Evaluation of Right-of-Way Fence Tags to Reduce Animal-Vehicle Collisions

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Jeffrey W. Gagnon https://orcid.org/0000-0002-8251-5977
Colin A. Beach https://orcid.org/0000-0002-3823-4721
Timothy P. McCarthy https://orcid.org/0000-0003-0061-5569
Chad D. Loberger https://orcid.org/0000-0001-5897-3524
Haley P. Nelson https://orcid.org/0000-0002-4825-4873
Scott C. Sprague https://orcid.org/0000-0002-9908-8596</td><td colspan="2">8. Performing Organization Report No.
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Animal-vehicle collisions (AVC) pose a serious and growing threat to motorists traveling on ADOT roads. Solutions exist to effectively mitigate AVC, such as wildlife crossing structures (overpasses and underpasses), however these solutions can be costly and untimely. Fence tags, a small reflective tag that is attached to the right-of-way fence and deter animals from crossing the fence, provide a potential cost-effective solution to reduce AVC. The research team evaluated the effectiveness of fence tags designed by Swift Creek, LLC, in reducing AVC. Fence tags were installed along both sides of five 2-mile segments of roadway and maintained for three years by replacing missing or damaged fence tags on a quarterly basis. The research team queried ADOT Crash Data to determine changes in AVC prior to the study (July 1, 2015 – June 30, 2018) and following fence tag installation (July 1, 2018 – June 30, 2021). Collisions in the areas where fence tags were installed were reduced by an average of 25.4 percent across all sites. This reduction was significant; however, the control sites were also reduced by a similar average of 25.8 percent across all study sites. These findings indicate that (1) the effectiveness of fence tags at reducing AVC were not noticeably different than the control, or (2) external factors that were not considered in the study, such as the effect of nearby road construction, may have influenced the effectiveness of the fence tags. To better understand the results of this study and improve available data for future projects and management decisions, the research team recommends: (1) further examining fence tags as a viable mitigation technique by looking at other aspects that could be taken into account in the study, such as other external factors affecting their use; measuring the effective tag size; implementing a longer observation period before, during, and after the intervention, etc. and (2) implementing data collection forms that capture animal type/species.</td></tr>
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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)		
^0F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^0C
		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)		
^0C	Celsius	1.8C+32	Fahrenheit	^0F
		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

ACIS	Arizona Crash Information System
ADOT	Arizona Department of Transportation
AVC	Animal-vehicle collisions
AZGFD	Arizona Game and Fish Department
BACI	Before-After Control-Impact
EB	Eastbound
IR	Infrared
LLC	Limited Liability Corporation
nm	Nanometer
MP	Milepost
WB	Westbound
ROW	Right of way
SR	State Route
TAC	Technical Advisory Committee
TI	Transportation interchange
UV	Ultraviolet

LIST OF SPECIES

Animal	**Scientific Name**
elk	*Cervus canadensis*
moose	*Alces alces*
mule deer	*Odocoileus hemionus*

EXECUTIVE SUMMARY

Animal-vehicle collisions (AVC), or vehicle collisions caused by the presence of animals, have the potential to cause motorist fatalities, injuries, and property damage. Solutions exist to effectively mitigate AVC, such as wildlife crossing structures (overpasses and underpasses), but these solutions can be costly and untimely.

Fence tags, small reflective tags originally designed to minimize the incidence of birds striking fences, provide a potential cost-effective solution to reduce AVC. These reflective tags emit ultraviolet (UV) light that is visible to ungulates, that, combined with their movement in the wind, is meant to deter animals from crossing a right-of-way fence when those tags are attached at regular intervals along the fence.

For this study, the research team evaluated how effective Swift Creek, LLC, fence tags were in reducing AVC. To do this, fence tags were installed along both sides of five 2-mile segments of roadway selected through analysis of Arizona Department of Transportation (ADOT) Crash Data from January 1, 2009, through December 31, 2017. These fence tags were maintained for three years by replacing missing or damaged fence tags on a quarterly basis. All maintenance efforts were documented. Once three years of field deployment and maintenance were completed, the research team queried ADOT crash data to determine changes in AVC prior to the study (July 1, 2015 – June 30, 2018) and following fence tag installation (July 1, 2018 – June 30, 2021). Finally, the team evaluated the robustness and level of UV and blue light emitted in the lab from randomly selected tags that were collected in the field after being deployed for various durations of time and compared to that of new undeployed tags. The key findings from the study are as follows:

- Collisions in areas where fence tags were installed reduced by an average of 25.4 percent across all sites. This reduction was significant, but collisions in the control sites were also reduced by a similar average of 25.8 percent across all study sites.
- Maintenance efforts were generally minimal.
- Fence tags became more brittle after year one of deployment but proved robust enough to last beyond the three-year evaluation period. Through laboratory testing, the team documented no discernable difference in the levels of UV and blue light emittance between new tags and tags collected from the field.

The research team's evaluation of three years' worth of fence-tag implementation data did not support the expected full mitigation effect of reducing AVC. As a result of the control and treatment segments of the study sites yielding overall similar reductions, the following conclusions were drawn:

- A conclusive, statistically significant reduction of AVC could not be attributed to the fence tags.
- There may be other confounding factors that were not considered in the current study that may have affected how effective the fence tags were.

A small reduction in collisions with animals, particularly large animals like elk and deer that pose safety concerns to motorists, could be beneficial to ADOT. The use of tags as a mitigation technique for AVC warrants further examination of the aforementioned considerations. Additionally, it is possible that different species reacted differently to the presence of fence tags. For example, deer may have avoided treated fences more than elk, or vice-versa. Currently, ADOT's Arizona Crash Form, which is used by Department of Public Safety and other law enforcement entities, combines all animals into one category called "Animal", including wildlife, domestic, and livestock. This does not allow for an effective analysis of what type of animal is likely to be hit in a given area on ADOT roads and makes effective mitigation decisions for future projects potentially challenging.

The research team recommends the following next steps:

- Continue the discussion of fence tags as a potential mitigating technique for ADOT by identifying confounding factors. These discussions could include additional data mining and correlations with other available data sources (e.g., weather conditions during the study period, driver behavior, environmental conditions like construction, crash data reporting, impact of changes in crash data collection, and species where available data sources identify what species were involved in the crash).
- Edit ADOT's Arizona Crash Form to collect animal type/specific animal species in crash reporting to enhance evaluation of animal-vehicle collisions to better inform research and mitigation decisions.

