cat	Skunk	Opossum
Entered road	46	123	685	1072	25	1955
Mit R-H	9	85	456	1000	15	1522
Remaining on road	37	38	229	72	10	433
Left road via WE	23	29	15	13	6	256
Unaccounted for	14	9	214	59	4	177

Table 6. Total number of rodents, cottontails, bobcats, and coyotes observed at each wildlife exit (WE) on State Highway (SH) 100 in Cameron County, Texas between February 2019 and November 2020. Bobcat and coyote counts are for all interactions with WE including successful crossings from one side of the chain-link fence to the other, entries/exits on the same side of the fence, and parallel interactions in which an individual walked along the fence and did not attempt to use the WE.

Wildlife exit	Rodents	Cottontails	Bobcats	Coyotes
WE01	184	576	5	18
WE02	40	-	1	19
WE03	441	2027	5	144
WE04	143	76	18	5
WE05	437	329	52	27
WE06	726	568	43	7
WE07	610	51	4	6
WE08	380	10	3	7
WE09	23	433	-	6
WE10	199	262	7	8

APPENDIX B

APPENDIX B

FIGURES

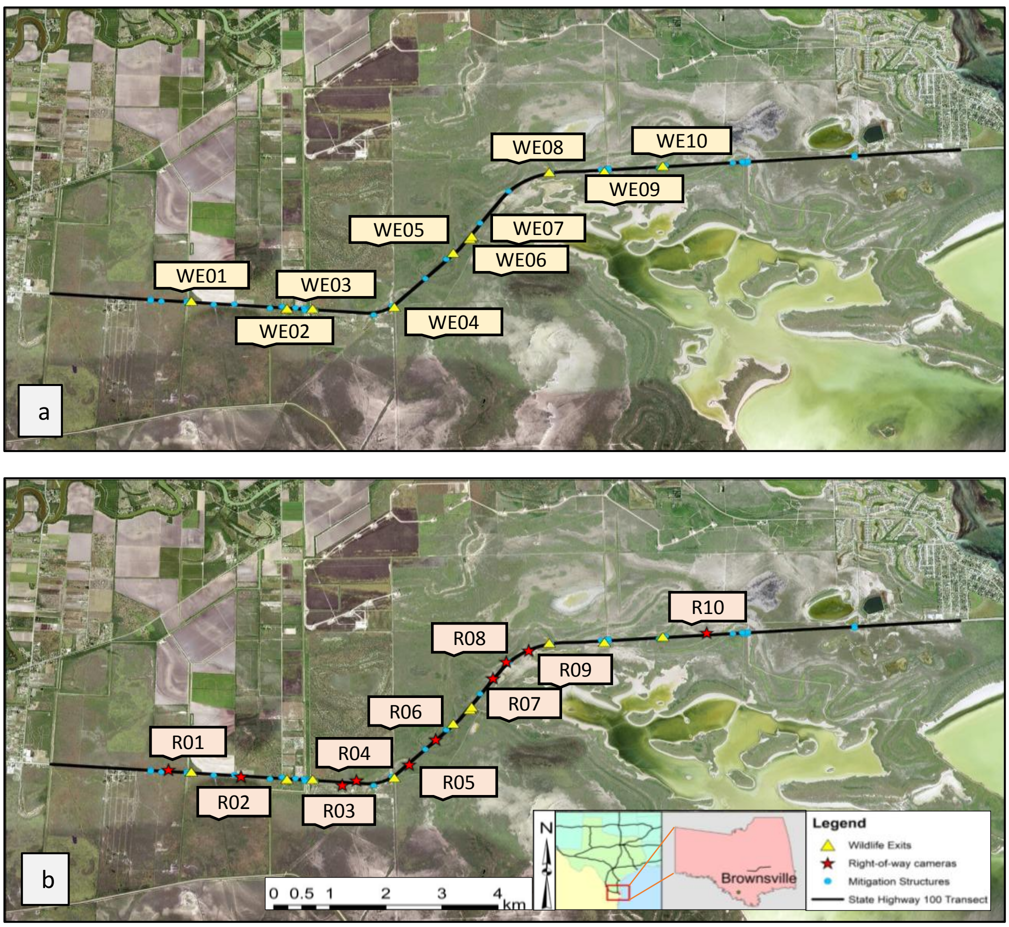


Figure 1. Map of the study area showing the locations of the ten wildlife exits (WE) (a) and the ten right-of-way (ROW) sites (b) along State Highway (SH) 100 in Cameron County, Texas. The mitigation area covers an 11.9 km transect of SH 100 that stretches from Los Fresnos, TX to Laguna Vista, TX. Wildlife exits were installed on February 13, 2019 by the Texas Department of Transportation to give wildlife that entered the ROW using a wildlife guard an option to escape into the habitat, aiming to reduce the number of wildlife road mortalities that occur on SH 100. The ROW cameras were installed in December 2019 to capture wildlife activity occurring in the ROW that was not being recorded on cameras next to a monitored mitigation structure.

