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Creating Multi-Use Highway Structures with Retrofitted Fencing to Reduce Collisions with Elk on Interstate 17

Arizona Department of Transportation Research Center

ADOT

Creating Multi-Use Highway Structures with Retrofitted Fencing to Reduce Collisions with Elk on Interstate 17

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July 2016

Prepared by:
Jeffrey W. Gagnon, Chad D. Loberger,
Scott C. Sprague, Susan R. Boe,
Kari S. Ogren, and Raymond E. Schweinsburg
Arizona Game and Fish Department
5000 West Carefree Highway
Phoenix, AZ 85068

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16. Abstract

In Arizona, vehicle collisions with elk are costly and can be deadly. Dedicated wildlife crossing structures have proven effective for elk elsewhere in Arizona. Planned highway reconstruction for Interstate 17 (I-17) included such wildlife crossing structures, but when construction was delayed, an alternative was developed: extending the height of right-of-way (ROW) fencing to funnel wildlife underneath existing highway bridges and overpasses. After 5.9 mi of ROW fencing (between mileposts 316.8 and 322.7) was extended to 8 ft high, this study evaluated its effectiveness in guiding elk to cross under two large bridges and the overpass and underpass of two traffic interchanges (TIs).

Following the fencing retrofit, researchers documented a 97.5 percent reduction in elk-vehicle collisions and an 88.9 percent decrease in crashes coded "Animal_Wild_Game" by the Arizona Department of Public Safety (DPS) along the 5.9-mi segment of I-17. No increase in collisions was reported within the 1-mi fence end segments or control areas. The researchers documented 217 percent and 54 percent increases in elk crossing under the Munds Canyon and Woods Canyon bridges, respectively, but no elk use of the modified TIs (Fox Ranch Road and Schnebly Hill Road). Following the retrofit, fence maintenance costs did not increase or exceed those of adjacent sections. Using the Huijser et al. (2009) estimated cost of $17,483 per elk-vehicle collision, the documented level of collision reduction will recoup retrofitting costs in less than five years. The findings indicate that fencing retrofits can reduce wildlife-vehicle collisions if given appropriate circumstances, such as adequate size and spacing of existing highway structures.

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Deer, deer-vehicle, elk, elk-vehicle, fragmentation, GPS telemetry, fencing, retrofit, *Cervus canadensis, Cervus elaphus,* passage rates, permeability, traffic volume, wildlife-vehicle collisions		This document is available to the US public through the National Technical Information Service, Springfield, Virginia 22161		
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
CNF	Coconino National Forest
DCR	Design Concept Report
DPS	Department of Public Safety
DVC	deer-vehicle collision
EVC	elk-vehicle collision
GIS	geographic information system
GPS	Global Positioning System
I-17	Interstate 17
MP	milepost
PeCoS	Performance Control Systems
ROW	right-of-way
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SE	standard error
SR	State Route
TI	traffic interchange
WCS	wildlife crossing structure
WVC	wildlife-vehicle collision

LIST OF SPECIES

Animals	Scientific Name
bobcat	*Lynx rufus*
black bear	*Ursus americanus*
caribou	*Rangifer tarandus*
coyote	*Canis latrans*
duck (mallard)	*Anas platyrhynchos*
elk	*Cervus canadensis*
Florida Key deer	*Odocoileus virginianus claviu*
gray fox	*Urocyon cineroargenteus*
great blue heron	*Ardea herodias*
grizzly bear	*Ursus arctos*
javelina	*Tayassu tajacu*
moose	*Alces alces*
mountain lion	*Puma concolor*
mule deer	*Odocoileus hemionus*
pronghorn	*Antilocapra americana*
raccoon	*Procyon lotor*
rock squirrel	*Spermophilis variegatus*
skunk	*Mephitis spp.*
white-tailed deer	*Odocoileus virginianus*
wolf	*Canis lupus*

Plants

ponderosa pine	*Pinus ponderosa*

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EXECUTIVE SUMMARY

Wildlife-vehicle collisions (WVC) injure motorists and significantly damage property. Wildlife crossings (e.g., underpasses and overpasses) are a common tool used to reduce WVC while maintaining habitat connectivity for wildlife. Wildlife crossings can be costly and generally are not implemented until roadway reconstruction, but reductions in transportation department budgets and revised reconstruction timelines necessitate considering alternatives to reduce WVC. Retrofitting existing drainage structures (e.g., culverts and bridges) with wildlife exclusion fencing is one potential cost-effective solution.

Researchers assessed elk highway crossing patterns and other interactions with Interstate 17 (I-17) from February 2012 to February 2014 along a 5.9-mi stretch (between mileposts [MP] 316.8 and 322.7) south of Flagstaff. This highway segment (the study area) is located atop the Mogollon Rim in an area known for high incidence of WVC, particularly with elk. The Arizona Department of Transportation (ADOT) and the Arizona Game and Fish Department (AGFD) identified existing structures along the study area that could potentially serve as elk crossings and help lower the high number of elk-vehicle collisions (EVC) if connected with fencing to guide elk to the structures. Following this assessment, AGFD and ADOT obtained federal funding for a limited fencing project that would retrofit the existing right-of-way (ROW) fence (raising the height from 4 ft to 8 ft) and connect existing structures between MP 316.8 and 322.7. The fence reconstruction was completed in February 2012.

This study evaluated the effectiveness of the higher fences in reducing EVC and funneling elk to cross at two existing highway drainage structures and two traffic interchange (TI) structures. The objectives of this research project were to investigate:

1. EVC rates along the study area
2. Wildlife use of existing structures
3. Elk movements, highway crossing distribution, and highway permeability
4. The cost-effectiveness of the project by comparing costs of fencing and construction to the monetary benefit to society realized through reduction in EVC
5. Maintenance concerns associated with the project

Following completion of the fencing retrofit on February 8, 2012, the research team documented one EVC in the following two years (0.5 EVC/yr). This represents a 97.5 percent reduction in EVC compared to the 2007 to 2010 mean (20.3 EVC/yr). According to Department of Public Safety (DPS) crash data, "Animal_Wild_Game" crashes decreased by 88.9 percent following fence construction. Furthermore, EVC and "Animal_Wild_Game" reports did not increase at the 1-mi fence end segments or at the remaining 24-mi control sections, indicating elk were not forced to cross the ROW at other areas. Researchers occasionally noted elk accessing the ROW by squeezing through the fence. Additionally, the cost-efficient type of fence used to focus on elk exclusion on this project still allowed deer and black bears into the ROW, and collisions with these species were documented.

Researchers evaluated wildlife use of the existing structures located within the study area with motion-activated still cameras. Over the 38 months of monitoring prior to and following the fence heightening, the cameras captured images of a total of 3,150 animals (consisting of 14 species) using the crossings. Of these, 2,340 elk (and 810 non-target wildlife) used the Munds Canyon and Woods Canyon bridges, demonstrating a 217 percent and 54 percent increase in elk use, respectively. Incidentally, the research team documented 435 deer using the Munds Canyon and Woods Canyon bridges, a 69 percent and 350 percent increase, respectively. The research team did not document any elk crossings at the Fox Ranch Road and Schnebly Hill Road modified traffic interchanges (TIs), also located within the newly fenced section.

The research team used Global Positioning System telemetry data to track the elk and compare their highway crossing locations and passage rates pre- and post-fence reconstruction. Changes in elk approaches, crossings, and passage rates were not significant, and crossing distribution indicated the animals were not forced to cross in areas beyond the fenced section.

COSTS AND MAINTENANCE

The fencing retrofit evaluated by this study originally cost $1.66 million. The affected highway segment had averaged 20.3 EVC/yr from 2007 to 2010; based on an estimated cost to society of $17,483 per EVC (Huijser et al. 2009), this amounted to a cost of $354,905/yr prior to the fence reconstruction. Following the fence reconstruction, a single EVC occurred from 2012 to 2013, resulting in a mean of 0.5 EVC/yr for a total cost of $8,742/yr, showing a reduction in cost of more than $346,000. With a similar reduction of EVC in subsequent years, the benefit will exceed the original retrofit cost in less than five years.

Maintenance activities for the first two years following the new fencing were not noticeably different from those activities normally conducted on the standard ROW fencing to keep cattle off the road. Fence maintenance costs on the study area, as logged on ADOT's Performance Control Systems (PeCoS), did not increase following the fence reconstruction or exceed costs for adjacent sections.

The research team noted cinders sloughing off the face of the jump-outs, or escape ramps, thereby reducing the potential for proper use and creating mounds that could allow elk easier access to the ROW. Repair and maintenance of the jump-outs will be required to ensure proper functionality.

RECOMMENDATIONS

The research team made several recommendations regarding future wildlife crossing structures, retrofitted fencing, and jump-outs. A summary of key recommendations follows:

- To effectively reduce EVC along the remaining stretches of I-17 while still maintaining habitat connectivity, the research team recommends that ADOT continue to include wildlife crossing structures (WCS) and fencing in the planning for the upgrade of I-17.

- It is recommended that ADOT work with AGFD and other stakeholders to identify existing bridges (similar to the Munds Canyon and Woods Canyon bridges) and adequately sized culverts that could function as wildlife crossings in areas of high WVC throughout the state. In areas where both high WVC and adequate structures exist, ADOT would collaborate with AGFD to determine whether retrofitting fencing is a feasible option, primarily focusing on the length of fencing and logical termini.

- Given the success of wildlife crossings and fencing in Arizona, it is recommended that ADOT continue to retrofit existing structures with fencing and build new WCS and fencing where appropriate.
- The research team recommends annual inspection and repair of the wildlife fence ahead of spring migration. In addition to thorough spring maintenance and repairs, maintenance personnel should watch for signs of fence issues throughout the year.
- In the long term, the research team recommends replacing the heightened barbed wire fence with the standard, stronger 8-ft woven-wire fence used elsewhere in Arizona to exclude elk from I-17.
- The research team recommends repairing jump-outs by adding metal mesh to the leading edge of the features to prevent erosion of cinders.
- Future ADOT jump-out projects should include a design that addresses soil retention. The final jump-out height should be 6 ft at the face. Jump-outs should be inspected during annual fence inspections to determine additional maintenance needs.

CHAPTER 1: INTRODUCTION

Wildlife-vehicle collisions (WVC) are a serious and growing threat to wildlife populations as well as a contributing factor in human injuries, deaths, and property loss (Conover et al. 1995, Groot Bruinderink and Hazebroek 1996, Schwabe and Schuhmann 2002). An estimated 26,000 injuries and 200 human deaths are attributed to WVC in the United States every year, with a yearly economic impact exceeding $8 billion (Huijser et al. 2008).

Wildlife crossing structures (WCS) are used to reduce WVC while still allowing wildlife to access resources (Foster and Humphrey 1995, Clevenger and Waltho 2000, Dodd, Gagnon, Boe, et al. 2007a, Gagnon et al. 2011, Bissonette and Rosa 2012, Sawyer et al. 2012). WCS allow wildlife to cross over or under roads away from the traffic volume versus crossing the highway at-grade (Gagnon, Theimer, Dodd, Boe, et al. 2007, Gagnon, Theimer, Dodd, Manzo, et al. 2007, Dodd and Gagnon 2011). Combining WCS with properly constructed and maintained wildlife exclusionary fencing—ranging in height from 8 to 10 ft—appears to be most effective at reducing collisions with most large ungulates while maintaining habitat connectivity (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Clevenger and Waltho 2000; 2005, Dodd, Gagnon, Manzo, et al. 2007, Gagnon et al. 2011, Bissonette and Rosa 2012, Dodd, Gagnon, Boe, et al. 2012, Sawyer et al. 2012). Clevenger et al. (2001a) reported an 80 percent reduction in ungulate mortalities along the Trans-Canada Highway in the Banff National Park in Alberta, Canada, following exclusionary fencing linking WCS. Woods (1990) reported a 94 to 97 percent reduction in WVC in Alberta following implementation of a WCS and funnel fencing. Two studies in the western United States documented reductions in mule deer mortalities — an 98.5 percent reduction in Utah (Bissonette and Rosa 2012) and a 81 percent reduction in Wyoming (Sawyer et al. 2012)—following installation of funnel fencing and construction of WCS. Collisions with Florida Key deer were reduced by 73 to 100 percent following installation of fencing and underpasses (Parker et al. 2008, 2011).

As transportation budgets have declined, WCS have been viewed as ancillary amenities. Additionally, while large-scale roadway reconstruction budgets can include WCS, projects can take years to decades to move through design, funding, and implementation. These fiscal and temporal constraints underscore the need for cost-effective, functional, and timely alternatives. Alternatives to WCS are numerous (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Huijser et al. 2008).

Of these alternatives, properly installed and maintained fencing combined with WCS appears to be the most effective. If fencing is used, WCS that allow wildlife to continue crossing the road for daily and seasonal movements are essential. Existing structures, such as culverts and bridges installed during initial highway construction for water drainage, or pedestrian or vehicular use, may function as WCS for some species (Reed 1981, Ward 1982, Clevenger et al. 2001a, Ng et al. 2004, Ascensão and Mira 2006, Donaldson 2007, Grilo et al. 2008, Sparks and Gates 2012). If the construction of new WCS is not feasible, there may be options to retrofit highways by installing fencing between existing culverts and bridges to accommodate wildlife passage and improve highway safety while providing a cost-effective alternative. Ward (1982) reported a greater than 90 percent reduction in WVC with mule deer along I-80 in Wyoming after a right-of-way (ROW) fence was heightened to 8 ft and directed deer to cross at structures originally intended for drainage and machinery. Researchers in Arizona documented an 85 to 97 percent reduction in the number of elk-vehicle collisions (EVC) following the completion of fencing projects between WCS and bridges constructed without sufficient exclusionary fencing. Prior to fencing, elk avoided the WCS and crossed over the highway; following fencing installation, EVC were reduced and use of the WCS increased (Dodd, Gagnon, Manzo, et al. 2007, Gagnon et al. 2010).