INTRODUCTION

Background

AVC are a concern in Arizona, especially as roadways expand to accommodate population growth and higher-volume traffic. For example, along State Route (SR) 260 above the Mogollon Rim, an annual average of 32 percent of crashes from 2005 to 2015 involved animals. This percentage increased over time, from 25 percent in 2015 to as high as 45 percent in 2013, which is more than an 80 percent increase between 2005 to 2015 (Gagnon et al. 2017). This average percentage of 32 percent of AVC against overall crashes is nearly seven times higher than the national average of 4.6 percent (Huijser et al. 2007). The percentage of accidents involving animals is even higher along State Route 64 (SR 64), at 48 percent of annual crashes, with some segments reaching as high as 75 percent (Dodd et al. 2012b).

Between Stoneman Lake and Flagstaff on Interstate 17 (I-17) from 2007 to 2010, researchers documented an annual average of 86 collisions with elk (Figure 1; *Cervus canadensi*s) and 14 collisions with mule deer (*Odocoileus hemionus*) (Gagnon et al. 2013). Along Interstate 40 (I-40) between Williams and Winona, an average of 91 collisions with large ungulates were documented per year from 2007 to 2011 (Gagnon et al. 2012), though these were not document on a per-species basis.

Figure 1. Bull elk killed by a vehicle along Interstate-17 in Flagstaff

Collisions with large animals cause motorist safety concerns due to the animals' sizes. For example, bull elk can exceed 1,100 pounds and cow elk can exceed 660 pounds (Toweill and Thomas, 1982). Collisions with elk and deer regularly cause property damage, but can also lead to severe motorist injury or even death (Huijser et al. 2007). Furthermore, the expense associated with collisions with these large animals can be quite high. For example, in 2009, the cost of a single elk collision, averaged across the nation, was an estimated $17,483, and a single deer collision was estimated to cost $6,617 (Table 1) (Huijser et al.

2009). Using these estimates to calculate the total annual cost of collisions with elk (85.5 per year) and deer (14 per year) along the aforementioned stretch of I-17, nearly $1.6 million was spent annually between 2007 and 2010 as a result of large-animal collisions. The combination of these costs and motorist safety concerns warrants increased measures to mitigate risks.

Table 1. Total costs of an individual AVC nationally (modified from Huijser et al. 2009)

Description per Collision	Deer (US$)	Elk (US$)	Moose (US$)
Vehicle repair costs	$2,622	$4,550	$5,600
Human injuries	$2,702	$5,403	$10,807
Towing, accident attendance, and investigation	$125	$375	$500
Hunting values per animal	$116	$397	$387
Carcass removal and disposal	$50	$75	$100
Total	**$6,617**	**$17,483**	**$30,760**

Wildlife crossing structures and exclusionary fencing have become common and effective measures to reduce collisions with large ungulates (Huijser et al. 2016, Rytwinski et al. 2016). In Arizona, ADOT and the Arizona Game and Fish Department (AZGFD) have worked together to reduce motorist collisions with elk and deer. For example, collisions with elk have been reduced by 85 to 97 percent along stretches of SR 260 and I-17 from 2002 to 2021 where fencing and suitable wildlife crossing structures have been installed (Dodd et al. 2007, Gagnon et al. 2010, Dodd et al. 2012a, Gagnon et al. 2016).

Although wildlife crossing structures and fencing have proven effective, such structures are expensive, and projects can take years to move through design, funding, and implementation. Thus, cost-effective, functional, and timely alternatives are desirable. A variety of cost-effective alternatives to modify driver or wildlife behavior have been evaluated throughout the past few decades (Huijser et al. 2007, Rytwinski et al. 2016). Modifications of driver behavior, or alertness, including active and passive signage, speed limit reduction, roadside clearing, and lighting, have shown mixed results (Pojar et al. 1975, Reed and Woodard 1981, Sullivan et al. 2004, Meisingset et al. 2014). Cost-effective efforts to modify ungulate behavior through sensory stimuli have shown similarly mixed results, with evaluated tactics including explosions, sirens, predator scents, tainting attractive resources, electrical shock, "deer whistles," various visual cues including reflectors, and lights (Fraser and Hristienko 1982, Gilsdorf et al. 2004a, Gilsdorf et al. 2004b, Andreassen et al. 2005, VerCauteren et al. 2005, Seamans and Vercauteren 2006, Valitzski et al. 2009, Hildreth et al. 2013).

Of the strategies affecting ungulate senses, measures that employ visual stimuli are some of the least understood, as it is unknown what exactly ungulates can see. As a result of this poor understanding of ungulate vision, any mitigation techniques aimed at reducing ungulate-human conflicts through visual stimuli have been hampered (Cohen et al. 2014), but they still have some potential. Ungulates have a combination of rods and cones in their retina that not only allow for the perception of light (similarly visible to humans) but also allow for vision under low-light conditions, or "night vision."

Deer are the most widespread ungulate in North America, meaning they are also the most studied. Nearly all evaluations of ungulate visual senses have been conducted using deer; however, it is expected that other species, including elk, likely have visual functionality that is somewhat similar to deer. Studies have been undertaken to evaluate the visual reactions of deer to light at various wavelengths of the visible light spectrum (400–700 nm), the UV light spectrum (10–400 nm), and the infrared light spectrum (IR) (700–1000 nm). Within the visible light spectrum, studies have been conducted to determine whether some wavelengths have more of an effect on deer behavior than others. For example, red lasers (630–650 nm) were used in an attempt to elicit a vigilant response from deer at the upper end of the visible spectrum but obtained no significant response. Because deer are generally active at night, researchers attempted to elicit a response via blue lasers (473 nm) and green lasers (534 nm) near the lower end of the visible light spectrum, but again were unsuccessful (VerCauteren et al. 2003, Vercauteren et al. 2006). Additional evaluations of the lower end of the visual spectrum also produced nominal results (Brieger et al. 2017). One study, however, rigorously tested the visual sensitivity of deer from 360–650 nm and found that deer have a greater perceptual sensitivity, as compared to humans, to shorter wavelengths even into the UV spectrum (Brieger et al. 2016). The physiological characteristics of ungulate retinas and the aforementioned experiments on vision suggest that using UV in AVC mitigation efforts could have potential.

Methods to Reduce AVC Via Visual Stimulus

Attempts to modify ungulate behavior through visual senses have included enhancing the perceived threat of oncoming cars, introducing flashing lights, and installing roadside reflectors, which have all shown mixed results (Waring et al. 1991, Reeve and Anderson 1993, Ujv?ri et al. 1998, Gilsdorf et al. 2004b, VerCauteren et al. 2005, D'Angelo et al. 2006, Blackwell and Seamans 2009).