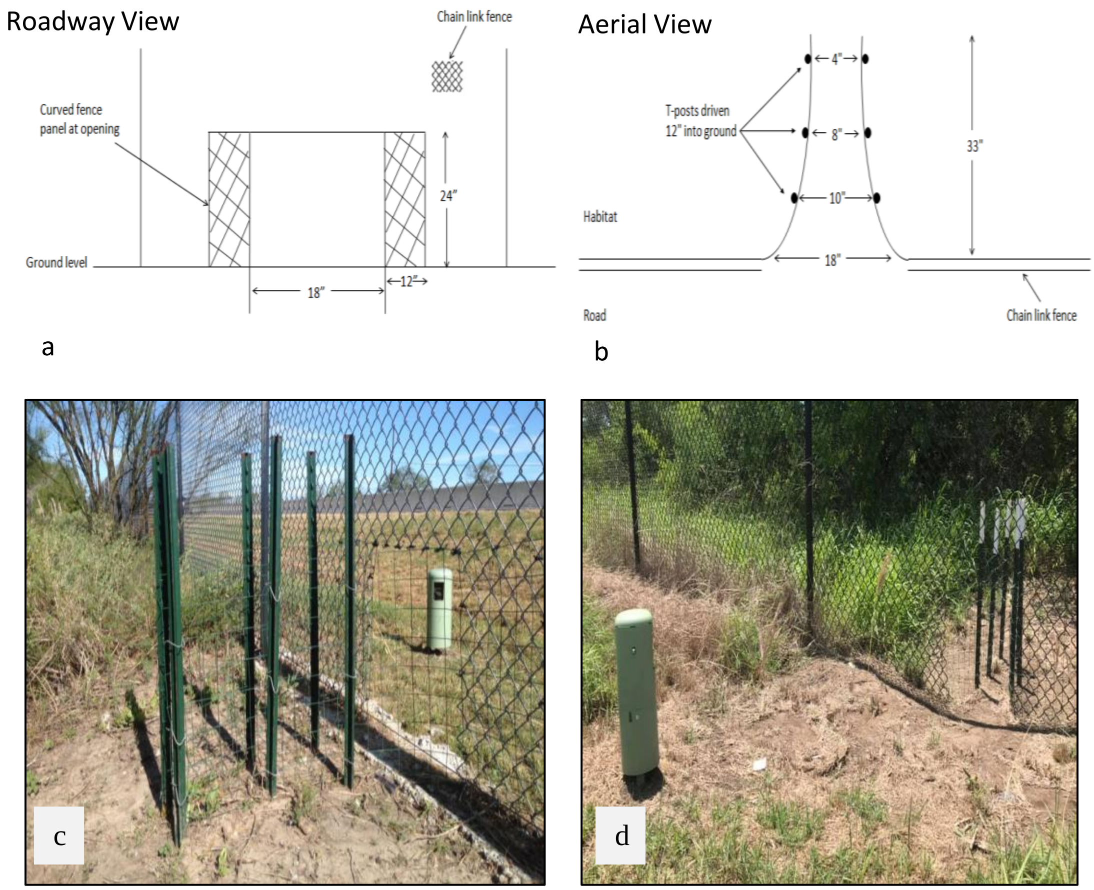


Figure 2. Wildlife exits (WE) were installed on State Highway 100 in Cameron County, Texas by the Texas Department of Transportation on February 13, 2019 to allow wildlife that entered the right-of-way via a wildlife guard an option to escape into the habitat. The dimensions of the WE are suitable for use across a wide range of species. The height of the exits are 24" tall with the opening measured at 18" wide (a. "Roadway View"). As the exit funnels into the habitat, it narrows to a final width of approximately five inches across, extending to a depth of 33 inches when measured from the chain-link fence (b. "Aerial View"). Actual pictures of wildlife exits as viewed from the habitat side of the chain-link fence (c) and from the roadside (d).

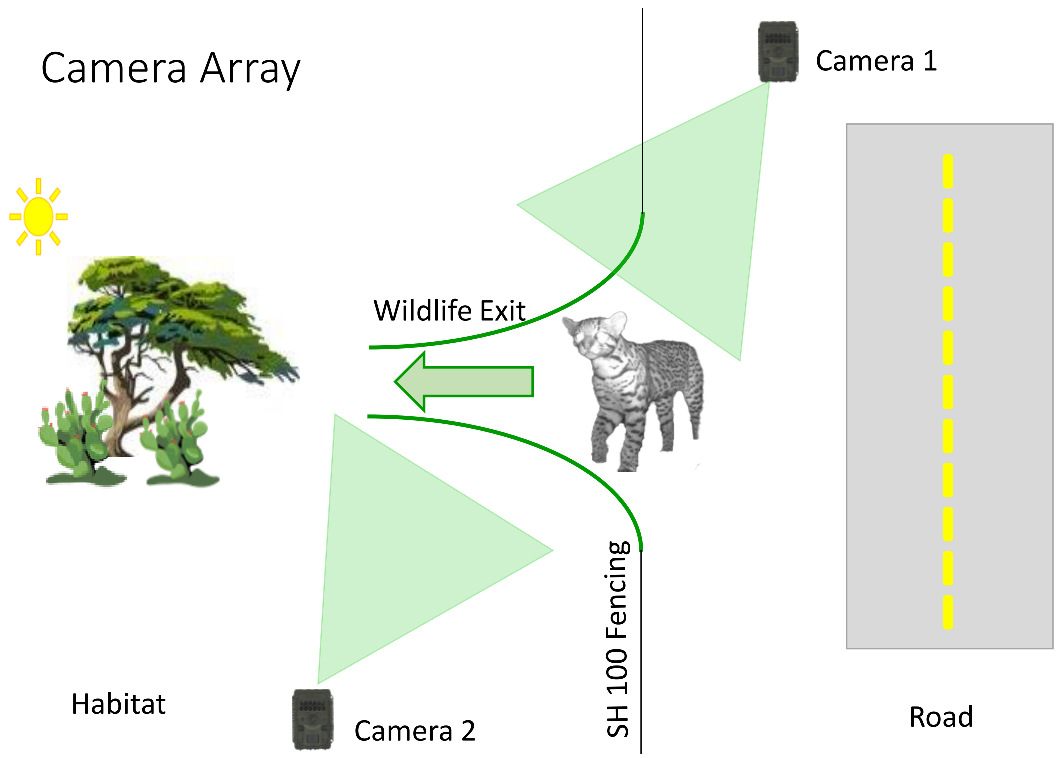


Figure 3. Diagram of the camera array at all ten wildlife exits along State Highway 100 in Cameron County, Texas from February 2019 – November 2020. Each site had two Reconyx HyperFire 2™ series cameras on either side of the chain-link fence facing perpendicular to the wildlife exit. The wildlife exits were designed to encourage wildlife trapped in the right-of-way to travel to the habitat side of the fence. All cameras were checked monthly at which point surrounding vegetation was cleared around each exit to a distance of 2-3 m.