Although connecting structures with exclusionary fencing to reduce WVC is not a new concept, there are minimal studies on the cost-effectiveness of such an approach. With funding for WVC reduction measures under close scrutiny, determining their cost-effectiveness is key. Cost-benefit analyses can provide information on a mitigation measure's ability to recoup costs (Reed et al. 1982, Huijser et al. 2009). This requires a cost to be placed on WVC, which includes deriving a value of wildlife in terms of hunter opportunity and recreation, along with the costs of emergency response, carcass removal, property damage, human injury, and fatalities (Huijser et al. 2009).

When considering the costs of mitigation options, values need to include design, implementation, and additional maintenance costs, but should also involve the controversial task of placing a monetary value on wildlife and on avoiding human injuries or fatalities (Conover 1997, Reed et al. 1982, Huijser et al. 2009).

Because the nationwide proportion of WVC that involve elk is an extremely low 0.5 percent (Huijser et al. 2009), few efforts exist to place a monetary value on EVC (Biggs et al. 2004, Huijser et al. 2009, Sielecki 2010). Most valuations of WVC focus on deer, as they are the animals most commonly involved (Reed et al. 1982, Hansen 1983, Bissonette et al. 2008). However, in parts of the western United States, animal-related crashes predominately involve elk, and in Arizona more than 80 percent of those crashes are EVC (Dodd, Gagnon, Boe, Manzo, et al. 2007, Gagnon et al. 2013). The large body size of elk increases the chance of vehicular damage, human injuries, and fatalities, and when combined with lost value to hunters, the costs of an EVC can substantially exceed the costs of a collision with a deer. For these reasons, this report describes measures that can be taken to mitigate EVC.

The Arizona Department of Transportation (ADOT) has been evaluating the long-range reconstruction of Interstate 17 (I-17) to address increasing traffic volumes and to improve highway safety. In 2006 ADOT began environmental surveys and development of a design concept report (DCR) for the stretch of I-17 between State Route (SR) 179 and Interstate 40 (I-40); see Figure 1.

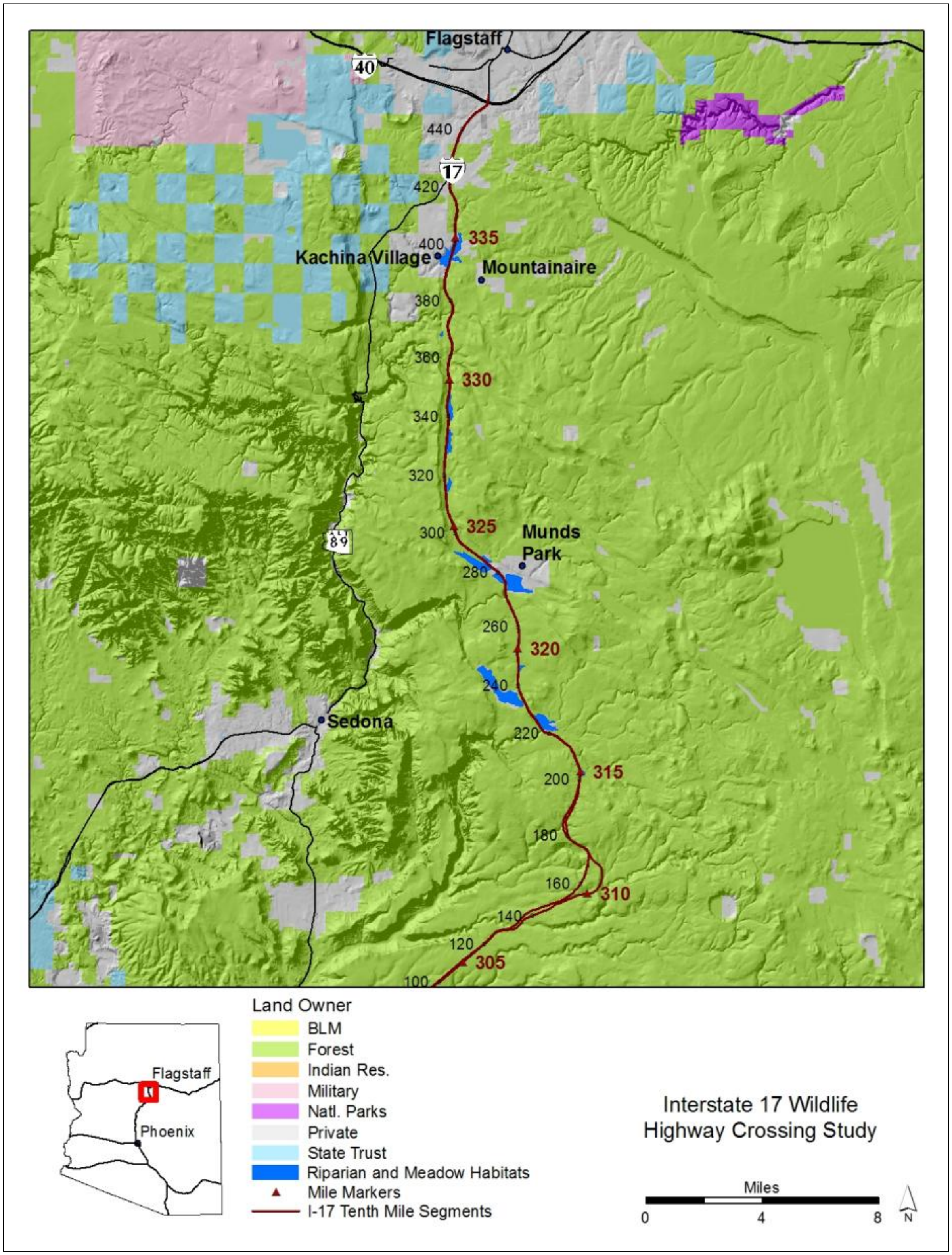


Figure 1. Interstate 17 from State Route 179 to Interstate 40

The initial DCR for ADOT included a WVC assessment that reported that more than 20 percent of all crashes in the segment involved wildlife (Stanley Consultants 2011). This is substantially higher than the national average, which is an estimated 4.6 percent of WVC among all types of collisions (Huijser et al. 2008); see Figure 2 for a comparison. Elk can weigh close to 1,000 lb, increasing the risk of injury or death to motorists when compared to collisions with smaller mammals (Figure 3).

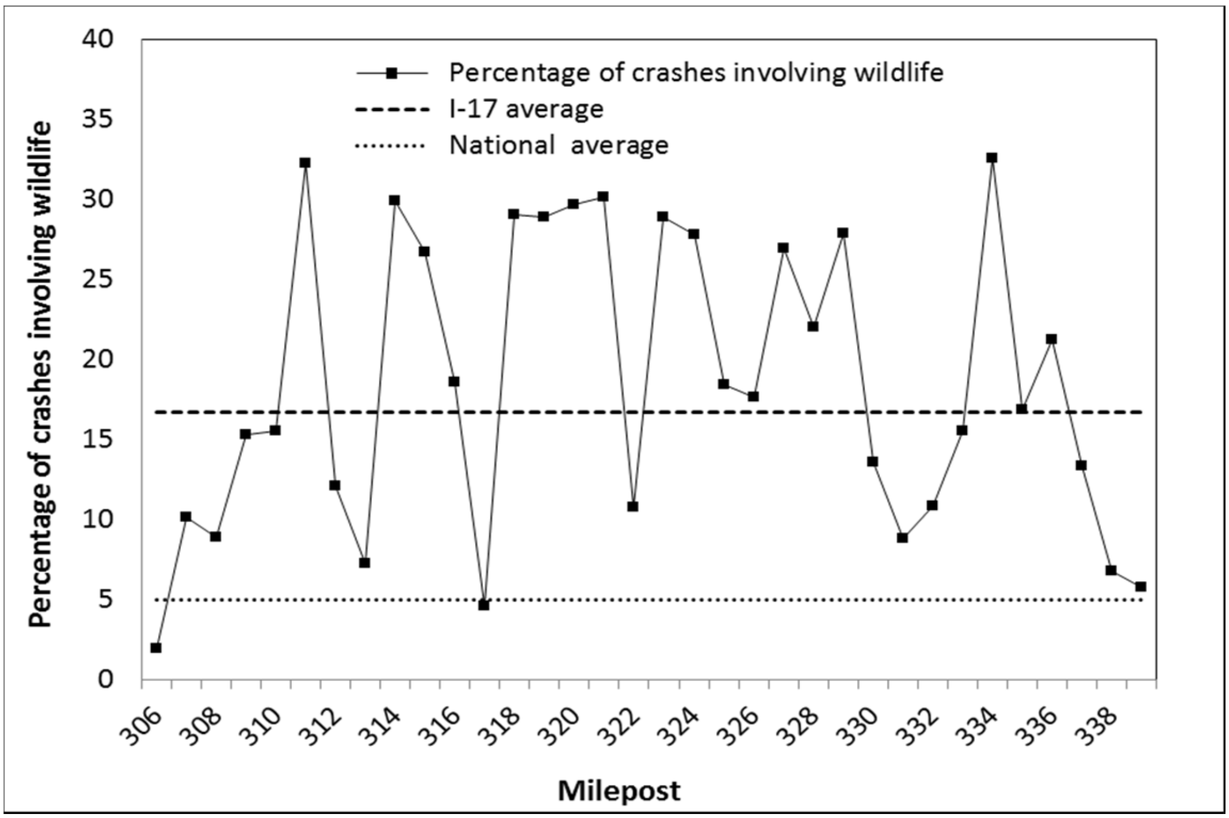


Figure 2. Single-Vehicle Crashes Involving Wildlife on Interstate 17 from Milepost 306 to Milepost 339 (1994 to 2008)

Figure 3. On Interstate 17, Bull Elk Killed by a Vehicle Near Munds Park (Left), and Vehicle Wreckage Resulting in Human Injuries Caused by an Elk-Vehicle Collision (Right)

During the planning process, ADOT also worked with the Arizona Game and Fish Department (AGFD) to gather elk movement and WVC data to inform the incorporation of WCS into the reconstruction plans for a 48-mi stretch of I-17. The study (Gagnon et al. 2013) established a pre-construction WVC baseline for comparison with post-construction parameters.

The researchers recorded an average of 79.0 EVC/yr involving elk, accounting for nearly 80 percent of all WVC. Using global positioning system (GPS) tracking collars, the research team found 912 collared elk crossings of I-17. The highest peak crossing zones were at the Munds Canyon Bridge and a 1-mi stretch of highway between MP 310 and MP 311 where lanes of the divided highway are separated by over 0.5 mi (Gagnon et al. 2013).

The 2013 study confirmed that I-17 constituted a significant barrier to the passage of elk across the highway. Given the strong barrier effect found along I-17, the incidence of EVC likely reflected the lethality associated with high traffic volumes; although fewer elk cross I-17, those that do are likely to be hit by a vehicle. The research team also determined locations suitable for potential WCS (Gagnon et al. 2013). Their recommendations concurred with the original 16 structures recommended for retrofit or construction in the I-17 draft environmental assessment (ADOT 2011).

Due to budget and timeline constraints, the reconstruction of I-17 was delayed, and the need arose for alternatives. ADOT and AGFD focused on the 5.9-mi segment that had a high incidence of EVC: 20.3 collisions per year, on average, from 2007 to 2010 (Figure 4).

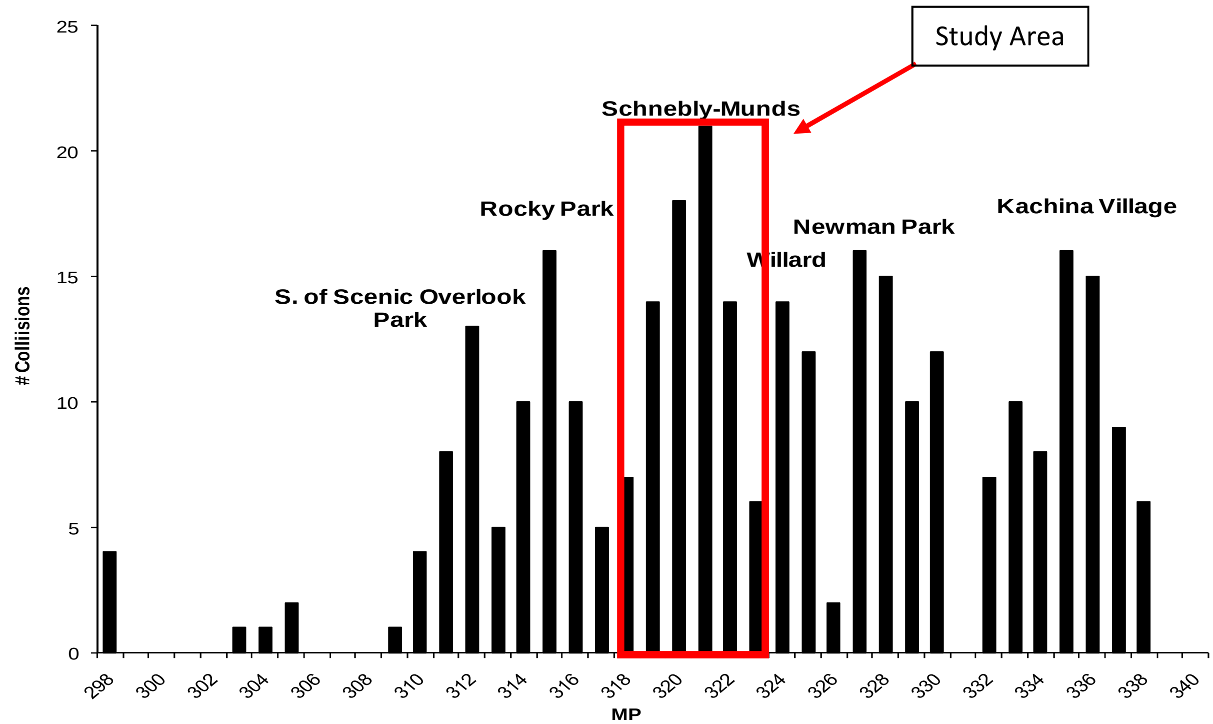


Figure 4. Distribution of Wildlife-Vehicle Collisions on Interstate 17 from State Route 179 to Flagstaff from 2007 to 2010 (Study Area Highlighted in Red)

The 5.9 mi along I-17 included four existing highway structures with the potential to function as WCS. These highway structures are detailed in Table 1 below and pictured in Figure 5.