Roadside reflectors, also called light-reflecting devices, are a visual-stimuli option for reducing AVC that have been frequently evaluated and may have potential for success. Aside from a manufacturer's claims or studies that show success, most research has shown minimal effectiveness. Reflectors require "activation," whereby the headlights of oncoming vehicles cause the reflector to shine or scatter light in a manner intended to scare deer away or cause them to hesitate long enough to allow vehicles to pass before attempting to cross the road (Brieger et al. 2016). Two attempts to use reflectors in Arizona have occurred in the past few decades, one along I-17 in the 1970s and one along SR 260 east of Heber in the early 2000s. According to a former AZGFD Regional Supervisor, the I-17 reflectors were quickly destroyed by snowplows and no solid results were obtained (in person interview, August 10, 2014). The second study was conducted by ADOT to evaluate reflectors along SR 260 (Figure 2); this study also showed inconclusive results. Reflectors were implemented in an area affected by a recent fire, and the new vegetation growth attracted more deer and elk to the area, which increased AVC (Gagnon et al. 2017).

Figure 2. Roadside reflectors along SR 260 east of Heber (photo courtesy of ADOT)

Brieger et al. (2016) evaluated the outcome of 43 studies using light-reflecting devices to reduce AVC over the past 50 years. Results from the studies showed no real evidence that reflectors effectively reduced collisions with ungulates, but differences in study design, length of road, length of study, and replication may have introduced variation into the results. Rytwinski et al. (2016) evaluated several studies focusing on AVC reduction and noted only a 1 percent reduction in AVC across all studies that evaluated reflectors, and warned against further implementation without appropriate study designs. Both Brieger et al. (2016) and Rytwinski et al. (2016) recommended that future studies include a Before-After Control-Impact (BACI) study design, meaning that adequate pre-treatment collision data are needed before and after implementing reflectors or any other mitigation measure for both the control and treatment areas.

Interestingly, researchers placed white bags over reflectors to serve as an evaluative control during one roadside-reflector study in Wyoming, and found that the reflectors with white bags reduced collisions and road-crossing behavior better than the reflectors themselves, even though the reflectors did provide some level of effectiveness (Riginos et al. 2018). These findings led to the recommendations by the authors that new vigilance-enhancing mitigation methods should be explored as a way to reduce AVC.

Fence tags—sometimes called fence diverters, markers, or flags—are another potential visual stimuli or vigilance-enhancing option to deter animals from crossing fences. Fence tags are attached directly to fences, eliminating the need for standalone posts. As many states already have fences along a majority of their rights-of-way (ROW), fence-tag installation would be quick and inexpensive relative to reflectors. Like reflectors, fence tags can reflect light, but they also move with the wind. Currently, only anecdotal evidence suggests that fence tags have any influence on animal behavior; however, they appear to work for birds. The idea of fence tags was first introduced to help reduce the possibility of birds striking fences during flight, which, in turn, would help reduce bird mortality rates. Two studies evaluating fence tag effectiveness in reducing fence-related bird mortality showed 84 percent (Baines and Andrew 2003) and

91 percent (Bryan et al. 2012) reductions for grouse species. The anecdotal evidence of fence tags deterring ungulates, combined with the positive results of fence tags in reducing bird strikes with fences, warrants the need to evaluate this method more thoroughly for ungulates, including elk and deer, as well as other wildlife species.

Study Objectives

This study's primary objective was to test the use of fence tags for reducing the number of AVC involving deer and elk by measuring AVC before and after the installation of Swift Creek, LLC, fence tags using a BACI study design over a full three-year period from July 1, 2018, through June 30, 2021. The length of the study helped to account for yearly variation. The secondary objective was to assess the installation costs, maintenance costs, and requirements associated with using fence tags.

Swift Creek, LLC, designed a fence tag that reflects light and flutters in the wind when placed on a fence; it could elicit vigilant-response behavior from animals. These fence tags gather sunlight during the day and re-emit absorbed light in the UV range (<400 nm) during the night. This UV range is less common at night in the natural environment but still within an ungulate's visible spectrum (Figure 3). The UV spectrum's "glow-in-the-dark" function does not require passing cars for activation and can continuously alert animals to the presence of the fence and associated roadway. The combination of the components of this product may elicit an avoidance response from animals that would inhibit their desire to cross the ROW fence, thus reducing AVC.

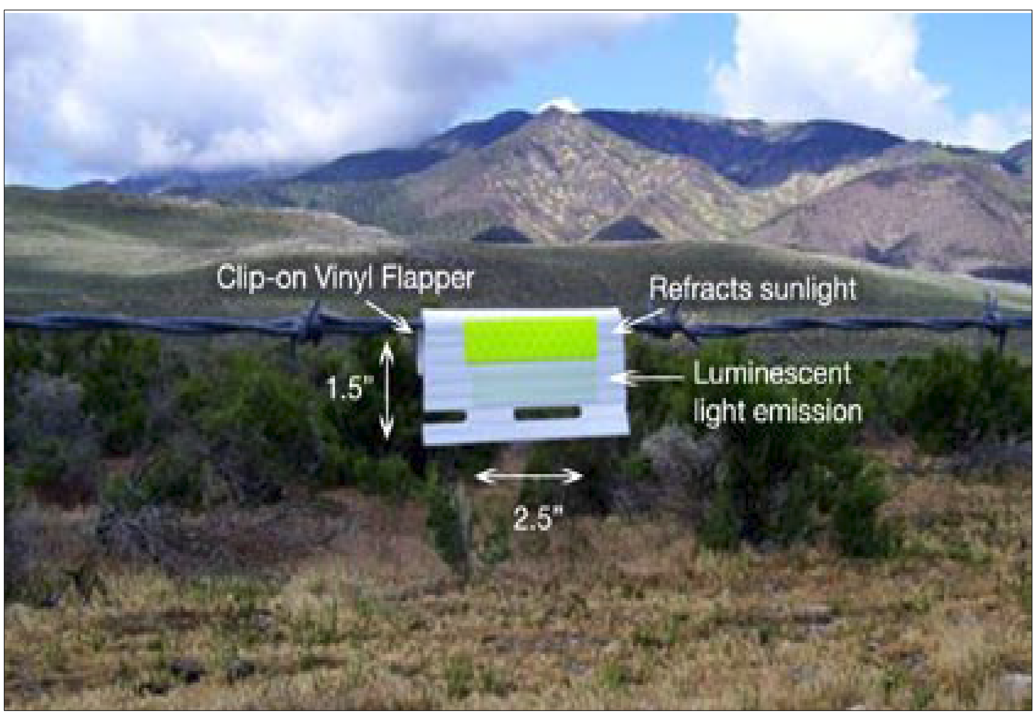

Figure 3. Swift Creek, LLC, fence tag with the different elements labeled (photo courtesy of Swift Creek, LLC)