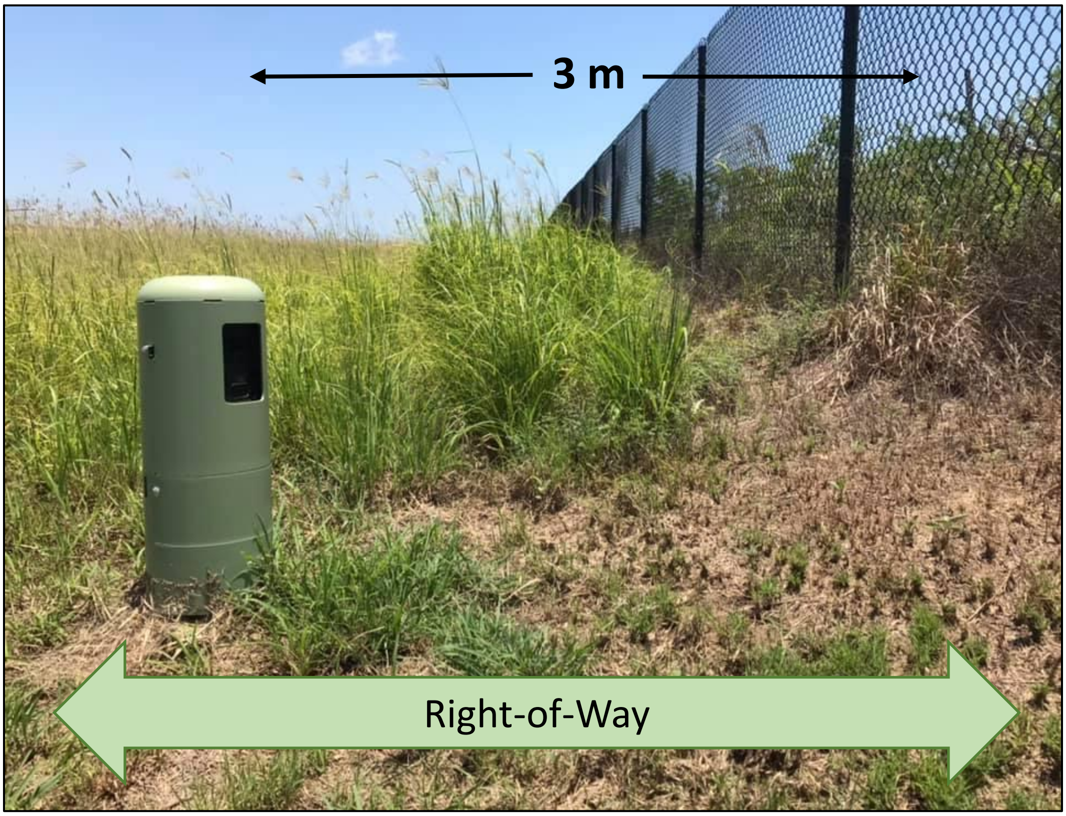
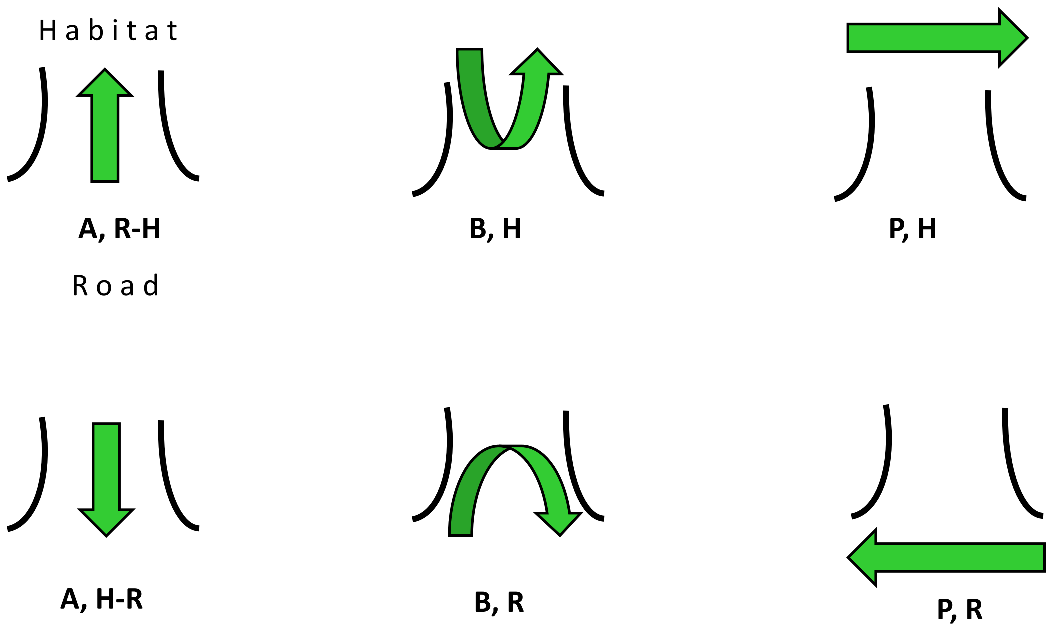


Figure 4. Ten right-of-way (ROW) cameras were placed on State Highway (SH) 100 in Cameron County, Texas facing the chain-link fencing to capture unmonitored wildlife activity occurring along the roadside of the fence. The ROW here is defined as the area between the road and the continuous chain-link fencing that separates the road from the habitat, measuring approximately 5-10 meters. Right-of-way cameras were placed approximately three meters from the chain-link fence. All cameras were checked monthly at which point surrounding vegetation was cleared around each ROW camera.

Figure 5. In addition to ten wildlife exits, current monitoring of mitigation structures along State Highway 100 in Cameron County, Texas exists in the form of 16 wildlife guards, 5 wildlife crossing structures, and 16 gates. Following three ocelot road mortalities that occurred in the span of four years, the Texas Department of Transportation began construction of these mitigation structures in September 2016 and concluded in May 2018.



Class	Direction	Description
A	R-H	Road entry, habitat exit
A	H-R	Habitat entry, road exit
B	H	Entry and exit on habitat side
B	R	Entry and exit on roadside
P	R	Individual moves parallel to road and does not enter the exit
P	H	Individual moves parallel to habitat and does not enter the exit

Figure 6. Potential interactions and categorizations of individual wildlife activity at wildlife exits on State Highway 100 in Cameron County, Texas. Interaction classes include successful crossings from one side of the chain-link fence to the other ("A"), entries/exits on the same side of the chain-link fence ("B"), and parallel interactions in which an individual walked along the chain-link fence and did not attempt to use the exit ("P"). Directions for species travel included habitat ("H") and roadway ("R").