Table 1. Details of Existing Structures Linked with Retrofit Fencing along the Study Area

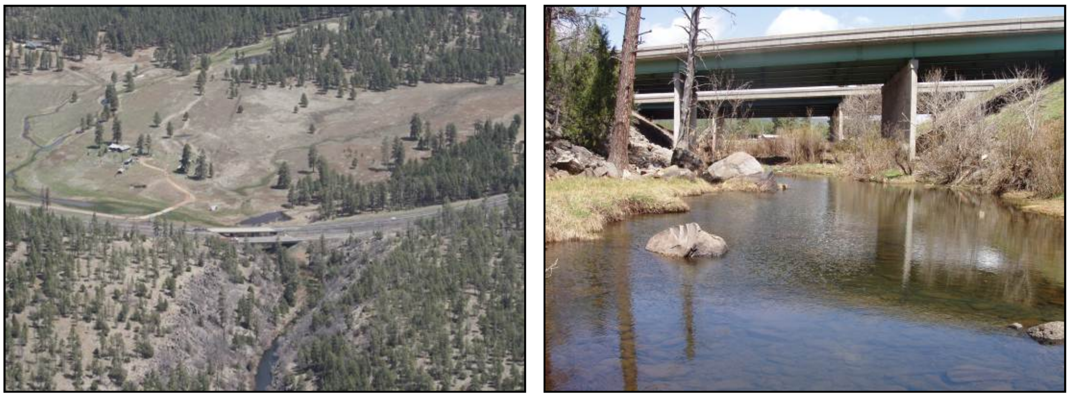
Structure Name	Structure Type	Milepost (Location)[1]	Length (ft)[1]	Height (ft)[2]	Width (ft)[3]
Woods Cyn Bridge	Bridge	317.0	197.0	20.0	126.0
Fox Ranch Rd	TI	317.9	26.0	N/A	225.0
Schnebly Hill Rd	TI	320.5	29.0	14.0	126.0
Munds Cyn Bridge	Overpass	322.0	353.0	50.0	186.0

[1] MP and length is the average of northbound and southbound lanes.

[2] Height is approximate from the lowest point.

[3] Width is calculated as width of lanes plus median.

5a. Views of Munds Canyon Bridge



5b. Views of Woods Canyon Bridge

5c. Views of Schnebly Hill Road Traffic Interchange

5d. Views of Fox Ranch Road Traffic Interchange

Figure 5. Four Selected Highway Structures along the Study Area

AGFD and ADOT jointly obtained federal funding for a fencing project that would retrofit the existing ROW fence along the 5.9-mi stretch, and the retrofitting began during summer 2011.

The phase of research documented in this report evaluated whether adding retrofit/heightened funnel fencing to the existing ROW fencing was effective in reducing EVC and facilitating wildlife movement across the highway corridor. Additionally, this project would demonstrate whether existing highway structures could effectively double as functional WCS. The specific objectives include:

- Compare pre- and post-fence reconstruction EVC rates and patterns along I-17.
- Compare pre- and post-fence reconstruction wildlife use of the existing Munds Canyon and Woods Canyon bridges.
- Document wildlife use of Schnebly Hill Road Traffic Interchange (TI) and Fox Ranch Road TI post-fence reconstruction.
- Compare pre- and post-fence reconstruction elk movement patterns and permeability along I-17 relative to fencing treatment area, adjacent area, and control areas.
- Evaluate cost and any issues pertaining to maintenance of elk fencing, electrified cattle guards, and escape measures.
- Develop general recommendations based on the results of the study.

CHAPTER 2: STUDY AREA

INTERSTATE 17 DESCRIPTION AND TRAFFIC VOLUMES

Located entirely within Arizona, I-17 is a 146-mi, four-lane divided highway that connects Phoenix and Interstate 10 at its southern terminus and Interstate 40 at its northern. Besides local traffic, I-17 is travelled each year by millions of people who visit the Grand Canyon and other Arizona parks and recreation areas. Much of I-17 through the study area exists as it was originally constructed in the mid-1970s—a two-lane road (State Route 79) which was then converted to a divided four-lane highway—although spot improvements have been made in the past 20 years.

Based on ADOT traffic data collected near Schnebly Hill Road TI (MP 319.4, Location ID 100383), I-17 AADT volumes from 2007 to 2013 through the study area were estimated at 16,692 vehicles/day (Figure 6). Based on the analysis of the continuous traffic counter, which was installed for *Elk Movements Associated with a High-traffic Highway: Interstate 17* (Gagnon et al. 2013) and then removed in 2011, traffic volumes were highest during daytime hours, with peak (14:00 to 16:00) hourly traffic approaching an equivalent AADT of 30,000 vehicles/day. Over the course of a full day, commercial trucks constituted an average of 26 percent of all traffic, but between 01:00 and 03:00 trucks accounted for half the vehicles travelling I-17, which highlights the highway's important role in the transport of goods. Traffic volume was highest from Friday to Sunday, averaging 19,242 vehicles/day compared to the rest of the week at 14,614 vehicles/day.

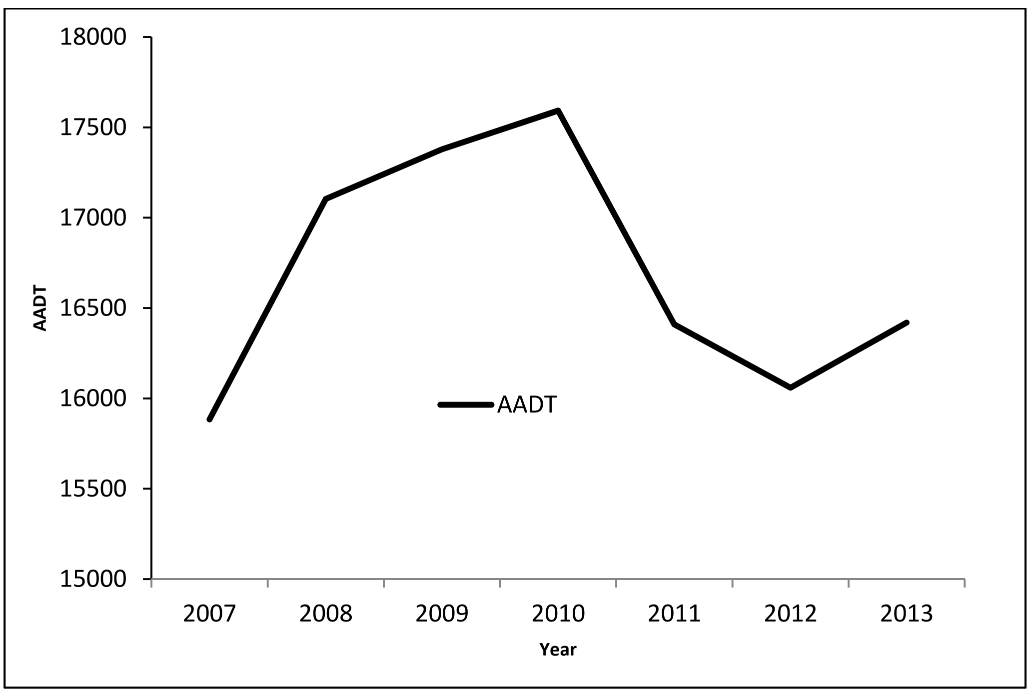


Figure 6. Estimated Average Annual Daily Traffic Through the Study Area from 2007 to 2013 (ADOT Transportation Data Management System 2015)

LAND OWNERSHIP, NATURAL SETTING, AND CLIMATE

The study area is located in the higher elevation summer range of elk (circa 6,500 ft). The land adjacent to I-17 is predominately (over 90 percent) managed by the United States Forest Service Coconino National Forest (CNF) with some small privately owned parcels. The climate is semi-arid, with hot summers, cool winters, and a strong bimodal precipitation pattern. July is the warmest month, with average highs of 90° F, and January the coolest, with average lows of 36° F. Average annual precipitation is 27.6 inches, and average winter snowfall is 37 inches. The vegetation within the study area is in the Petran Montane Coniferous Forest biotic community (Brown 1994, Spence et al. 1995), and ponderosa pine dominate the landscape. Many wet meadows are located along or adjacent to I-17, including Munds Park Golf Course; the locations of these wet meadows influence elk movements (Manzo 2006, Dodd, Gagnon, Boe, Manzo, et al. 2007, Gagnon et al. 2013).

WILDLIFE FENCING RETROFIT PROJECT

The northernmost 32.2-mi stretch of I-17, from Stoneman Lake Road to I-40, is located on the Mogollon Rim and passes through elk winter and summer habitat. This stretch has a high incidence of EVC, which account for 75 percent of all WVC (mean = 79.0 [standard error (SE) ± 7.3] EVC/yr accounting for 85.5 [SE ± 8.1] elk mortalities/yr; [Gagnon et al. 2013]).

Within this 32.2-mi stretch, the research team focused on a 7.9-mi portion: 5.9 mi of modified fenced highway and 2 mi of the adjacent fence end sections (the study area). The remaining 24.3 mi served as a control for the study. The 5.9 mi of highway included exclusionary fencing along the right-of-way and four structures (already described in Table 1) that could function as WCS — Munds Canyon and Woods Canyon bridges, Fox Ranch Road TI, and Schnebly Hill Road TI. The structures and the study area are mapped in Figure 7.

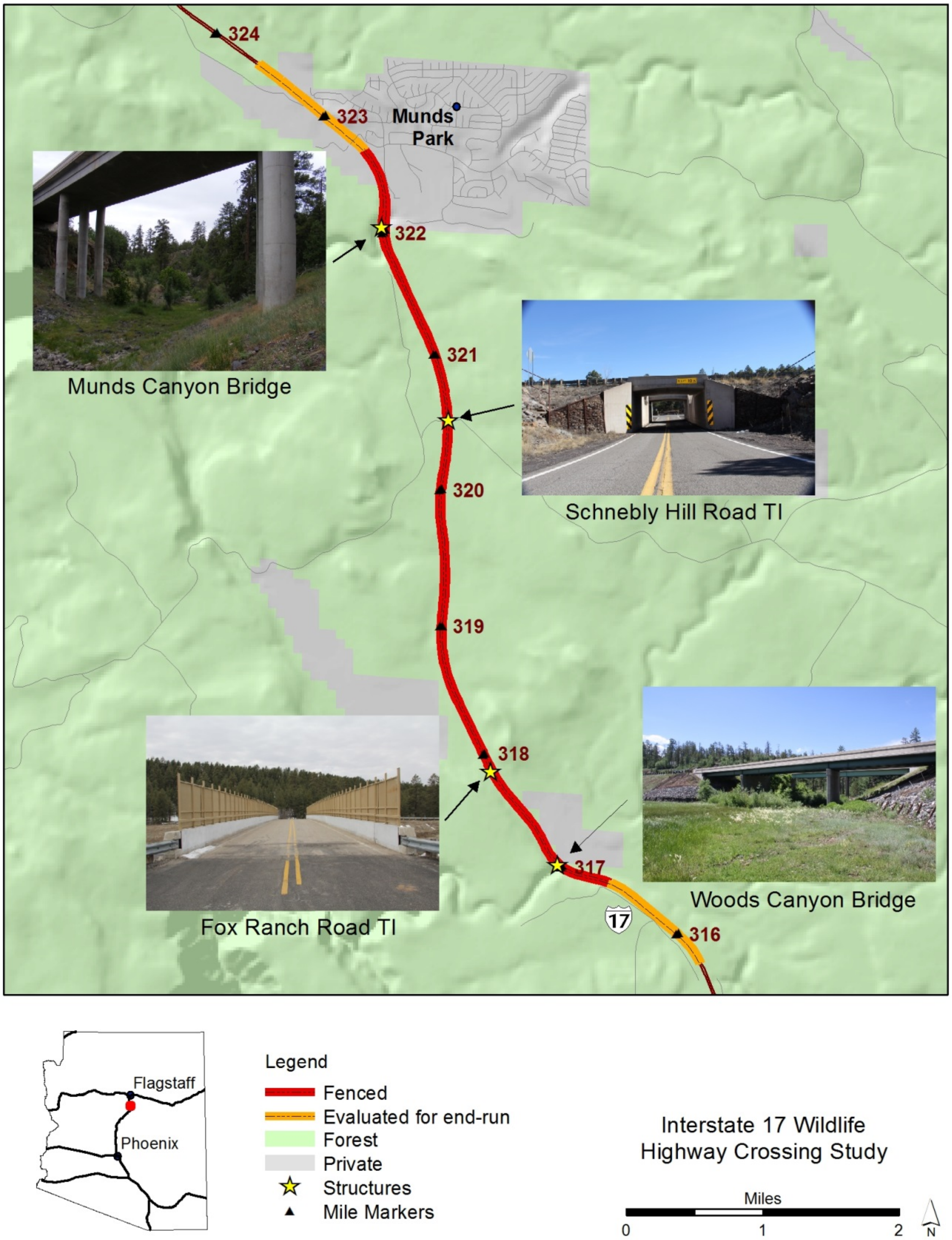


Figure 7. Enhanced Map of Study Area

In 2011, the 4-ft-high, four-strand barbed wire ROW fence along the study area was extended to a height of 7 to 8 ft by coupling new T-posts to the old T-posts with metal extension sleeves (Figure 8). To provide additional support, new steel corner posts, brace posts, and line posts were installed along with additional stays that connected the top wires to the bottom ROW fence. New T-posts and barbed-wire fencing were installed where the ROW fencing was too degraded to retrofit. The type of heightened fencing used had, in previous testing, reduced EVC by 97 percent (Gagnon et al. 2010) and was less expensive than woven wire.