SITE SELECTION AND ANALYTICAL METHODS

Analysis of Historic Animal-Vehicle Collisions and Selection of Study Areas

The research team evaluated ADOT crash data from sites known for high incidence of AVC that were either evaluated in previous ADOT/AZGFD studies (I-17, I-40, SR 260 west of Show Low, SR 64) or recommended by the Technical Advisory Committee (TAC) (SR 87, US 60, SR 260 east of Show Low). With assistance from ADOT personnel, AZGFD queried the Arizona Crash Information System (ACIS) database from March 2008 to March 2018 for the following locations:

- I-40, Williams to Winona Milepost (MP) 165–212, Eastbound (EB) and Westbound (WB)
- I-17, Rim to Flagstaff MP 312–340, Northbound (NB) and Southbound (SB)
- SR 64, Williams to Grand Canyon MP 186–235, Both Directions
- SR 260 W, Heber to Show Low MP 305–340, Both Directions
- SR 87, Payson to South of Winslow MP 255–340, Both Directions
- US 60, Vernon to Springerville MP 361–387, Both Directions
- SR 260 E, Show Low to Eager MP 345–394, Both Directions

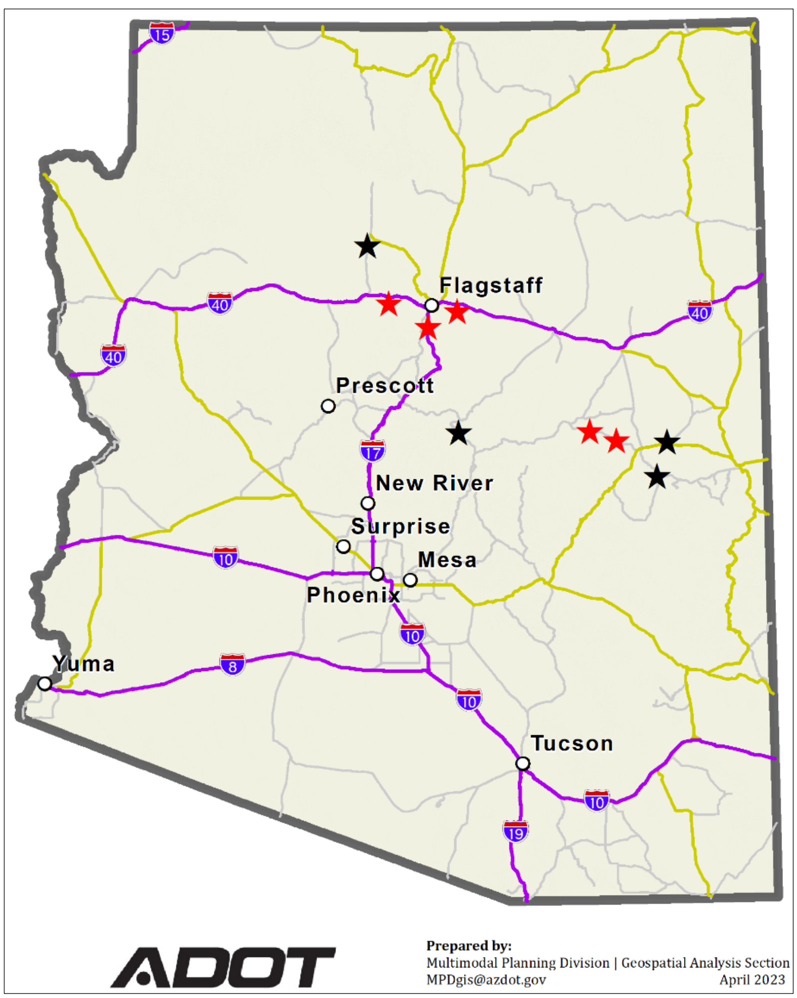

Figure 4. Locations of Historic Study Areas for Animal-Vehicle Collisions

The query resulted in 13,382 records. Of these records, there were 2,970 animal-related accidents. Of the 2,970 animal-related accidents, 2,794 (94 percent) were with “Animal_Wild_Game,” 80 (2.7 percent) were with “Animal,” 74 (2.5 percent) were with “Animal_Livestock,” and 22 (0.7 percent) were with “Animal_Pet.” In 2017, ADOT combined all animal-related accidents into one category for the updated crash data collection forms. For consistency, the research team also combined and reported the aforementioned crash incidents as AVC.

After the exclusion of 51 records without clear MP and roadway information from the data set, the research team’s final analysis included 2,908 AVC. Table 2–Table 4 outline the characteristics of AVC by outcome, severity, and roadway.

Table 2. Outcome of AVC reported from 2008 to 2018

Outcome of AVC	Number of AVC
Animal Only	2,684
Collision With Object	25
Collision With Vehicle	39
Leave Lane or Road	122
Other	4
Overturn/Rollover	34
Total	**2,908**

Table 3. Motorist status following AVC from 2008 to 2018

Motorist Status Following AVC	Number of AVC
Fatal	4
No Injury	2,641
Possible Injury	69
Suspected Minor Injury	183
Suspected Serious Injury	11
Total	**2,908**

Table 4. Output of AVC by roadway from 2008 to 2018

Road ID	Number of AVC
I-17	477
I-40	730
SR 260 E	175
SR 260 W	526
SR 64	530
SR 87	380
US 60	90
Total	**2,908**

Data which cover only partial years between 2008 and 2018 were also excluded, thereby leaving the final data set to cover only the period from January 1, 2009, through December 31, 2017. This resulted in 2,666 AVC across the seven selected stretches of roadway. Because each stretch of roadway is a different length, the research team calculated AVC per mile to standardize the data.