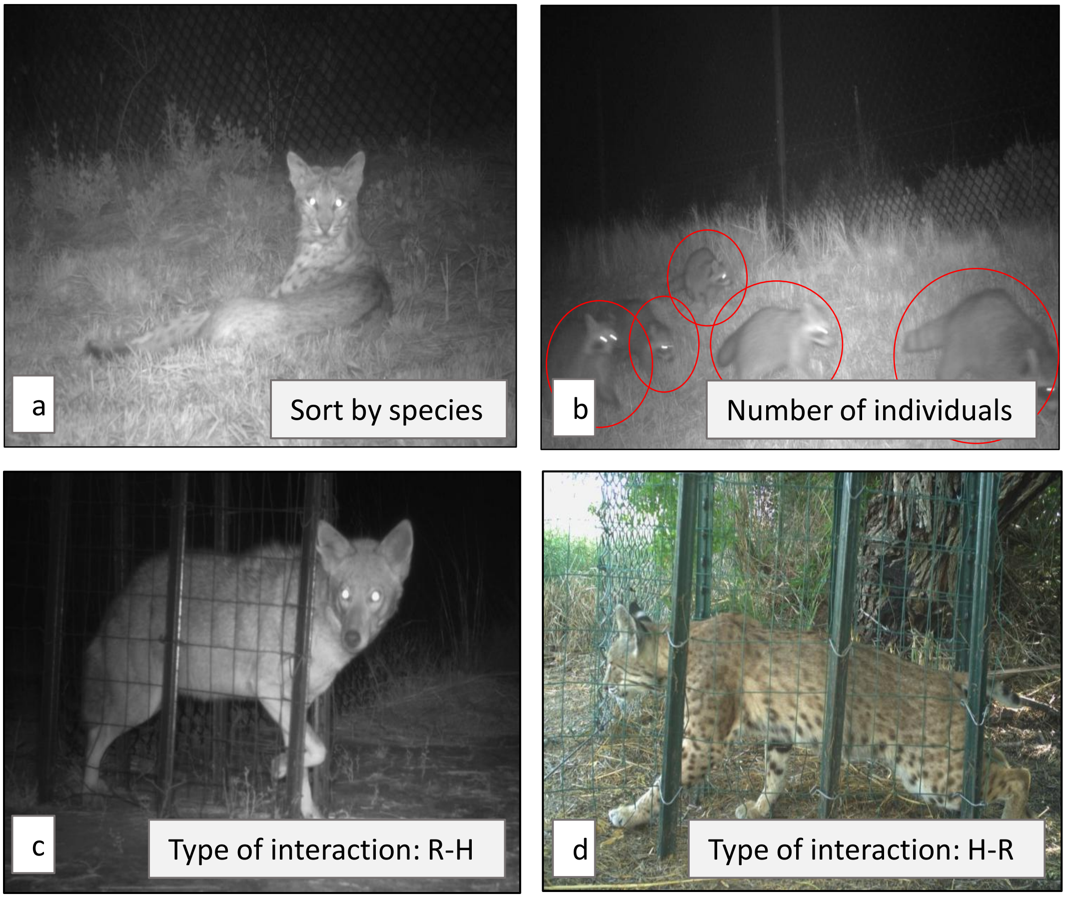


Figure 7. After wildlife exit pictures were collected from the field, they were sorted first by species captured in the photo (a), then by the number of individuals in that photo (b), and finally by the type of interaction that an individual had with the wildlife exit (c, d). Interactions depicted include a successful road to habitat (R-H) crossing of a coyote (c) and an incorrect habitat to road (H-R) crossing of a bobcat (d).