Figure 8. Heightened Fencing along the Study Area: Metal Couplers Attached Extensions to Existing T-Posts (Top Panel); New 8-Ft-High Fencing Replaced Fencing that Was Too Degraded to Heighten (Bottom Panel)

To help elk escape being trapped in the ROW, ADOT installed jump-outs and slope-jumps (Figure 9) at various locations. Jump-outs (also referred to as escape ramps) are the most common method of allowing ungulates to exit the ROW and have shown some success with elk when properly designed and installed (Bissonette and Hammer 2000). Jump-outs consist of gradually sloping ramps made of natural materials that allow ungulates to jump down and out of the ROW while prohibiting them from jumping back in. Slope-jumps are a section of lowered fence positioned where the terrain slopes downward. The concept relies on elk's physical inability to jump uphill over the fence and into the fenced corridor; instead, elk jump more easily downslope. Slope-jump effectiveness, which has not yet been proven, is based on the concept of functional fence barrier height increasing with the slope steepness (Payne and Bryant 1994). Less expensive than jump-outs, this method requires the slope to be gradual enough that the animal is able to land without dropping too far, and steep enough that elk cannot easily jump up from the bottom.

Figure 9. Examples of Jump-out (Left) and Slope-jump (Right)

To block entry into the ROW and guide elk to the TI, ADOT installed electrified cattle guards at the on- and off-ramps of the Schnebly Hill Road TI and Fox Ranch Road TI (Figure 10). These electrified cattle guards give an elk a shock when stepped on, thereby deterring crossing. The cattle guard's electric current shuts off during daylight hours and a flashing LED (daytime only) indicates functionality. Although the cattle guard is safe for pedestrians wearing shoes, a deactivation button was installed to assure safe pedestrian crossing if needed. A similar electrified cattle guard installed along SR 260 in 2010 continues to show positive results in deterring access to the ROW, although further testing is needed (Gagnon et al. 2010, Huijser et al. 2015). To eliminate wildlife jumping off the Fox Ranch Road TI, ADOT erected a fence on the parapet, already shown in Figure 5d.

Figure 10. Electrified Cattle Guards Installed at Schnebly Hill Road TI (Left) and at Fox Ranch Road TI (Right; Guards Circled)

Preliminary camera data collected by ADOT in 2004 showed that elk and deer used Munds Canyon bridge (Figure 11), but there were no data on elk using either of the TIs or the Woods Canyon Bridge. To minimize the potential of “end runs” of the fence termini by elk, the northern terminus ended just beyond Munds Canyon Bridge, at a lighted TI, and the southern terminus was located just beyond Woods Canyon Bridge at large cliffs. This selection of termini allowed elk to encounter a suitable crossing structure prior to reaching the fence ends that were located in areas that hinder elk movements (Gulsby et al. 2011).

Figure 11. Elk Using Munds Canyon Bridge in 2004

CHAPTER 3: METHODOLOGY

ELK-VEHICLE COLLISIONS

To document EVC, the research team compiled Department of Public Safety (DPS) Collision Supplement Reports, AGFD Wildlife Vehicle Collision Reports, and ADOT Reports of Animal Hits into a database that included date, time, location (to the nearest 0.1 mi), species, sex, and reporting agency. The research team deleted duplicate reports, and defined pre-retrofit data as data collected between 2007 and 2010 and post-retrofit data as data collected between February 2012 and February 2014. The researchers did not include 2011 in the evaluation because the fence was being retrofitted during this time and there were large gaps in the fencing. For EVC analysis, the research team additionally evaluated the 1.0-mi section beyond the fence limits to determine if elk were crossing the road beyond the fence termini (Bellis and Graves 1971, Ward 1982, Clevenger et al. 2001b, McCollister and van Manen 2010, Bissonette and Rosa 2012). The remaining 24.3 mi (10.0 mi south and 14.3 mi north) was used as the control section to compare to areas within the exclusionary fence project.

To supplement the EVC analysis and provide a more consistent evaluation of WVC trends over time that were independent of research efforts, the team calculated rates of WVC based on DPS vehicular collision reports. DPS responds to and reports crashes with wildlife that result in motorist injury or significant property damage as an “Animal_Wild_Game” incident. Crashes reported by DPS do not differentiate species, but generally involve larger animals. Using DPS response data the research team compared rates of “Animal_Wild_Game” in the treatment, fence end, and control sections before and after fencing.

ELK USE OF EXISTING STRUCTURES

To determine elk use of existing structures, the research team installed Reconyx® Professional Model single-frame cameras under the structures. The primary objective was to document the number of elk and other species that used the Munds Canyon and Woods Canyon bridges before and after fencing-retrofit, and the Fox Ranch Road TI and Schnebly Hill Road TI after the fencing retrofit. The research team felt the two bridges selected for fencing retrofit would provide some level of elk connectivity while reducing the high levels of EVC experienced along the study area. The modification of the two TI was an experimental opportunity to investigate the level of adaptability of elk while providing additional potential crossing opportunities. Each bridge required multiple cameras to photograph the crossing area, while each TI needed only one camera. To minimize vandalism, the research team mounted the bridge cameras roughly 12 ft high (Figure 12).

Given the large expanses of the bridges, the research team was not able to derive passage rates, also more recently referred to as success rates (Dodd, Gagnon, Boe, et al. 2007a, Cramer 2013). Passage rates are used as a quantitative metric of the relative effectiveness of WCS independent of variation in species distributions. The objective was not to assess functionality among structures, but to assess changes in utilization at each structure across time (pre- and during- retrofit versus post-retrofit). Therefore, given the reasonable assumption that species distributions remained constant, direct crossing rates are a valid measure of relative pre- versus post-retrofit utilization. Additionally, to evaluate wildlife interaction at jump-outs, slope-jumps, and electrified cattle guards, the research team installed cameras at three jump-outs, three slope-jumps, and four electrified cattle guards (Figure 12).

Figure 12. Examples of Camera Orientations at Munds Canyon Bridge (Upper Left); Schnebly Hill Road TI (Upper Right); Jump-out Near MP 320 (Lower Left); Electrified Cattle Guard at Schnebly Hill Road TI (Lower Right)

ELK HIGHWAY PERMEABILITY AND CROSSING DISTRIBUTION

To determine whether elk movements or highway permeability changed, the research team compared pre-retrofit (2008 to 2010) and post-retrofit (2012 to 2013) GPS telemetry data. The team captured elk using modified Clover traps (Clover 1954) baited with salt and alfalfa hay within the study area and 1.0 mi beyond the termini. The team physically restrained and fitted elk with a combination of Telonics, Inc., Model TG3 and Model TG4 store-on-board and Model SST-TG3 Spread Spectrum GPS collars programmed to receive eight relocations per day at 2-hr intervals—between 17:00 and 07:00, when elk were most active—for approximately two years (Figure 13). After two years, a pre-programmed release mechanism allowed the collars to fall to the ground, and they were located and retrieved using VHF telemetry. Following download of the data from the collars, the researchers used ArcGIS Version 10

Geographic Information System software for GPS data analysis, which the team used during previous projects (Dodd, Gagnon, Boe, Manzo, et al. 2007, Dodd, Gagnon, Boe, et al. 2007b, Dodd, Gagnon, Sprague, et al. 2012, Gagnon et al. 2013).

Figure 13. Capture of Elk along Interstate 17: Processing an Elk in a Clover Trap (Left) and Release of Collared Elk to Begin Data Collection (Right)

The research team calculated a mean passage rate for elk in the fenced retrofitted section, fence end sections, and control sections (Dodd, Gagnon, Boe, et al. 2007b). To calculate passage rates, the team determined the ratio of crossings to approaches. An approach occurred when an animal traveled from a point outside a 0.15-mi buffer zone to a point within 0.15 mi of I-17, as determined by successive GPS fixes (Figure 14). The approach zone corresponded to the road-effect zone associated with traffic-related disturbance (Rost and Bailey 1979, Forman and Deblinger 2000), which had previously been used for elk along I-17 and other Arizona highways (Dodd, Gagnon, Boe, et al. 2012, Dodd, Gagnon, Sprague, et al. 2012, Gagnon et al. 2013). Animals that traveled from a point beyond 0.15 mi and crossed I-17 were counted as an approach and a crossing. The research team calculated passage rates as the proportion of highway crossings to approaches for elk that had at least four approaches to I-17. The research team used Mann-Whitney *U* tests (Sokal and Rohlf 2003) to test the null hypothesis that no differences occurred between pre-retrofit measurements (crossings, approaches, and passage rates) and post-retrofit measurements. Additionally, the research team compared the proportion of all crossings associated with the fenced retrofitted section, existing structures, and 1.0-mi areas beyond the fence ends.

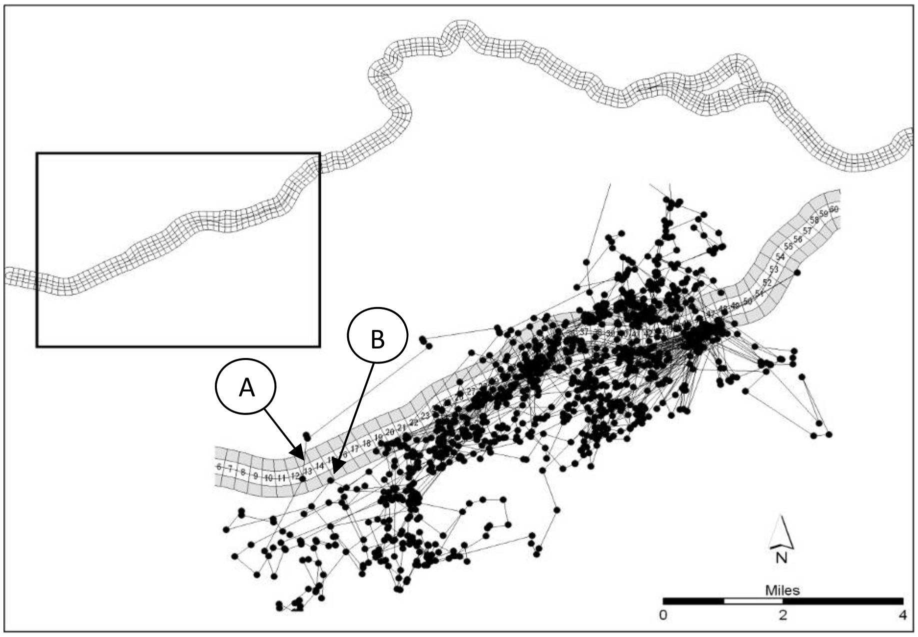


Figure 14. GPS Elk Locations and Lines Between Successive Fixes to Determine Highway Approaches and Crossings in 0.1-mi Segments

Note: The expanded section shows GPS locations of elk and the lines between successive fixes used to determine approaches to the highway (shaded band) and crossings (clear numbered bands). Example A denotes an elk approach and crossing; Example B denotes an approach without a crossing.

PROJECT COSTS AND MAINTENANCE

Huijser et al. (2009) produced one of the most recent and thorough applications of calculating the cost versus benefit of various types of mitigation measures. More importantly, it is one of the few efforts to apply a cost-benefit to EVC. To evaluate the cost-effectiveness of this project, the research team compared the 2007 to 2010 pre-retrofit costs of EVC (Huijser et al. 2009) to the reduced costs of EVC avoided post-retrofit (2012 to 2013) to derive a benefit to society, and the time in years when the benefit realized by the fencing would exceed its cost.

The team used data from ADOT's Performance Control Systems (PeCoS) IV database to document differences in maintenance costs between the retrofit fence and standard ROW fence. This database is used to record and report the labor hours and equipment and materials costs spent on maintenance activities. The research team compared total costs of maintenance for the study area for the four years before and two years after the fencing retrofit. Additionally, the team compared maintenance costs in an adjacent comparable control section (MP 323 to 329) for two years following fence construction to those incurred on the retrofit section.