After evaluating AVC per mile by year for each roadway, the research team noted an observable increase in AVC between years 2009–2013 and 2014–2017 for all highways except US 60. The average increase in AVC per mile across all seven roadways between 2009–2013 and 2014–2017 was 33.5 percent. A paired T-test showed that this difference was statistically significant (*t=3.2, df 6, p=0.01*), and was even more pronounced (37.5 percent increase) when US 60 was removed from the analysis (*t=5.3, df 6, p=0.002*). The research team surmised that the increase in AVC could be the result of various factors, including changes in adjacent habitat, roadway traffic volume, wildlife population increases, annual precipitation, or other unknown factors. To account for possible changes in biotic and abiotic factors, the research team only used the data from 2014 to 2017 in the final identification of fence-tag placement and comparative control locations. Given the reduction of AVC during the study along US 60 and the relatively few data points for both US 60 and SR 260 East, the research team removed US 60 and SR 260 East from the seven roadways initially under consideration. The remaining roadways (I-40, I-17, SR 64, SR 87, and SR 260 W) each had more than 40 AVC per mile from 2014–2017.

Segments of the remaining five highways were further excluded where AVC mitigation (I-17 MP 316–322) and long-term construction (I-17 Willard Springs Transportation Interchange [TI]) are ongoing. The research team determined it was unlikely that shorter-term, non-fence-related construction, such as that planned for I-17, would have an influence on the results as long as the treatment and control areas experienced the same construction activities and durations. Improvements to fencing, such as along SR 64 from MP 222–238 in 2018, could reduce AVC if the fence were more difficult for animals to get over. This might show a reduction that would be incorrectly linked to fence tags. Because some of the higher peaks in AVC along SR 64 occurred along the stretch planned for fence replacement, and collisions in other areas of SR 64 occurred at relatively low rates, SR 64 was excluded as a primary location for fence tag placement. Along SR 87, much of the area with adequate data for evaluation (MP 267.00–268.99) fell within the town of Pine, AZ, with development and intermittent fences being possible confounding factors. As a result, SR 87 was removed as a primary location for fence tag placement. The remaining highway segments suitable for evaluation of fence tag effectiveness included I-17, I-40, and SR 260 W.

The research team evaluated two-mile segments along the three remaining highway segments (I-17, I-40, and SR 260 W), with the goal of selecting 10 segments across the three highways. Priority was given to paired two-mile areas (one treatment and one control) with a combined average yearly collision rate greater than 5.0 AVC. Treatment and control segments were paired based on (1) having total combined AVC per-year rates as close to equal as possible and (2) close proximity to each other to reduce environmental variation. Because animals tend to respond differently to highway type and traffic volume, the research team determined that it was important to have treatments along both two- and four-lane roads.

Based on these criteria, the following locations were selected for treatment (brown boxes) and control (blue boxes), as shown in Figure 5Figure 7.

- I-40 W, Fence Tags 1, MP 168.00–MP 169.99; I-40, Control 1, MP 172.00–MP 173.99
- I-40 E, Fence Tags 2, MP 202.00–MP 203.99; I-40, Control 2, MP 197.00–MP 198.99
- I-17, Fence Tags 1, MP 328.00–MP 329.99; I-17, Control 1, MP 334.00–MP 335.99
- SR 260 W, Fence Tags 1, MP 312.00–313.99; SR 260 W, Control 1, MP 317.00–MP 318.99
- SR 260 W, Fence Tags 2, MP 323.00–324.99; SR 260 W, Control 2, MP 326.00–MP 327.99

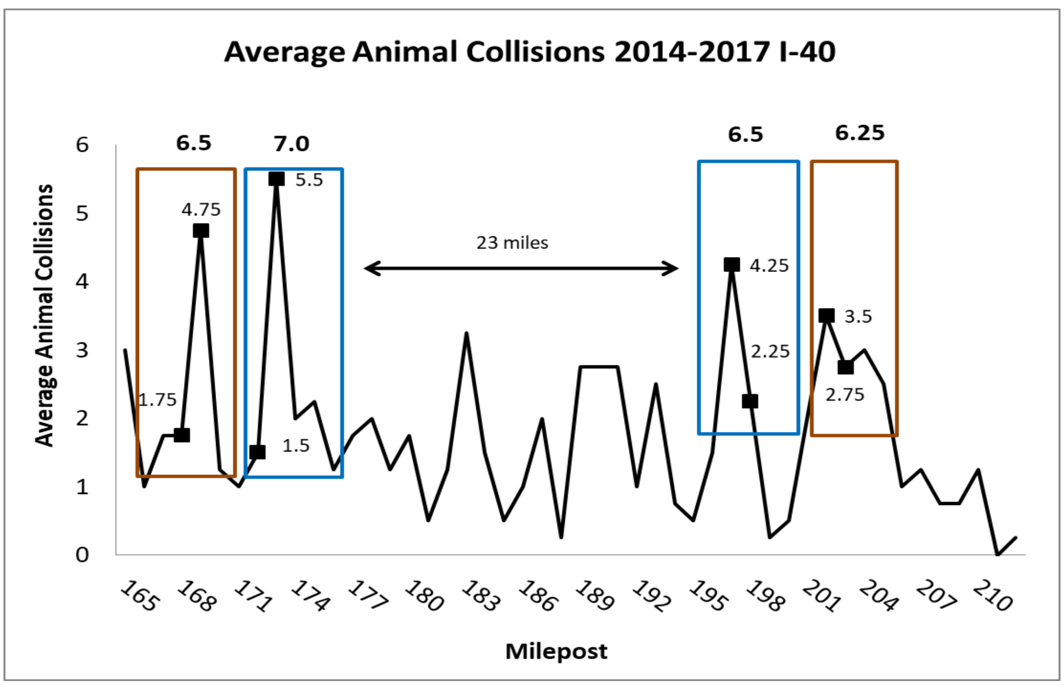

Figure 5. Two-mile stretches of highway selected along I-40 for fence tags (brown boxes) and controls (blue boxes) and their respective number of AVC (black markers) and total number of AVC for each two-mile section