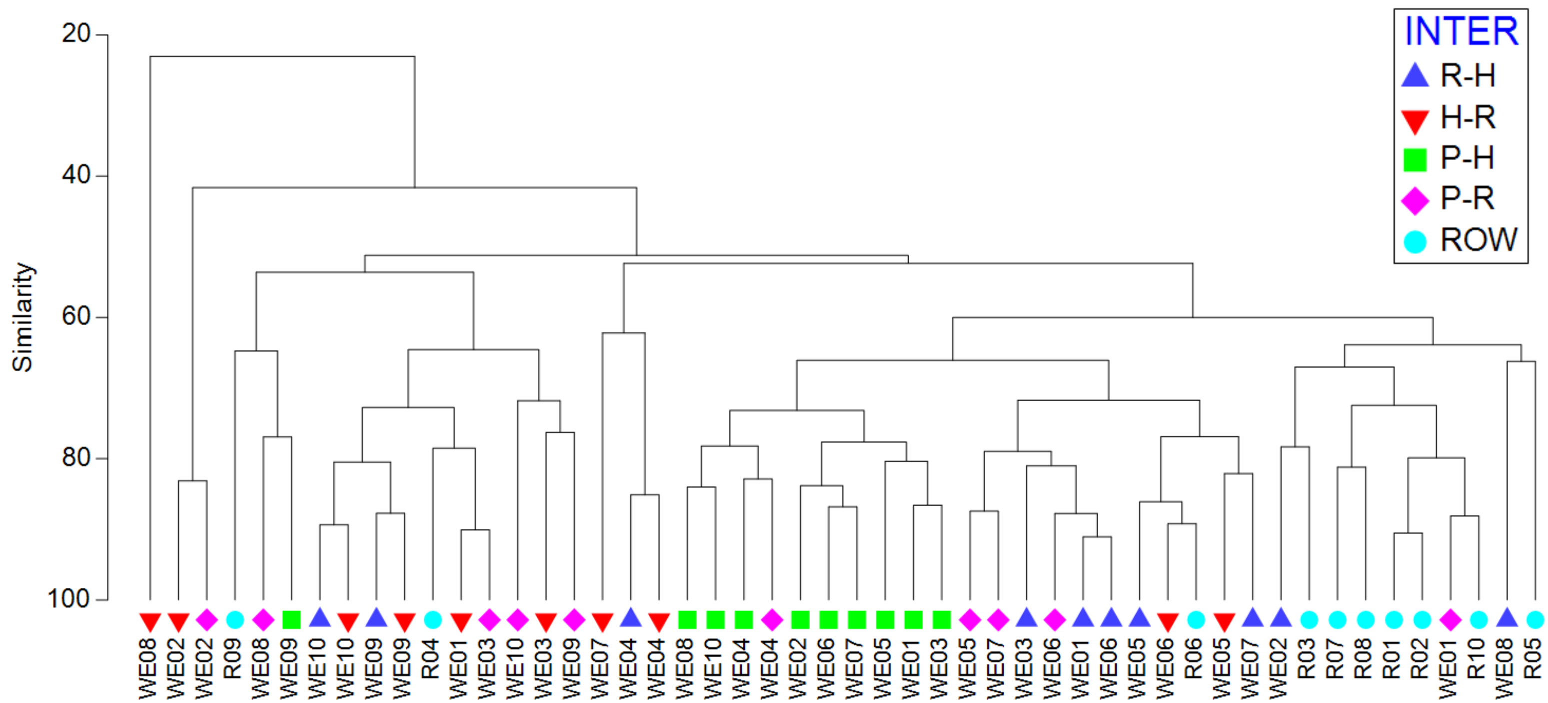


Figure 8. Dendrogram of all observed wildlife interactions across wildlife exits (WE) and right-of-way (ROW) locations on State Highway 100 in Cameron County, Texas. Interaction types for WE include successful crossings from the road to the habitat side of the chain-link fence (R-H), crossings from the habitat to the road (H-R), and parallel interactions in which an individual walks past the WE on the road (P-R) or the habitat (P-H) without attempting to use the exit. All ROW data consisted of individuals walking parallel to the continuous chain-link fencing on the roadside of SH 100. Data collection for WE was from February 2019 – November 2020; data collection for ROW cameras was from December 2019 – December 2020.

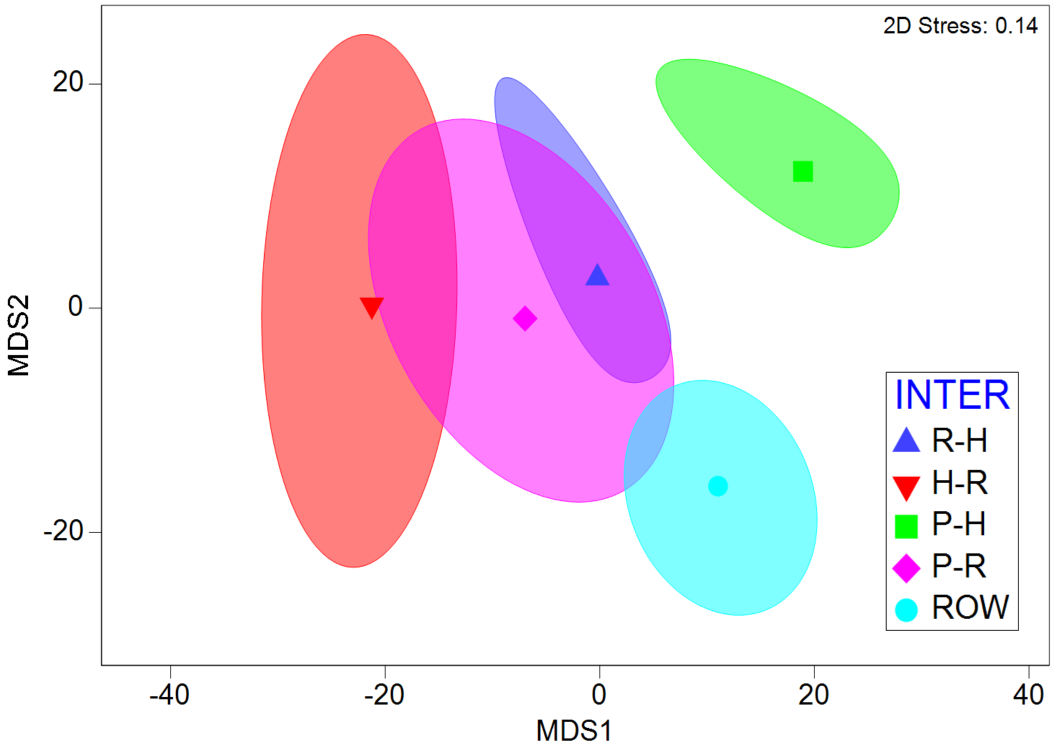


Figure 9. Bootstrapped metric multidimensional scaling (mMDS) plot produced with a 95% confidence region of fourth root transformed data on Bray-Curtis similarity matrix provided visual representation of the differences between interaction type observed at all ten wildlife exits on State Highway 100 from February 2019 to November 2020, as well as differences at ROW sites from December 2019 to December 2020. PERMANOVA results from the full model showed that interaction type was the only significant factor (d.f. = 4, pseudo-F = 4.0898, p = 0.0001). Pair-wise test for the four interaction types revealed that parallel interactions occurring along the habitat side of the chain-link fencing (P-H) were dissimilar when individually paired with each of the other three interaction groups (all p-values < 0.025). Additionally, wildlife activity for road to habitat (R-H) and habitat to road (H-R) pair-wise comparisons were significantly different (p = 0.0153). All pair-wise tests for interactions were significantly different from ROW (all p-values < 0.025).