CHAPTER 4: RESULTS

ELK-VEHICLE COLLISIONS

During the two-year post-retrofit WVC monitoring (February 8, 2012, to February 8, 2014) the research team documented nine WVC within the retrofit section: six mule deer, two black bears, and one elk. These numbers showed a 97.5 percent reduction in EVC compared to the 2007 to 2010 pre-retrofit mean 20.3 EVC/yr, on average (Figure 15 and Table 2). The researchers also found a 55.6 percent EVC reduction within the 1.0-mi segments adjacent to the study area, whereas the remaining 24.3 mi control sections showed a 5.3 percent reduction (Table 2). The research team also noted that within the study area, there was a 50 percent decrease in deer-vehicle collisions (DVC)—from 3.0 to 1.5 DVC/yr, on average—even though the retrofitted-fence did not restrict deer as well as it did elk.

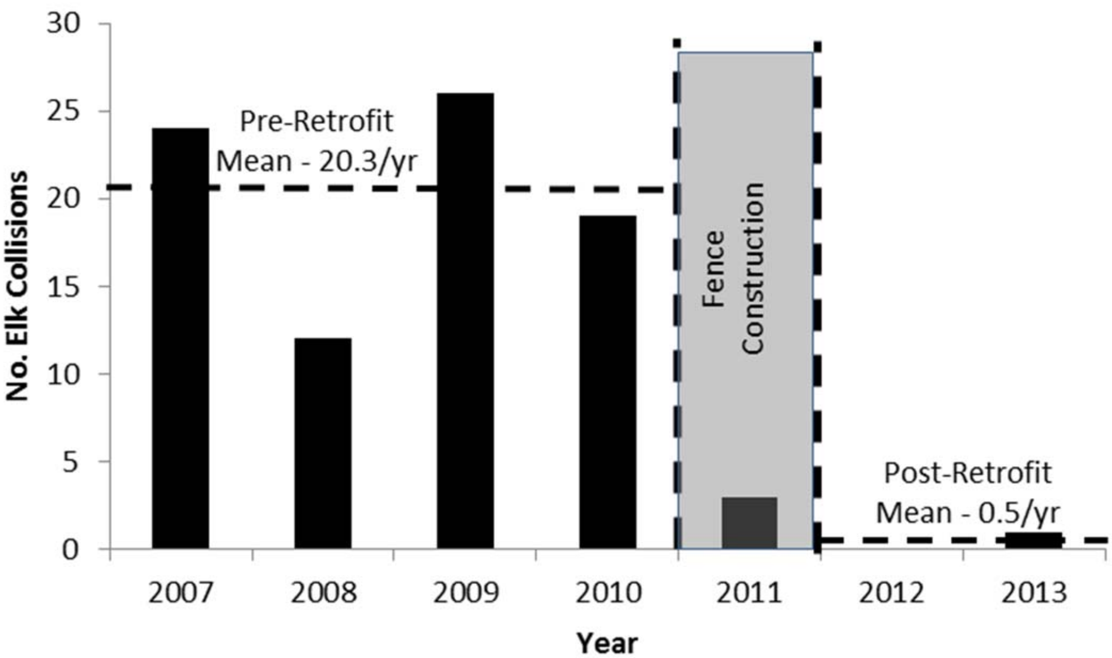


Figure 15. Number of Elk-Vehicle Collisions by Year Before, During, and After Fencing Retrofit Along Study Area of Interstate 17 (2007 to 2013)

Note: Bars indicate total number of elk-vehicle collisions, horizontal dashed lines indicate mean number of collisions, vertical dashed lines show construction timeline.

Table 2. Frequency of Elk-Vehicle Collisions and "Animal_Wild_Game" Responses Collected by AGFD, ADOT, and DPS Before and After Study Area Fencing (2007 to 2013)

Year[1]	I-17 Fenced Sections (5.9 mi)			I-17 Fence End Sections (2.0 mi)			I-17 Control Sections (24.3 mi)	
	EVC	DPS Response[2]		EVC	DPS Response		EVC	DPS Response
Before Fencing Retrofit								
2007	24	21		3	3		68	39
2008	12	10		6	6		79	47
2009	26	14		3	4		62	50
2010	19	9		6	4		40	33
Total	81	54		18	17		249	169
Mean	20.3	13.5		4.5	4.25		62.3	42.25
After Fencing Retrofit								
2012	0	0		3	3		64	37
2013	1	3		1	3		54	48
Total	1	3		4	6		118	85
Mean	0.50	1.5		2	3		59	42.5
% Change	-97.5%	-88.9%		-55.6%	-29.4%		-5.3%	0.59%

[1]2011 Transition Year – Fence Construction – excluded from this analysis
[2]DPS Crash Data do not differentiate elk from other wildlife

In 2007 to 2010, prior to fencing, DPS responded to 54 WVC (13.5/yr, on average) in the study area, 17 WVC (4.25/yr, on average) in the fence end sections, and 169 WVC (42.25/yr, on average) in the control sections (Table 2). Following the fencing retrofit, the research team documented three WVC (1.5/yr, on average) within the fenced sections, six WVC (3/yr, on average) in the fence end sections, and 85 WVC (42.5/yr, on average) in the control sections. These numbers showed decreases of 88.9 percent in the fenced sections and 29.4 percent in the fence end sections, and a nominal 0.59 percent increase in the control sections (Table 2). For comparison, supplemental DPS records showed officers responded to 2,214 crashes along the entirety of the 32.2 mi stretch on I-17 from 2007 through 2013, 378 (17 percent) of which involved "Animal_Wild_Game" or WVC.

ELK USE OF EXISTING STRUCTURES

To document changes in structure use before and after fencing, the research team used 19 months of camera data prior to and during fence construction, and 19 months of camera data captured after the fencing retrofit. During the 38 months, the cameras detected a total of 3,150 bridge crossings by 14 species (Table 3); 2,340 of these bridge crossings were by elk . Bridge use by non-target species included 435 crossings by deer (416 mule deer, 19 white-tailed deer), 269 crossings by mesocarnivores (20 bobcats, 12 coyotes, 42 gray foxes, 188 raccoons, six skunks, and one ringtail cat), and four crossings by large carnivores (three mountain lions and one black bear), as highlighted in Figures 16 through 18. Other wildlife species crossings recorded included two javelinas, 94 rock squirrels, five mallard ducks, and one great blue heron. Non-wildlife crossings included 79 cattle, 34 dogs, eight house cats, six unidentified animals, and multiple pedestrians.

Table 3. Wildlife Use of Munds Canyon and Woods Canyon Bridges over 38 months (2010 to 2013)

Number of Crossings	Elk	Deer	Mesocarnivores	Large Carnivores	Other	All
Munds Canyon	2,270	358	225	4	58	2,915
Woods Canyon	70	77	44	0	44	235
Total	2,340	435	269	4	102	3,150

At the Munds Canyon and Woods Canyon bridges, the research team documented an increase in elk crossings following installation of the retrofit fencing (Figure 19). At Munds Canyon Bridge, the larger of the two, researchers documented 545 elk crossings pre-retrofit and 1,725 elk crossings post-retrofit, a 217 percent increase. At Woods Canyon Bridge, the team documented 26 elk crossings pre-retrofit and 44 crossings post-retrofit, a 54 percent increase.

Incidentally, although deer were not the study's focal species, the research team documented a 69 percent (n = 358 and 350 percent (n = 77) increase in deer use of Munds Canyon and Woods Canyon bridges, respectively, following the retrofit. During the 24 months following retrofit completion, the research team documented no ungulates crossing the TI structures, although one raccoon and one coyote crossed.

Figure 16. Elk Using Munds Canyon and Woods Canyon Bridges

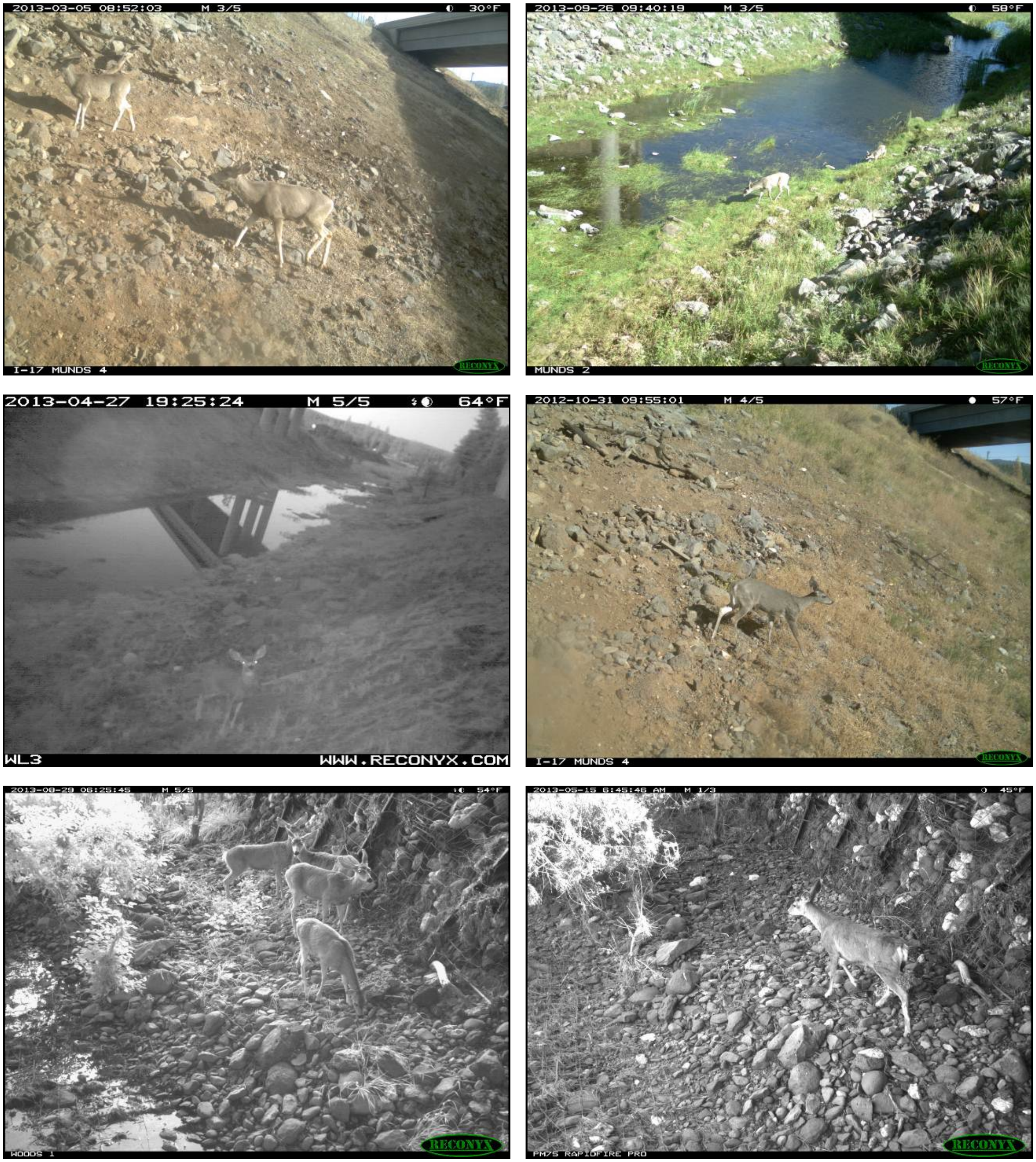


Figure 17. Deer Using Munds Canyon and Woods Canyon Bridges

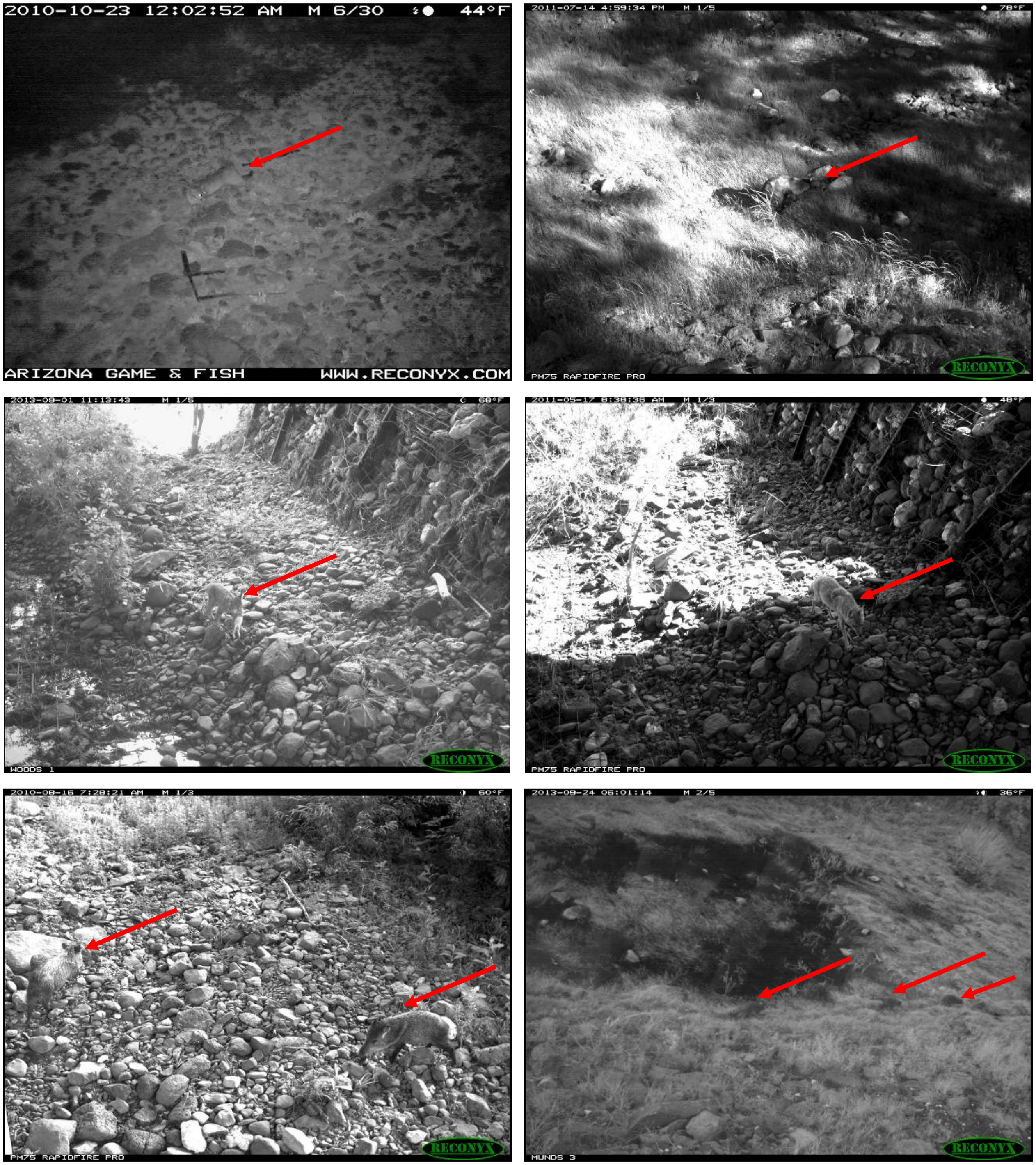


Figure 18. Wildlife Using Munds Canyon and Woods Canyon Bridges (Red Arrows), Clockwise from Top Left: Cougar, Black Bear, Coyote, Raccoon, Javelina, Bobcat (with Rabbit in Mouth)