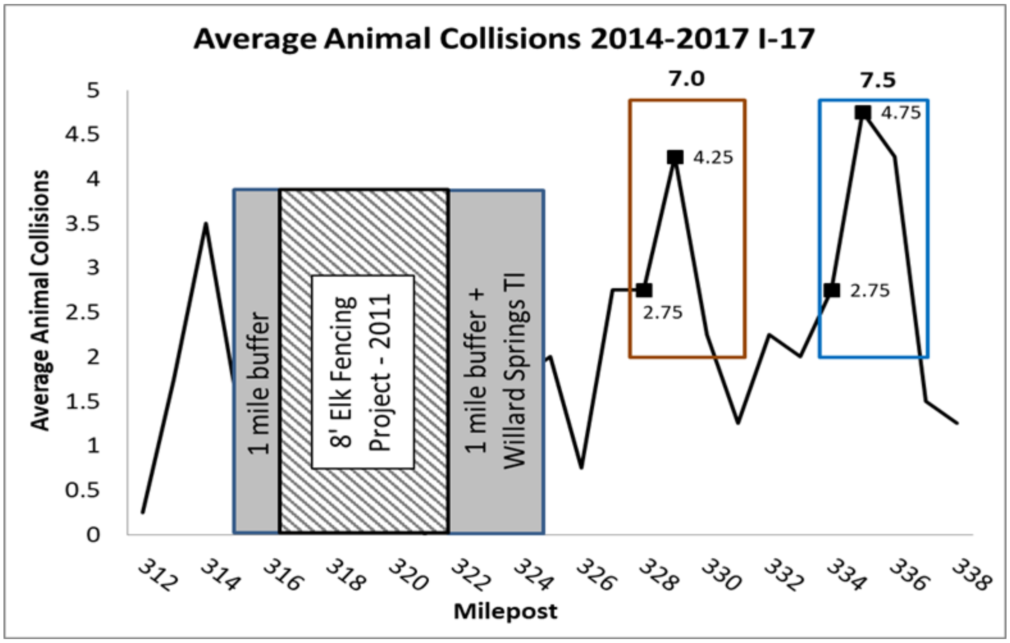

Figure 6. Two-mile stretches of highway selected along I-17 for fence tags (brown boxes) and controls (blue boxes) and their respective number of AVC and total AVC for each section, with avoidance areas for fence tags with an 8-foot elk fence and surrounding one-mile buffers

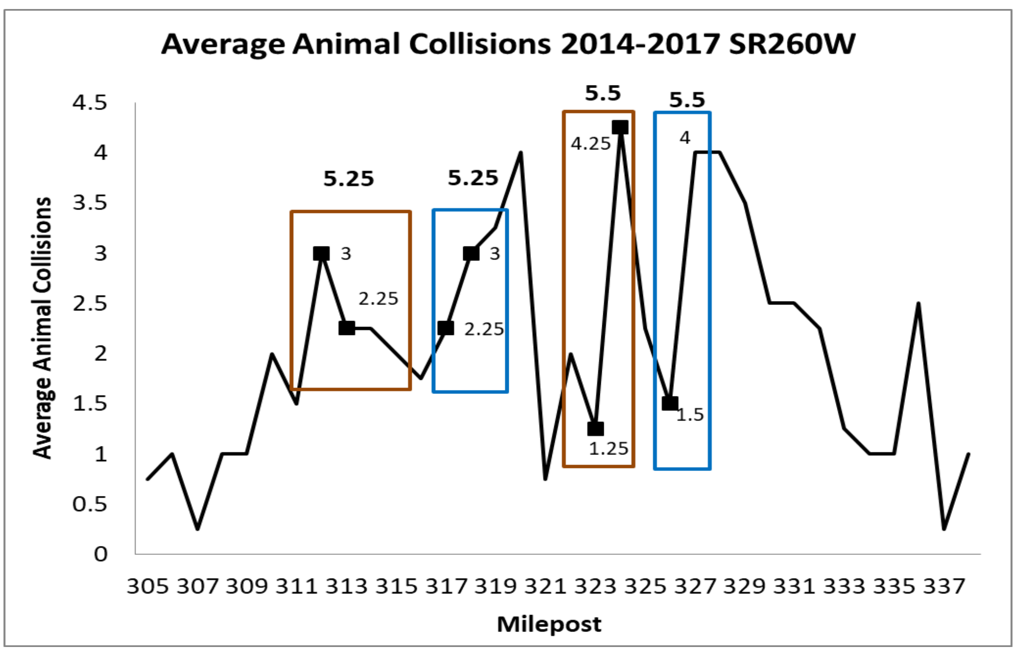

Figure 7. Two-mile stretches of highway selected along SR 260 West for fence tags (brown boxes) and controls (blue boxes), their respective number of AVC (black markers), and the total number of AVC for each two-mile section

Effectiveness of Fence Tags: Analytical Method

The purpose of the pre- versus post-fence tag analysis between treatment and control areas was to determine if the presence of tags provides a statistically significant reduction in AVC compared to the absence of tags. Results from this analysis could help determine if the implementation of fence tags is a plausible solution to reduce AVC elsewhere in Arizona.

The research team used data from site selection as the pre-treatment data set, which included three years of data from 2014 to 2017. This pre-treatment dataset was compared to the post-treatment dataset that included three years of data from July 1, 2018, to June 30, 2021. The data were evaluated and reported as a percent-reduction or -increase from the pre-treatment dataset. The research team used a non-parametric Wilcoxon Signed Rank Test (U) with 1 degree of freedom (df) to evaluate differences among areas with fence tags compared to their respective control areas, as well as pre- and post-evaluations of the locations of fence tags and the controls themselves. Given the small sample size, the team considered a result statistically significant at probability (P) <0.10.

TAG MONITORING AND MAINTENANCE

This chapter documents the maintenance requirements of using fence tags as a device to minimize AVC in order to present the time spent monitoring the upkeep of fence tags to ensure they remain in functional condition. Data covers a three-year period from July 2018 to June 2021, and encompasses the research team's time spent monitoring the fence tags, factors that account for the replacement of missing or damaged tags, the number of tags replaced, and other associated costs.

Monitoring Mechanism

The fence tags installed for this project were maintained by research team members, who performed quarterly inspections on tags along each of the 10 two-mile stretches identified as high-AVC areas. During inspections, each stretch of the road was either walked or driven (depending on terrain, weather, lighting conditions, etc.) in its entirety. Tags were evaluated and designated accordingly as either missing, damaged, collected, or dislodged. The fence tag status, location, action taken, and time spent to perform an action (i.e., re-installing dislodged tags) were all recorded in a Survey123 computer application and mapped for future analysis of the data.

A "missing" tag designation means no tag was present on the fence. A tag was designated as "damaged" either when a tag found along the fenceline was damaged so significantly that it could not be re-installed (Figure 8) or an obstacle was blocking either one or both sides of the fence tag (Figure 9). If the fence tag was intact but blocked by a barrier, it was marked as damaged, and the barrier was removed, leaving the existing fence tag in place. If the fence tag itself had sustained damage, the barrier was removed and a new fence tag was installed in place of the damaged fence tag. In cases when the inspector randomly selected and removed a tag to examine how brittleness and reflectivity change over time, a new tag was installed and designated as "collected." A "dislodged" tag designation means the tag was not setting properly on the fence or had fallen to the ground, but was not damaged and could be re-installed.