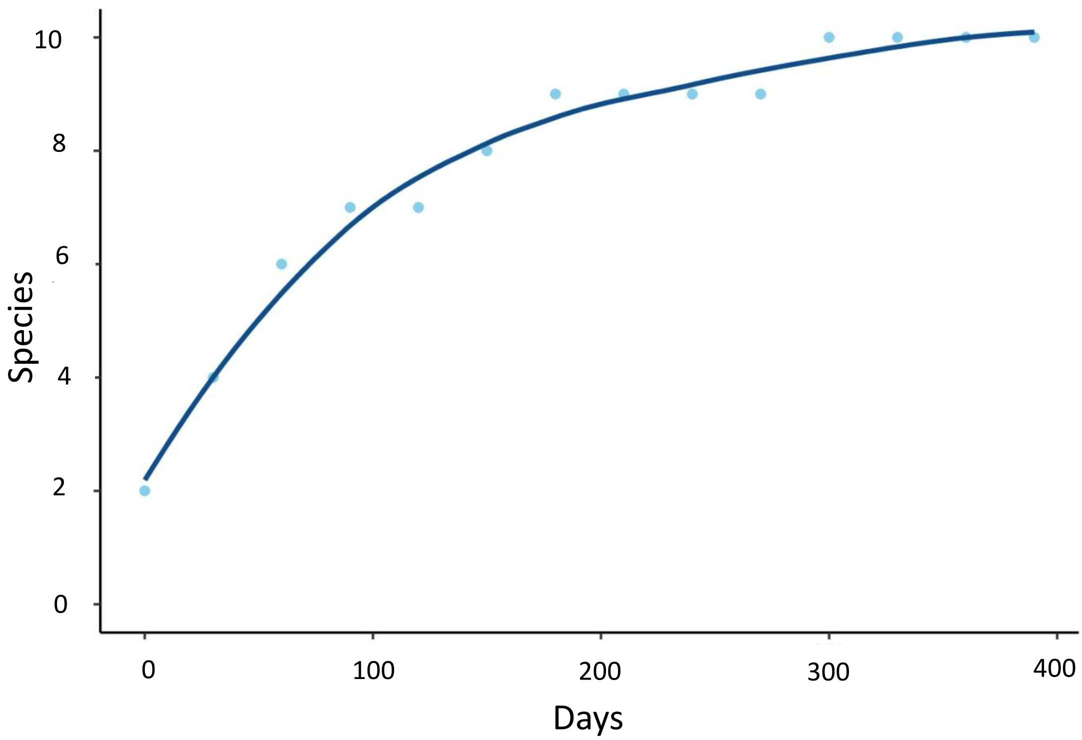


Figure 10. Total number of species recorded per 30-day sampling period using all wildlife exits (WE) in the road to habitat direction on State Highway 100 in Cameron County, Texas. Time period extended from February 2019 through the time of the first WE closure in mid-April 2020. Wildlife exits were closed once either a bobcat or coyote was observed using a WE to incorrectly access the roadway, traveling in the habitat to road direction. At the end of the data collection period in November 2020, four of the ten wildlife exits had been closed.

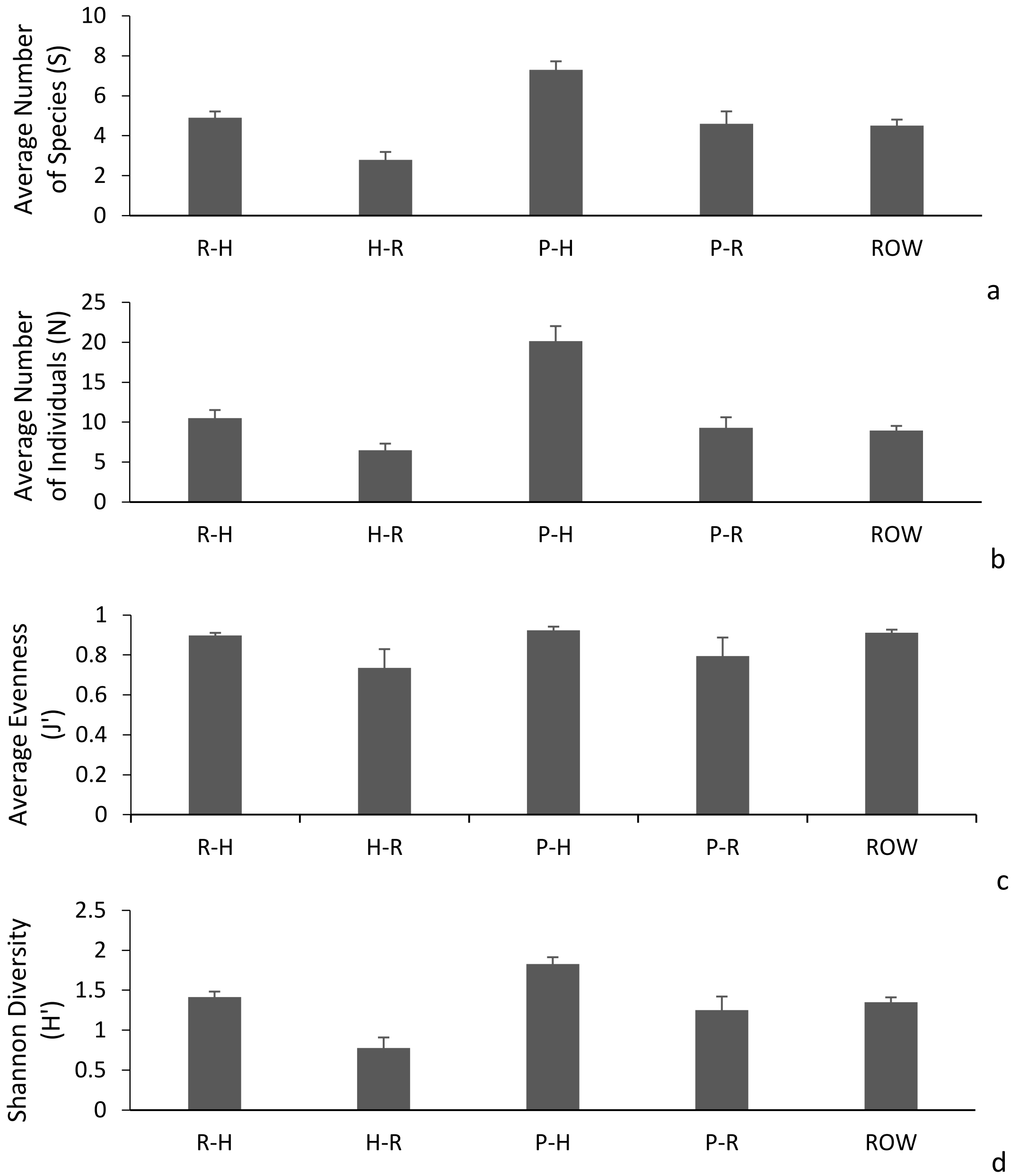


Figure 11. Diversity indices produced on log-transformed data for all five interaction types observed at wildlife exits (WE) and right-of-way (ROW) cameras on State Highway 100 in Cameron County, Texas. Averages reported for total number of species (a), total number of individuals (b), evenness (c), and Shannon diversity (d) by interaction type. Interaction types include road to habitat (R-H) crossings, habitat to road (H-R) crossings, parallel events on the habitat (P-H) side of the chain-link fencing, parallel events on the roadside (P-R), and individuals traveling parallel on the road next to right-of-way locations (ROW). Data collection for WE was from February 2019 – November 2020; collection for ROW cameras was from December 2019 – December 2020.