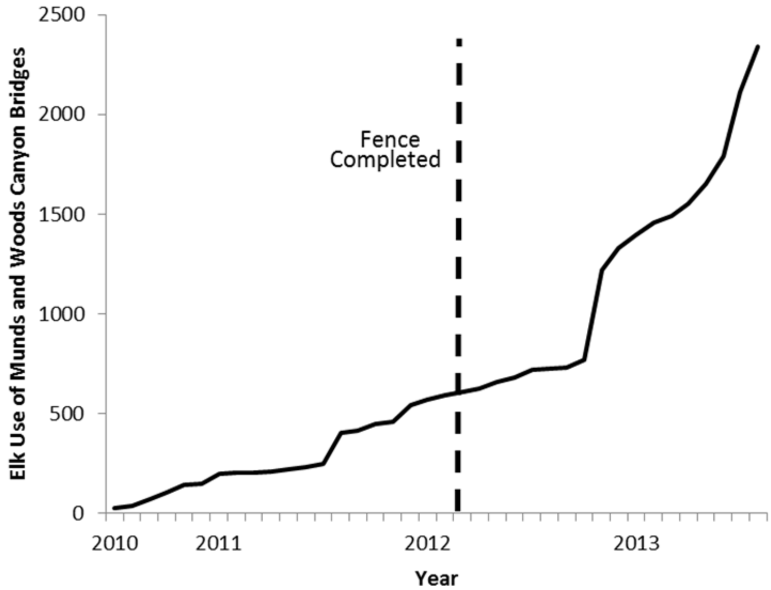


Figure 19. Elk Crossings Under Munds Canyon and Woods Canyon Bridges Before (19 Months) and After (19 Months) Fencing Retrofit of the Study Area

The research team's monitoring of jump-outs and electrified cattle guards provided minimal information on their effectiveness. Overall, few animals interacted with jump-outs and electrified cattle guards (Figure 20). The data being collected from jump-outs and cattle guards along I-17 (combined with data from SR 260, U.S. Route 93, and a test site near Payson, Arizona) will provide information for the "Gaps in Knowledge" identified in the NCHRP 25-25, Task 84 *Construction Guidelines for Wildlife Fencing and Associated Escape and Lateral Access Control Measures* (Huijser et al. 2015).

Figure 20. Along Study Area: Elk Using Jump-out to Escape Right-of-Way (Top); Mule Deer Experiencing Shock from Electrified Cattle Guard (Bottom)

ELK HIGHWAY PERMEABILITY AND CROSSING DISTRIBUTION

GPS collar data collected from 2007 to 2011 along I-17 where the fence was later retrofitted showed that the 33 collared elk (collared for approximately two years each) had a mean of 67.61 (SE±11.53) approaches and a mean of 4.30 (SE±1.12) crossings per elk (Gagnon et al. 2013). The mean passage rate for all elk along the study area prior to fencing was 0.07 (SE±0.02) crossings/approach.

The research team also obtained GPS data from 32 elk that wore collars after the retrofit for an average of 483.29 (SE±25.73) days (Figure 21). These collared elk crossed the highway 103 times (a mean of 3.32 crossings per elk) from 2012 to 2014, with 13 crossing the highway at the study area; crossings within the study area dropped to 2.38 (SE±1.01) crossings per elk, a 44.65 percent decrease from the 2007 to 2011 mean. Following retrofit, the mean number of approaches did not differ significantly (82.72 ±9.59 approaches; n =29) as shown in Table 4. The mean passage rate within the study area was also reduced to 0.03 (SE±0.01) crossings per approach, which represents a 57.14 percent reduction (Table 4).

A similar comparison of pre- and post-retrofit passage rates within the 1.0-mi fence end sections showed a 66.67 percent reduction, from 0.03 (SE±0.02) to 0.01 (SE±0.01) crossings per approach. However, the control sections showed a 28.57 percent increase in passage rate; 0.07 (SE±0.01) prior to the retrofit, and 0.09 (SE±0.04) after the retrofit. In all cases, the differences were not significant (Table 4).

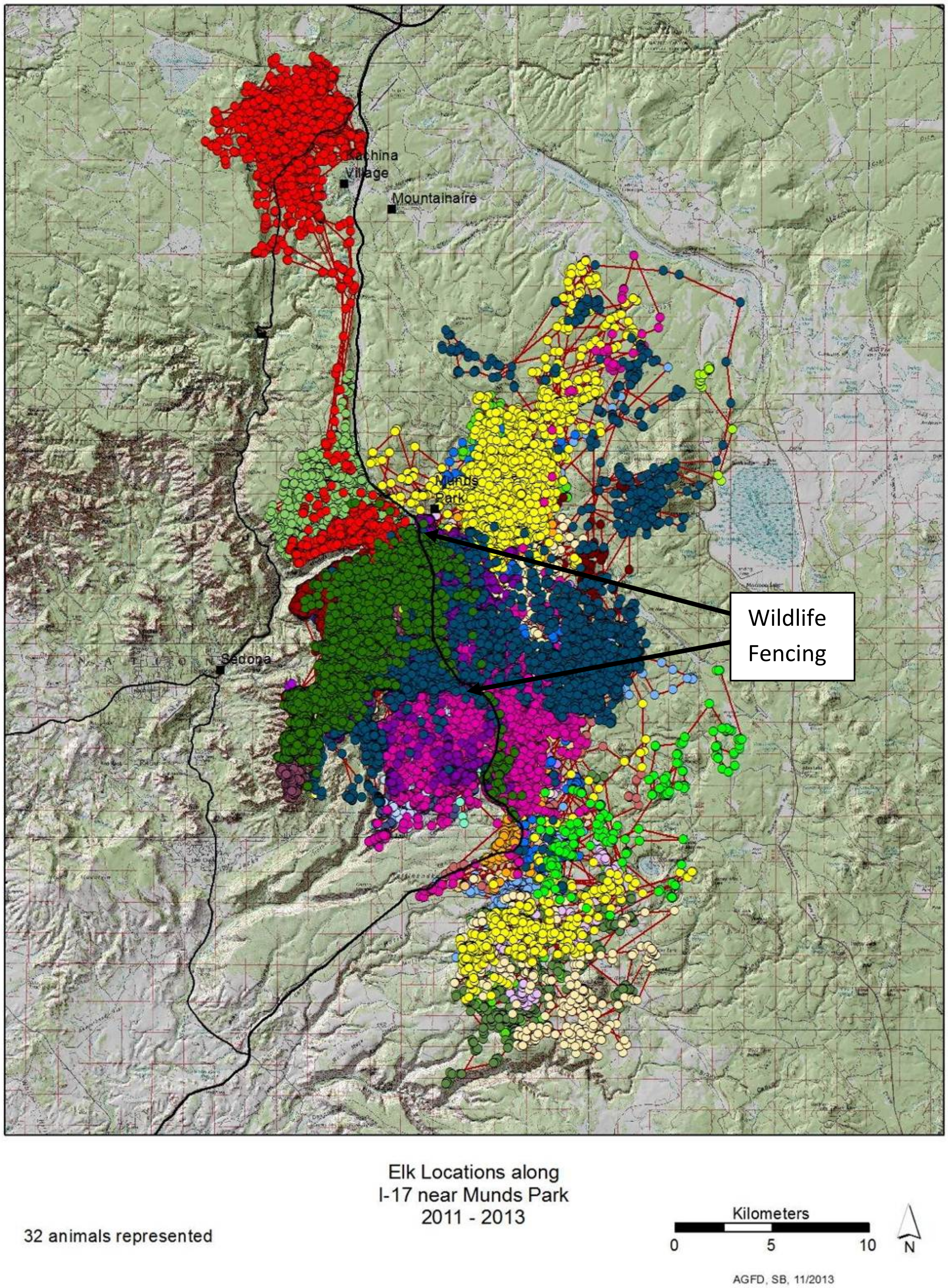


Figure 21. GPS Data from 32 Collared Elk in the Fencing Retrofit Area and 1.0-mi Fence End Sections (Milepost 315.8 to 323.7)

Note: Each color represents an individual elk, and each dot represents a location every 2 hours from 17:00 to 7:00.

Table 4. Comparison of GPS Determined Elk Highway Crossings, Approaches, and Passage Rates along Interstate-17 Before and After Fence Modification (2010 to 2014)

		Mean (±SE)[1]			
	Parameter	**Before Fencing Retrofit**	**After Fencing Retrofit**	**Difference (%)**	**Mann-Whitney *U*-Test Comparison of Means**
Fenced Sections	No. highway crossings/elk	4.30 (1.12)	2.38 (1.01)	-44.65	*U* = 397.5, *P* = 0.224
	Highway approaches/elk	67.61 (11.53)	82.72 (9.59)	+22.35	*U* = 597, *P* = 0.224
	Passage rate (crossings/approach)	0.07 (0.02)	0.03 (0.01)	-57.14	*U* = 405, *P* = 0.271
Fence End Sections	No. highway crossings/elk	0.55 (0.29)	0.33 (0.22)	-40.00	*U* = 115, *P* = 0.800
	Highway approaches/elk	26.10 (4.63)	26.0 (4.54)	-0.38	*U* = 126, *P* = 0.830
	Passage rate (crossings/approach)	0.03 (0.02)	0.01 (0.01)	-66.67	*U* = 114, *P* = 0.753
Control Sections	No. highway crossings/elk	6.67 (1.80)	1.80 (0.76)	-73.01	*U* = 302, *P* = 0.190
	Highway approaches/elk	68.69 (9.65)	34.10 (8.47)	-50.36	*U* = 259.5, *P* = 0.061
	Passage rate (crossings/approach)	0.07 (0.01)	0.09 (0.04)	+28.57	*U* = 352.5, *P* = 0.630

[1]Elk were collared for approximately 2 years

The research team noted a shift in the distribution of GPS-collared elk highway crossings at the bridges in the study area before and after the fencing retrofit (Figure 22). The highest peak was at Munds Canyon Bridge with another smaller peak at the Woods Canyon Bridge. In the total study area between the bridges (MP 317.0 to 322.0), the proportion of crossings prior to the retrofit (0.32) did not differ substantially following the retrofit (0.38). The two TIs lacked suitable crossings before and after fencing. No significant peaks in elk crossing distributions occurred at either fence end (Figure 22).