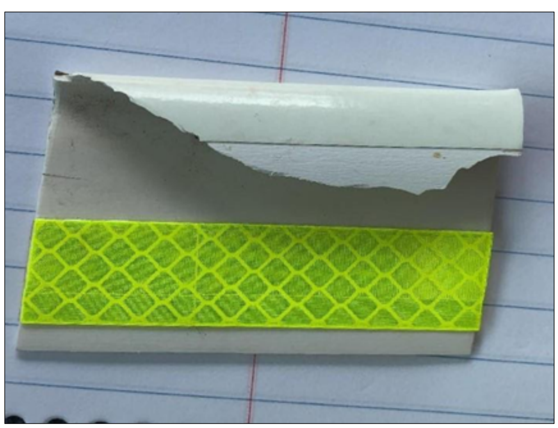

Figure 8. A fence tag that has been damaged and cannot be placed back onto the fence

Figure 9. Trash covering both sides of a fence tag, blocking visibility

Tag Replacement

The following situations required tags to be replaced.

- **Following the completion of maintenance work, such as fence repair or replacement.** The research team observed that multiple missing tags found in short distance of each other usually occurred in areas where maintenance work was reported. For example, during the May 30, 2019, inspection of SR260 EB MP 323-325, the research team found four missing tags around a recently repaired section of fence.
- **When a fence is damaged.** For example, on December 6, 2019, a downed tree at SR260 EB MP 312-314 along a section of fence where tags used to be installed required new fence tags to be reinstalled on the repaired fence (Figure 9).
- **Presence of human disturbances.** The research team observed several instances of trash or large windblow objects obstructing the fence tags (Figure 9).

Figure 10. A downed tree blocking the visibility of a fence tag on SR 260

Tag Reinstallation

In some situations, the original tag was dislodged and had to be reinstalled. For example, on February 24, 2021, a stretch of 12 tags in the eastern portion of I-40 WB MP 168-170 were discovered to be dislodged, likely due to wind (Figure 11). However, all tags still appeared to be functional (Figure 12), and the tags were re-installed on the fence.

Figure 11. A dislodged fence tag from the February 24, 2021, inspection

Figure 12. A tag that appears undamaged but was likely blown off by the wind; it can be reinstalled

Maintenance Requirements

Our evaluation of fence tag maintenance requirements included 12 quarterly checks at all study areas that occurred over the course of three years, from July 1, 2018, to June 30, 2021. Most inspections were conducted by two team members, which helped expedite the process. Team members' level of experience varied from intern to lead biologist. Maintenance inspections started in Phoenix, and the team logged approximately 500-700 miles per quarter, depending on whether staff stayed overnight to perform one continuous check or returned to Phoenix to split up inspections.

Table 5 shows the average and total time spent per visit once on site. The I-17 MP 328-330 study area took the longest amount of time to survey, with an average of 1.9 hours per inspection. This was likely due to the tall berm on the western side of the highway that required more time for on-foot investigations. In comparison, SR260 MP 323-325 took the shortest amount of time, with an average of 1.1 hours per inspection, because team members were able to inspect fence tags from a vehicle.

Table 5. Average and total monitoring time (hours) spent at each study

Study Area	Average Time Per Visit by Study Area (hours)	Total Time Per Visit by Study Area (hours)
I-17 MP 328–330	1.9	22.5
I-40 MP 202–204	1.6	18.9
I-40 MP 168–170	1.6	19.6
SR 260 MP 312–314	1.5	18.0
SR 260 MP 323–325	1.1	13.2
Average/Total	**7.7**	**92.2**

Most missing and damaged tags were noted on fences lining open plains and pastures. The tags surrounded by vegetation were better protected from disturbances caused by weather and livestock. The February 24, 2021, and June 2, 2021, inspections confirmed this assumption. On these dates, a half-mile stretch of missing or damaged tags was found on a relatively open fenceline along I-40 (Figure 13).

Figure 13. Locations of missing or damaged tags from the June 2, 2021, inspection

Tag Replacement Effort

During approximately 92 inspection hours over the course of the evaluation period, a total of 304 of the initial ~13,200 fence tags (2.3 percent) were replaced with new tags. Of these 304 tags, 163 were missing, 82 were damaged, and 59 were replaced after sections of fence were repaired. This accounted for just 2 percent of the total number of tags initially deployed. One hundred and twelve tags were dislodged, but researchers were able to immediately re-install them because they were undamaged.

Table 6 contains a breakdown of the number of replaced tags. The most tags (75) were replaced on the I-40 MP 202-204 study area.

Table 6. Total number of tags replaced at each survey stretch by study area

Study Area (starting milepost number)	Tags Replaced Per Survey Stretch	Tags Replaced Per Study Area
I-17 NB	32	71
I-17 SB	39	
I-40 EB (202)	41	75
I-40 WB (202)	34	
I-40 EB (168)	27	64
I-40 WB (168)	37	
SR 260 EB (312)	21	55
SR 260 WB (312)	34	
SR 260 EB (323)	16	39
SR 260 WB (323)	23	
Total	**304**	**304**

Overall, 38 percent of the tags that were either replaced or reinstalled occurred during spring when winds were generally at their highest in northern Arizona. Figure 14 shows the total number of tags replaced by season and inspection year.