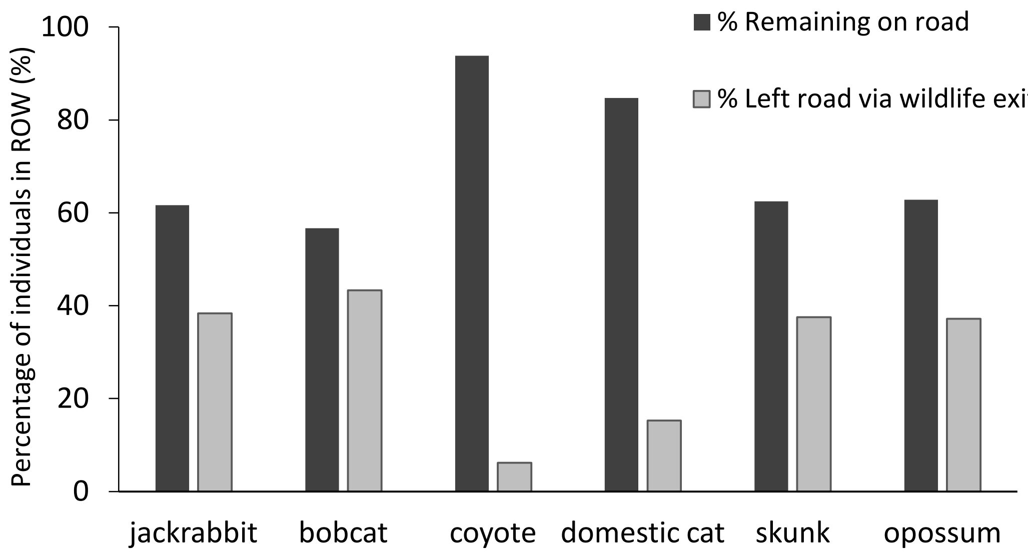


Figure 12. Percentage of wildlife that left the highway using a wildlife exit (WE) along State Highway 100 in Cameron County, Texas compared to the number of individuals remaining on the road after all road to habitat (R-H) exits via a mitigation structure. The time period for all entries and exits used in analysis was from February 2019 – November 2020. Of the bobcats remaining on the road, around 43% of them found and used a WE to escape into the habitat. Approximately 6% of coyotes left on the road successfully used a WE to return to the habitat.

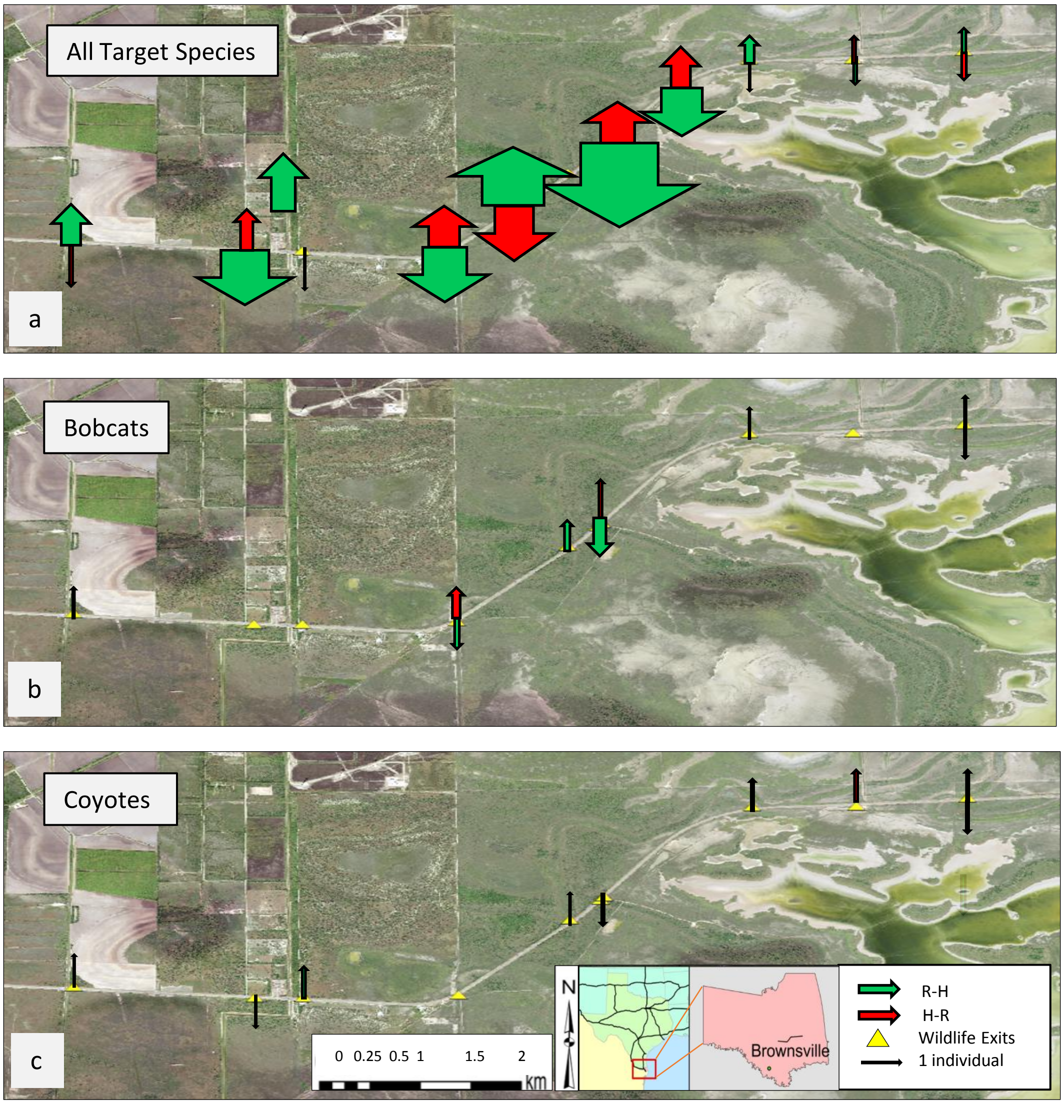


Figure 13. Species density maps indicating the proportion of total wildlife traffic in the intended direction of road to habitat (R-H, green arrow), and unintended direction of habitat to road (H-R, red arrow) along State Highway 100 in Cameron County Texas from February 2019 – November 2020. Species included in the analysis were black-tailed jackrabbits, bobcats, coyotes, domestic cats, striped skunks, and virginia opossums (a). Bobcat density map (b) illustrating the proportion of bobcat traffic in the R-H and H-R directions. Bobcats successfully used six of the ten wildlife exits to travel from the road to the habitat during the data collection period. Coyote density map (c) illustrating the proportion of coyote traffic in the R-H and H-R directions. Coyotes successfully used eight of the ten wildlife exits to travel from the road to the habitat during the data collection period. All road to habitat (green) arrows designate the side of the highway that the wildlife exit is present.