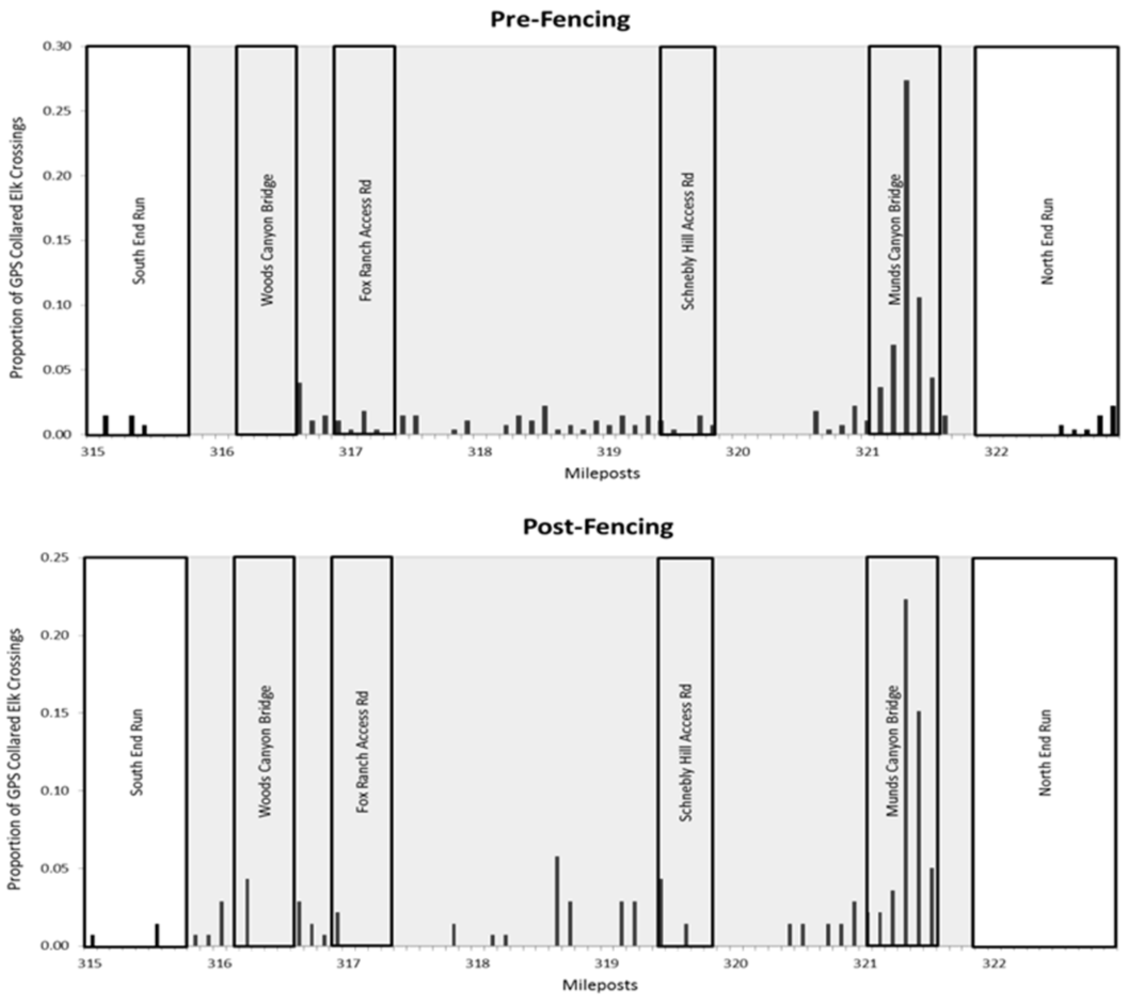


Figure 22. Proportion of Elk Crossings along Study Area Before Fencing Retrofit (2006 to 2010) and After Retrofit (2012 to 2013)

Note: GPS collar data collected for 7.9 mi (5.9 mi fencing retrofit, 1.0 mi beyond each fence end). Gray shading indicates fenced retrofit section. Black boxes depict class bins attributed to existing structures and fence end sections.

COST AND MAINTENANCE

Huijser et al. (2009) calculated the mean cost to society of an EVC as $17,483. Pre-retrofit, the annual mean cost along the study area, which averaged 20.3 EVC a year, was $354,905. In the first two years following the fence retrofit, the research team documented a single EVC, or $8,742/yr; this 97.5 percent decrease in EVC represented an economic benefit of $346,163/yr. The total cost of the fencing project was $1.66 million; thus, if all remains constant, the project will pay for itself in less than five years. Additionally, numerous serious human injuries and possibly even deaths were and will be avoided, and elk habitat connectivity was maintained.

Maintenance activities on the retrofitted fence during the first two years of the project consisted of similar tasks to that of maintaining standard ROW fencing, and included removing fallen trees, repairing cut wires and washouts, and standard yearly inspections. The research team assisted with identification of maintenance needs, and where possible, assisted with repairs. The PeCoS data analyzed by the research team and ADOT maintenance personnel indicated that time spent maintaining the wildlife exclusionary fencing in the study area did not substantially exceed that of the adjacent areas. The maintenance cost for the fenced section following construction (2012 through 2014) was $3,479.31 ($1,739.65/yr, on average), versus the pre-retrofitting (2007 through 2010) cost of $8,437.16 ($2,812.39/yr, on average), indicating a 36.8 percent decrease in yearly maintenance costs. For comparison, from 2012 through 2014 a 6.0 mi-section of the study's control (MP 323.0 to 329.0, adjacent to the study area) with standard ROW fencing had a maintenance cost of $4,133.91 ($2,066.96/yr, on average), or 18.81 percent higher than the study area (see Chapter 6: Conclusions and Recommendations, for caveats).

The research team noted additional maintenance concerns associated with jump-outs. Cinders used for backfill at the jump-outs began sloughing off the face of the gabion baskets, creating piles at the base of the jump-outs. In these instances, not only were gabion basket tops exposed, which deterred elk use in the proper direction, but the piles also provided an elevation that allowed elk easier access to the top of the ramp and entrance to the ROW. After noting a couple of instances where elk accessed the ROW through the jump-outs via these mounds, the research team removed the mounds and elk ceased using the jump-outs in the wrong direction. Future maintenance will need to address these issues more permanently (see Chapter 6: Conclusions and Recommendations).

Maintenance of the electrified cattle guards was conducted by CrossTek LLC and will continue through 2017, at which point maintenance responsibilities transfer to ADOT. Aside from regular checking of voltage to ensure proper function, maintenance activities have consisted of the replacement of a cracked composite board and brass conductive strip that were likely damaged during plowing. CrossTek LLC did notice reduction in voltage when ADOT applied snow melting chemicals to the road; however, few elk were seen in these areas during heavy snow.

CHAPTER 5: DISCUSSION

In this study, elk exclusion fencing linking existing structures reduced EVC by 97.5 percent. Habitat connectivity, although minimal, was maintained by the use of the large bridges, particularly the Munds Canyon Bridge. GPS movement showed no significant change in the ability of elk to cross I-17, but did show an increase in elk use at the Woods Canyon Bridge. Elk crossings and EVC rates did not increase at the fence termini, suggesting that elk movement patterns after the fence installation did not result in an "end run" effect. The research team determined that the benefit realized through reduced EVC would exceed the cost of implementing mitigation measures in less than five years. Although this project reduced EVC at a relatively low cost while still allowing elk to cross I-17, several caveats need to be considered before using these types of fencing and structures on other highways.

ELK-VEHICLE COLLISIONS

Although the research team showed a significant reduction in EVC, they still documented elk in the ROW on multiple occasions. The fencing used for this project was not the typical 8-ft woven-wire fencing employed to exclude animals from roadways; instead, ADOT heightened the existing barbed-wire cattle exclusion fence, and the elk that entered the ROW likely pushed their way between the fence wires. The research team selected this fence type for the lower cost and the fence's tested ability to exclude elk without hindering other wildlife movements (Gagnon et al. 2010). AGFD and CNF biologists felt it was important to avoid hindering the movements of smaller wildlife because existing structures were not spaced appropriately (Bissonette and Adair 2008). For example, Bissonette and Adair (2008) recommend spacing crossings approximately every 1.1 mi for mule deer versus 2.2 mi for elk based on their natural home range sizes. For smaller, shorter ranging, and less mobile species, the distances between crossings would have to be even less than for mule deer.

The ROW in the study area of I-17 also lacks resources that elk are often attracted to; vegetation along I-17 was not substantially preferable to the surrounding habitats during most of the year, the Munds Canyon and Woods Canyon bridges allow access to water and riparian areas, and elk have adjusted their migration patterns to parallel I-17. However, these conditions will not be commonly shared, and elk will have greater motivations in other areas to cross into the ROW. In cases where these motivations to cross exceed the deterrent of the barrier effect of a highway, standard 8-ft woven-wire ungulate-proof fence has been proven effective in keeping ungulates off highways when combined with WCS. It is essential when using any type of fencing to also connect newly built WCS or existing structures (Clevenger and Waltho 2000, Bissonette et al. 2008, Gagnon et al. 2011, Sawyer et al. 2012).

Appropriate siting of exclusion fence termini is critical to minimize concentrated "end runs" (Bellis and Graves 1978, Clevenger et al. 2001b, McCollister and van Manen 2010, Gulsby et al. 2011). The research team did not detect an increase in EVC at the fence ends; this suggests that locating the ends within a short distance of suitable existing (or newly built) structures and immediately beyond the structures that elk would otherwise avoid was appropriate. As an alternative to locating exclusion fencing termini at structures or specific avoidance areas, fencing can be extended well beyond areas of WVC. Bissonette and Rosa (2012) noted that a lack of increased collisions at fence termini was attributable to extending fences beyond collision hotspots. Ward (1982) noted that an increase in DVC at the end of newly constructed ungulate-proof fence in Wyoming was mitigated by constructing an additional 1 mi of fencing. In all of these cases, including this research study, the success of the exclusion fencing hinged on the presence of WCS or existing structures within the fenced area. Installing exclusion fencing without the presence of usable crossing structures is less effective at excluding wildlife from the road (Bellis and Graves 1978, Falk et al. 1978, Feldhamer et al. 1986).

ELK PERMEABILITY AND USE OF EXISTING STRUCTURES

In 2012, prior to the fencing retrofit in the study area, elk passage rates were an already low 0.09 crossings/approach for the overall 32-mi highway corridor, and 0.07 crossings/approach for the eventual study area (Gagnon et al. 2013). Low passage rates prior to fencing indicate an impediment caused by vehicular traffic. Roads with traffic volumes that exceed 10,000 vehicles/day can quickly become a significant barrier to wildlife (Iuell et al. 2003, Seiler 2003); as this stretch of I-17 has AADT volumes that exceed 16,000 vehicles/day, the traffic volume likely provides a substantial barrier to elk movements and acts as a "moving fence" (Bellis and Graves 1978). Although elk are a highly mobile species, it appears there is a threshold of traffic along higher volume highways like I-17 that, when exceeded, severely reduces elk crossings. Highways with higher levels of traffic often also have multiple lanes in each direction, and the configuration of the highway and size of the median may also affect the likelihood of wildlife crossings.

Interestingly, elk along I-17 were able to overcome this traffic impediment by crossing at Munds Canyon Bridge and in areas where lanes were separated by medians nearly 0.5 mi wide (Gagnon et al. 2013). At these wide medians, elk were essentially crossing two separate highways, each with traffic volumes of approximately 8,000 AADT, versus the remainder of I-17, when lanes were bundled or close together, presenting a combined traffic volume of 16,000 AADT and consequently an elk passage rate of 0.07 crossings/approach (Jaeger et al. 2005). As a comparison, along two-lane segments of SR 260 with approximately 8,000 AADT, elk exhibited a passage rate of 0.81 crossings/approach (Dodd, Gagnon, Boe, Manzo, et al. 2007, Gagnon, Theimer, Dodd, Boe, et al. 2007).

Some researchers suggest avoiding fencing when species show high road avoidance (Jaeger and Fahrig 2004). Elk along I-17 appear to show higher road avoidance than elk along other highways in Arizona (Dodd, Gagnon, Boe, et al. 2007b, Dodd, Gagnon, Sprague, et al. 2012); however, the animals that do attempt to cross face a high probability of mortality. Gagnon et al. (2013) noted that though frequent crossers accounted for only 8.4 percent of the collared elk, they accounted for 60.0 percent of the EVC that involved collared elk along I-17. Jaeger and Fahrig (2004, page 1651) suggest the use of fences in locations where " …traffic is so high that animals almost never succeed in their attempts to cross the road." This appears to be the case for elk along I-17, and combined with the severe risks of EVC to motorists, fencing is warranted even where elk show some level of road avoidance. With the increase in use of Munds Canyon and Woods Canyon Bridges documented by the research team, it appears those "pioneer" elk that still attempt to cross I-17 along the study area have been directed to the existing WCS by the exclusionary fencing.

Although the research team did not document a significant change in elk ability to cross the road, this should not be taken to mean that exclusion fencing linking existing structures or WCS will not impinge upon the ability of wildlife to cross the road. Besides adequate fencing, existing structures or WCS need to be properly located, designed, and sufficiently sized. Improperly designed structures reduce the ability of wildlife to cross roads even if they are linked with funnel fencing. During this study, elk did not use the two TIs along the study area either before or after the fencing was installed. Even the Woods Canyon Bridge, a relatively large structure (in terms of width and height) that showed a 54 percent increase in elk use (from 26 to 44 animals), was inferior to the larger Munds Canyon Bridge that allowed 1,725 elk passages after completion of the retrofit. In previous studies, elk were also initially reluctant to use even larger, more open structures (Dodd, Gagnon, Boe, et al. 2007a, Gagnon et al. 2011).

Given that elk require time to adapt to structures, it is likely that use of Woods Canyon Bridge will increase (Clevenger and Waltho 2003, Gagnon et al. 2011), but this does not imply that elk will use all structures over time as the animals appear to have a lower tolerance for smaller structures than mule deer or white-tailed deer (Gagnon et al. 2011, Sparks and Gates 2012, Cramer 2013). Connecting fencing to existing structures translates to greater success in promoting connectivity for species that have a higher tolerance for marginal structures, but even these more accepting species can reach a threshold where they become unwilling to cross (Gordon and Anderson 2003, Sparks and Gates 2012, Cramer 2013). This reluctance to cross can lead to animals jumping the fence, forcing their way through or under the fence at gaps, or traversing the end of the fence, creating an “end run.” If animals cannot adapt to the structure or negotiate the fence, in extreme cases they can be confined to a seasonal range where they cannot survive year-round (Patricia Cramer, personal communication, 2014). Thus, before retrofitting structures, it is necessary to evaluate structure size and design in relation to the species of concern while also balancing these decisions with considerations for motorist safety.