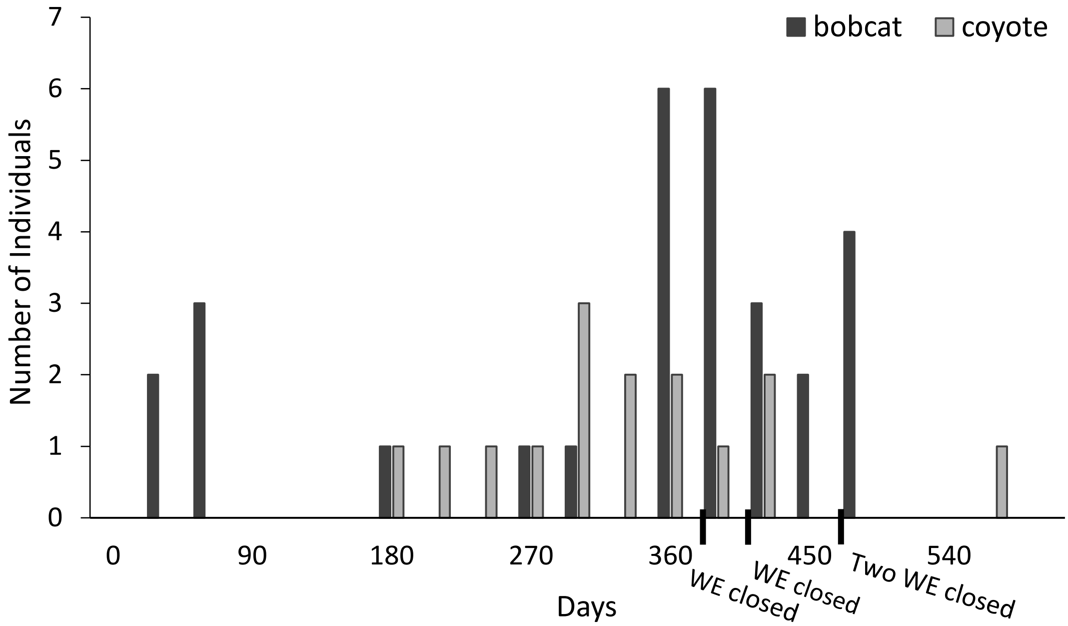


Figure 14. Total number of bobcats and coyotes on State Highway 100 in Cameron County, Texas that learned to use the wildlife exits to travel from the road to the habitat from February 2019 – November 2020. At the end of this collection period, four of the ten wildlife exits had been closed, potentially explaining the decrease in mesocarnivore R-H activity around a year and a half into the collection period. Bobcats used six of the ten wildlife exits and coyotes used eight of the ten wildlife exits.

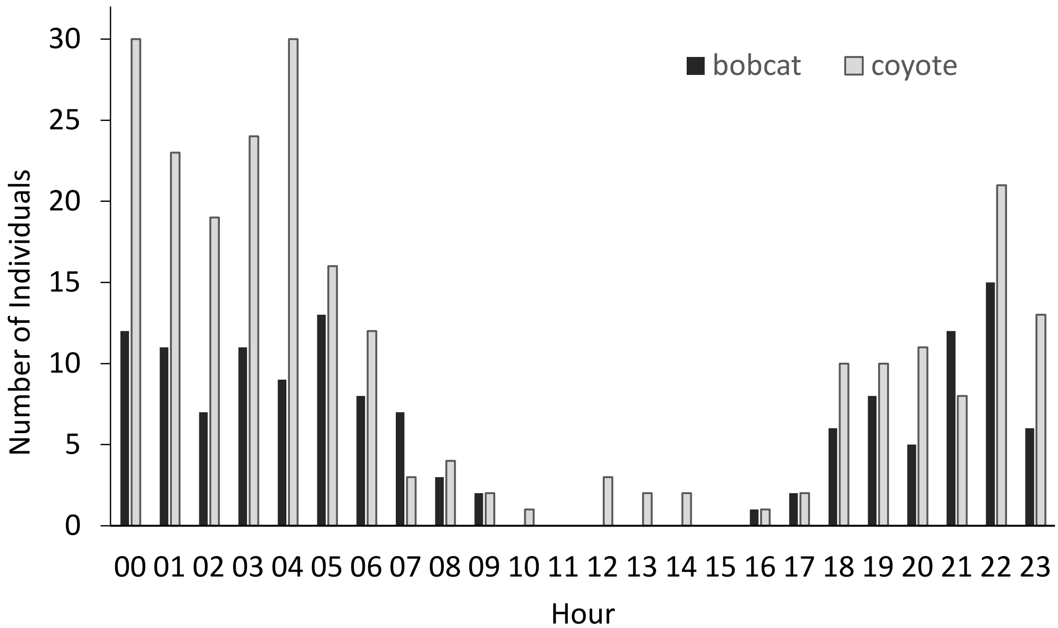


Figure 15. Bobcat and coyote activity as a function of hour of the day for all bobcats and coyotes observed across all interaction types captured on cameras at the wildlife exits (WE) on State Highway 100 in Cameron County, Texas between February 2019 and November 2020. Average bobcat activity at WE occurred between the hours of 6 pm and 7 am and average coyote activity occurred between 6 pm and 6 am. Time was based on a 24-hr clock.

BIOGRAPHICAL SKETCH

Zarina N. Sheikh is originally from the SF Bay Area where she attended San Francisco State University and earned her Bachelor of Science in Biology with a concentration in Zoology in May 2015. After graduation, she immersed herself into every wildlife opportunity and got the chance to work with a variety of species in different settings. Zarina has worked across taxa, from mist-netting and banding birds, to pit-tagging giant gartersnakes, and collaring white-tailed deer, acquiring an assortment of techniques and applying research methods learned over the years.

After four years of gaining experience in the fields of wildlife biology, ecology, and conservation, Zarina attended graduate school at the University of Texas Rio Grande Valley (UTRGV), joining the ocelot and jaguarundi monitoring project. Her thesis examined the effectiveness of wildlife exits along State Highway 100 in south Texas. In May 2021, Zarina earned her Master of Science in Biology from UTRGV, immediately returning home to California to escape the humidity. Ultimately, she is aiming to secure a position as a wildlife field biologist in the mountains of the Pacific Northwest. Zarina N. Sheikh can be reached at her personal email: bellaromano@yahoo.com.