To address both WVC and highway permeability concerns in the study area, as well as along the entire 48-mi stretch of I-17 where a large number of EVC have been documented, ADOT should consider the inclusion of WCS and fencing in future planning. Recommendations to accompany the initial environmental assessment and DCR are outlined in the ADOT report *Elk Movements Associated with a High-traffic Highway: Interstate 17* (Gagnon et al. 2013). Based on prior successes from Arizona and other states and countries, it is anticipated that having WCS in place would reduce collisions with wildlife by over 90 percent, and would substantially increase permeability .

PROJECT COSTS AND MAINTENANCE

Huijser et al. (2009) determined that a pre-mitigation level of 1.2 EVC/km/yr (converted to 1.2 EVC/0.62 mi/yr) is the break-even point to justify wildlife fencing and underpasses over a 75-year period; this means the reduction of one EVC/km/yr over a 75-year period will justify the cost of underpasses and fencing for a stretch of road. Any further reduction is considered a surplus savings benefit. The study area experiences 2.21 EVC/km/yr, approaching twice the justification level. In addition, the research team excluded the costs of the underpasses from this comparison since ADOT utilized existing drainage structures, highlighting the cost-effectiveness of retrofits versus constructing new WCS with funnel-fencing. This estimate does not include DVC, since deer can still access the ROW within the study area, but given the observed reduction in DVC and the increased deer use of the bridges, the research team believes the benefit of the retrofit exceeds the costs of using elk collision reduction alone.

Maintenance for the first two years following the retrofit fell within the normal scope of activities. Due to the type of fence ADOT installed for the retrofit, maintenance time and costs for the study area were less than for the same section prior to fencing and less than for the adjacent section following fencing. This is likely a function of the age of the ROW fencing in the project area and vicinity. Although the heightened fence in the retrofit section used the existing fence, efforts were made to repair and rebuild sections that were highly degraded. This heightened fence will require less maintenance to begin with, but will likely eventually require more maintenance than the standard woven-wire fence. Huijser et al. (2009) showed costs of connecting fences to underpasses include additional maintenance and fence replacement every 25 years in order to match a crossing structure life of 75 years. Despite these long-term maintenance costs, the fact that the benefit of the retrofit fencing will exceed its cost in less than five years highlights its value as a cost-effective stop gap measure in reducing motorist injuries and property damage.

Ultimately, given the number of EVC in the study area and costs to society, combined with the inadequate spacing and design of the structures and the maintenance requirements of the installed fencing, it is essential to eventually transition to properly designed WCS and standard woven-wire ungulate-proof fencing. However, given that highway construction budgets were tight at the time of this study and the upgrade of I-17 was postponed indefinitely, this retrofit fencing project provided a much needed alternative to increase both motorist and elk safety until long-term solutions can be incorporated.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This study used a data-driven approach to evaluate the utility and cost-effectiveness of creating WCS by connecting existing highway structures with wildlife fencing, making multiple use of existing structures in lieu of constructing new, more costly WCS. The following are key conclusions and recommendations from this research project.

ELK-VEHICLE COLLISIONS

After retrofitting 5.9 miles of existing ROW fencing to 8 ft in height, the research team documented a 97.5 percent reduction in EVC along the study area. This project further supports the effectiveness of wildlife crossings and funnel-fencing to reduce WVC. Remaining sections of I-17 north of Stoneman Lake Road continue to experience high levels of EVC (over 60/yr), and WVC are one of the highest causes of vehicular crashes overall; 20.92 percent of northbound lane crashes and 19.77 percent of southbound lane crashes are WVC (ADOT 2011).

Recommendation

To effectively reduce EVC along the remaining stretches of I-17 while still maintaining habitat connectivity, the research team recommends that ADOT continue to include WCS and fencing in the planning for the upgrade of I-17 in order to achieve similar outcomes to those seen on SR 260 east of Payson (Dodd, Gagnon, Boe, et al. 2012). Locations and designs of WCS and fencing were included in the planning process for the I-17 project between SR 179 and I-40 (ADOT 2011). When planning for the upgrade of I-17 continues, these documents should be referenced for proper reduction of WVC and enhanced highway permeability.

ELK USE OF EXISTING STRUCTURES

Aside from the 97.5 percent reduction in EVC documented along the study area, the research team documented a dramatic increase in the use of the Munds Canyon and Woods Canyon bridges by elk and deer; in all, the bridges were used by a total of 3,150 animals of various species. These results point to the utility of connecting existing structures with wildlife fencing where funding is lacking for newly constructed WCS.

Recommendation

ADOT should work with AGFD and other stakeholders to identify existing bridges (similar to the Munds Canyon and Woods Canyon bridges) and adequately sized culverts that could function as wildlife crossings in areas of high WVC throughout the state. In areas where both high WVC and adequate structures exist, ADOT should collaborate with AGFD to determine whether retrofit fencing is a feasible option, primarily focusing on the length of fencing and logical termini.

ELK HIGHWAY PERMEABILITY AND CROSSING DISTRIBUTION

The ability of elk to successfully cross the highway is primarily limited by high traffic volumes. Because resources essential for survival exist on both sides of I-17, elk still attempt to cross, and those elk that do cross I-17 are likely to be killed by vehicles. Although fencing can limit WVC, it can further fragment habitats and detrimentally affect wildlife. Adequately spaced and sized WCS not only maintain habitat connectivity, but substantially increase wildlife movements by allowing safe passage under or over the road. Along SR 260 near Payson, the spacing of WCS played a primary role in the ability of elk to cross under the road. When underpasses and fencing along four-lane sections of road were located close to each other, elk crossed at a higher rate than at the unfenced two-lane sections of road. As noted on SR 260 (Dodd, Gagnon, Boe, et al. 2012, Gagnon et al. 2010), proper spacing of structures is key to successful connectivity. When WCS were spaced far apart, elk permeability dropped substantially (Figure 23).

Along the study area on I-17, effective structures (the Munds Canyon and Woods Canyon bridges) were located almost 5 mi apart, thus resulting in a 0.03 percent passage rate. Future planning should include efforts to space WCS approximately 2 mi apart as outlined by Gagnon et al. (2013), shown in Figure 23, and consistent with Bissonette and Adair (2008).

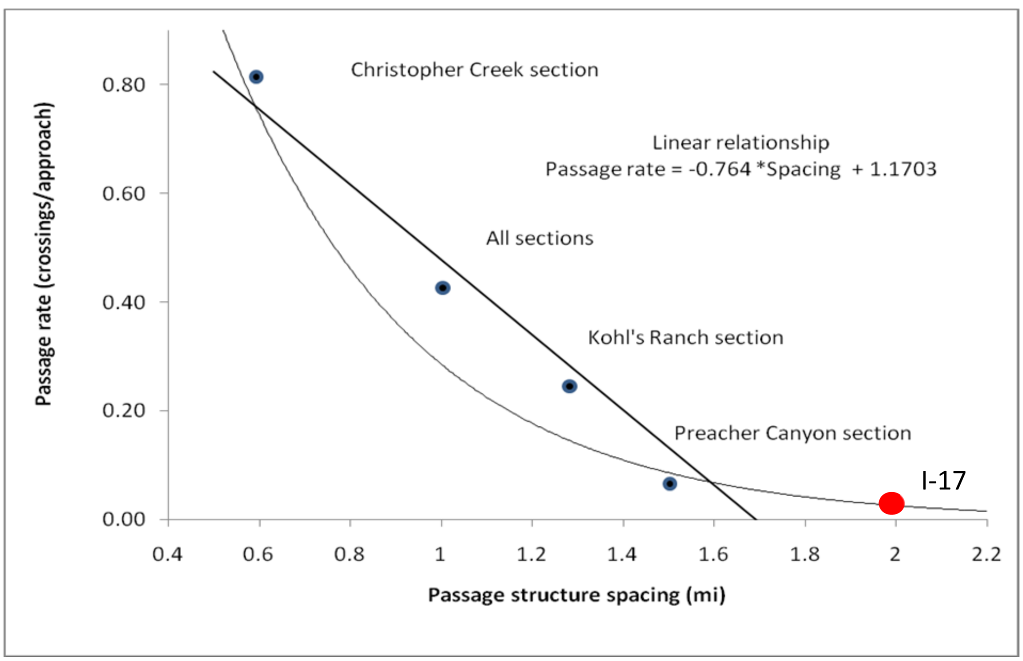


Figure 23. Elk Passage Rate on State Route 260 after Wildlife Crossing Spacing (from Dodd, Gagnon, Boe, et al. 2012, Gagnon et al. 2013)

Note: Red dot represents recommended maximum structure spacing for future upgrade of Interstate 17.

PROJECT COSTS AND MAINTENANCE

The cost of this wildlife fencing retrofit project was $1.58 million. With a continued 97.5 percent reduction in EVC, the benefit to society will exceed the cost of the project within five years. This nearly immediate recovery of costs points to the utility of retrofitting existing structures as a cost-effective alternative in reducing EVC while still allowing elk to access resources. This fencing project, combined with the lessons learned from the SR 260 project (Dodd, Gagnon, Boe, et al. 2012, Gagnon et al. 2010), indicates that WCS and fencing will substantially reduce EVC and maintain habitat connectivity if properly implemented in areas of high EVC. Along SR 260 and I-17, fencing combined with adequate structures for wildlife passage have shown reductions in EVC of over 85 percent. Huijser et al. (2009) estimates that combining underpasses and fencing are justified expenses on sections of road with greater than 1.2 EVC/km/yr (a converted rate of 1.2 EVC/0.62 mi/yr), when assuming an 86 percent reduction over the life of the structure (from data averaged over several nationwide projects).

Recommendation

> Given the success of wildlife crossings and fencing in Arizona, it is recommended that ADOT continue to retrofit existing structures with fencing and build new WCS and fencing where appropriate.

Based on the reduction in EVC along the study area, the electrified cattle guards placed at the Fox Ranch Road TI and Schnebly Hill Road TI on- and off-ramps appear to sufficiently exclude elk from accessing the ROW; however, the cameras did not collect enough information to quantify their effectiveness. In addition, no elk were documented using either TI to cross I-17. Maintenance activities during the study included replacing a cracked board that likely occurred during snow plowing,

Recommendation

> The research team continues to monitor the electrified cattle guards and both TIs to gather sufficient data on the effectiveness of electrified wildlife crossing guards. The data gathered from this continued monitoring can help inform the decision on adaptive management and the continued operation and maintenance of the electrified cattle guards.

The wildlife fencing ADOT used for this retrofit was less expensive than standard 8-ft woven-wire fence used elsewhere in Arizona (e.g., along SR 260, U.S. Route 93, State Route 86, and State Route 77). Maintenance of the wildlife fencing for the first two years following the retrofit fell within the normal scope of activities. However, as the fencing degrades over time, maintenance for this lower cost wildlife fence will possibly exceed that of standard ROW fence. Regular maintenance of fencing is essential to a continued reduction in collisions with ungulates. Although the research team noted a 97.5 percent reduction during the two-year study, the research team continued to work with ADOT and DPS and documented four elk killed in 2014 within the study area. Compromised fence integrity due to erosion and cuts in the fence contributed to three of the four elk mortalities. The reason for the fourth elk mortality is inconclusive; it was in proximity to an electrified cattle guard. Periodic inspections and immediate maintenance of fence breaks or washouts is important, as these breaches can quickly lead to concentrated collision zones where animals will follow the fence to the first opening they encounter (Figure 24).

Figure 24. Example of Wash-out (Red Arrow) Near Site of an Elk-Vehicle Collision in 2014

Recommendation

The research team recommends annual inspection and repair of the wildlife fence ahead of spring migration. In addition to thorough spring maintenance and repairs, Flagstaff District maintenance personnel should watch for signs of fence issues throughout the year. Aside from typical ROW fence repairs associated with fallen trees, wash-outs, cuts in the fence, etc., maintenance personnel should inspect fences in the areas of elk roadkill or excessive elk tracks to determine the point-of-entry, and repair the location(s) immediately. In the long term, the research team recommends replacing the heightened barbed wire fence with the standard, stronger 8-ft woven-wire fence used elsewhere in Arizona to exclude elk from I-17 (Figure 25). This replacement should occur either during the upgrade of I-17 as initially described in the 2011 environmental assessment (ADOT 2011), or sooner if the fencing becomes too degraded to exclude elk or be properly maintained. Brace and line posts that were added to support the heightened ROW fence would also support the replacement woven-wire fence.

Figure 25. Example of Standard Woven Wire Ungulate-Proof Fence Recommended for Interstate 17

Jump-outs provide elk with an opportunity to escape the ROW when needed. The gabion basket-style jump-outs, while much less expensive than the original jump-out designs used along SR 260, will require additional repair and maintenance to function properly over the long term. This is because the cinders used to backfill the jump-outs can slough off of the leading edge of the jump-outs, exposing gabion basket wire and forming mounds of cinders at the base (Figure 26).This erosion can lead to elk being reluctant to use the escape ramp. Instead, elk can return to the ROW seeking another means of escape, and sometimes elk use the mounds of eroded cinders to gain entry into the ROW (Figure 27).

Figure 26. Photograph of Erosion of Interstate 17 Jump-outs

Figure 27. Elk using Mound Created by Erosion to Use Jump-out in the Improper Direction

Recommendation

The research team recommends repairing the jump-outs by adding metal mesh to the leading edge of the features to contain the cinders, and replacing the cinders with those from the mounds formed at the base (Figure 28).

Figure 28. Example of Expanded Metal Mesh to Retain Soil

Future ADOT projects should include a design that better addresses soil retention (Figure 29). The final jump-out height should be 6 ft at the face. Jump-outs should be inspected during annual fence inspections to determine additional maintenance needs.

Figure 29. Example of Optimal Style of Jump-out

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