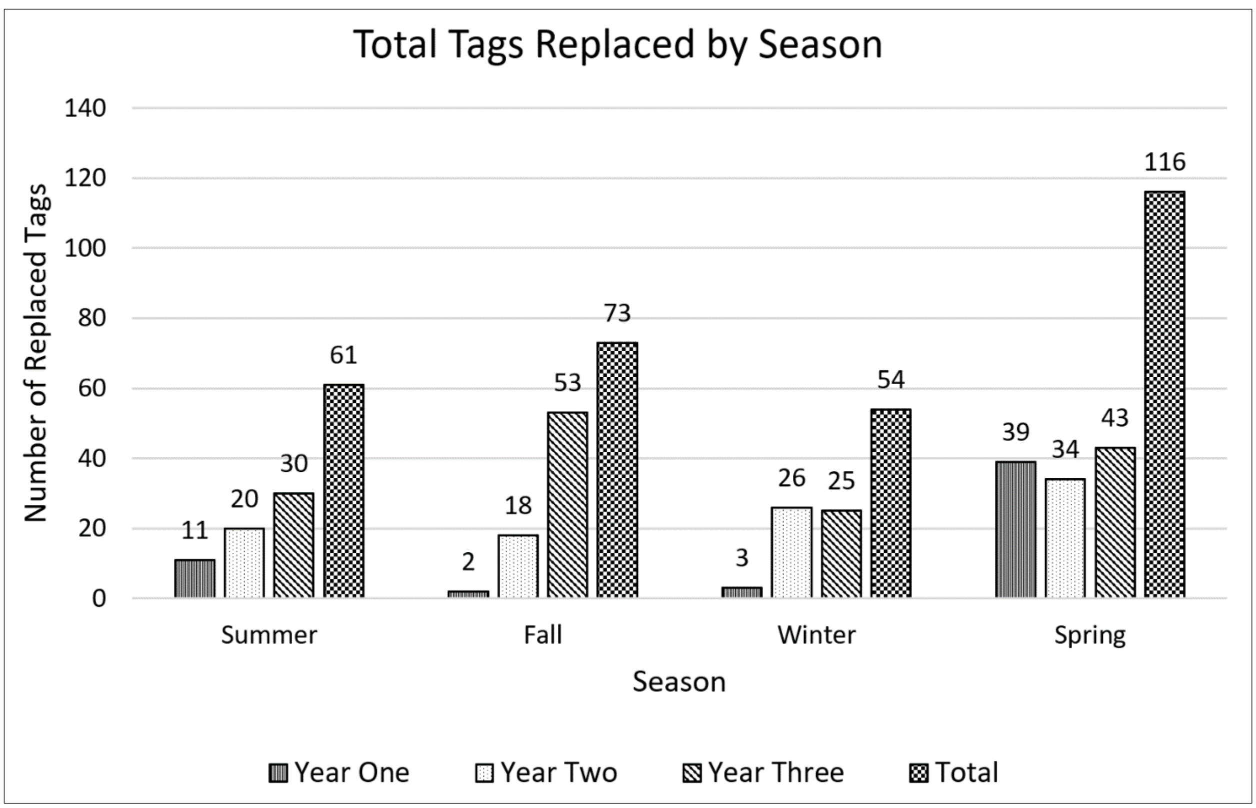

Figure 14. Total fence tags replaced by season, by inspection year

To visualize the geographic pattern of fence tag replacement that took place during the three-year inspection period, heat maps were developed for each study area. Due to the variance in distance between mileposts, road segments between the beginning and end of each study area were split into 20 evenly sized segments. The count in each segment represents the combined number of missing or damaged tags replaced on both sides of the highway within that segment over the three-year study period (Figure 15Figure 19).

Figure 15. A heat map of replaced tag locations along I-17 mileposts 328 to 330

Figure 16. A heat map of replaced tag locations along I-40 mileposts 202 to 204

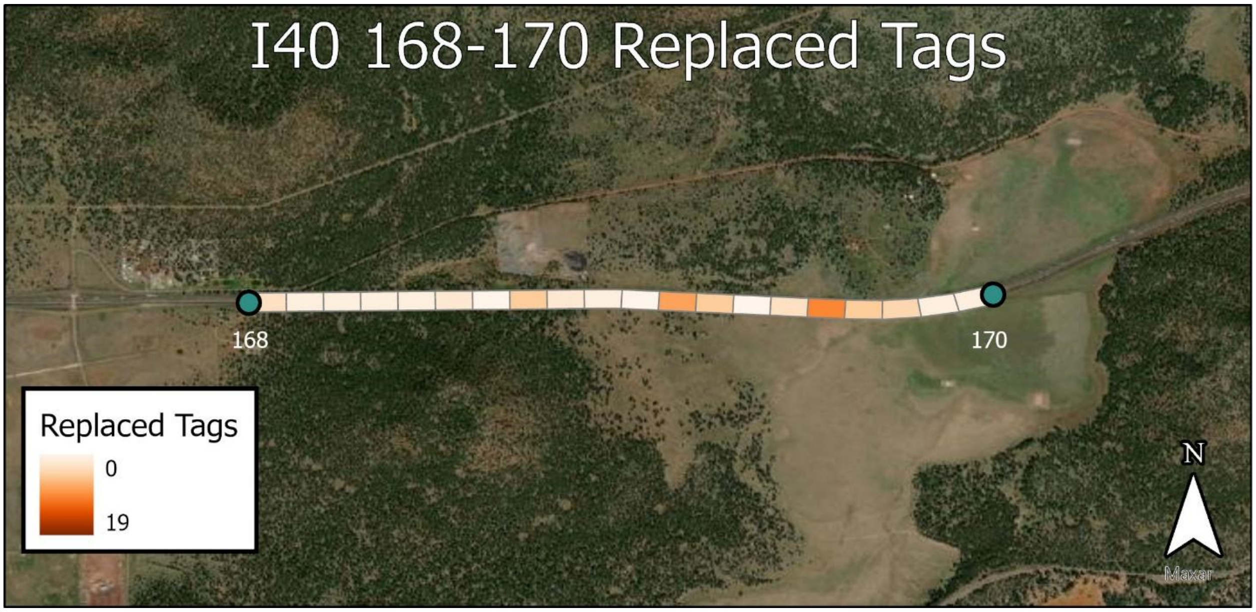

Figure 17. A heat map of replaced tag locations along I-40 mileposts 168 to 170

Figure 18. A heat map of replaced tag locations along SR 260 mileposts 312 to 314

Figure 19. A heat map of replaced tag locations along SR 260 mileposts 323 to 325

Maintenance Cost Considerations

Fence Tag Costs – The fence tags used for this study were purchased at a discounted price of $1.00 per tag. The cost per fence tag may change in the future.

Labor Cost – Maintenance checks can be completed by one staff member, but are often more efficient with two, as this allows for a driver and a spotter on stretches where fence tags can easily be seen from the road. A two-member team could cover more ground in areas that require walking. It is generally considered good practice to allocate more time for on-foot inspection in areas covered with snow, or in open areas where high winds can dislodge or damage a large number of tags. Man-hour labor costs include the drive time to the nearest maintenance facility or origin of inspection trip per inspection day.

Vehicles and Mileage – Vehicles used for inspections include safety lights to warn motorists they are driving on the shoulder or pulling off the road to replace tags or inspect on foot. Mileage costs are calculated from the nearest maintenance facility or origin of inspection trip.

Additional Items – Use of a mobile app that is uploaded to GIS could help track areas with higher maintenance needs, which in turn can help staff members plan subsequent inspection times and potential tag replacements.

EVALUATION RESULTS AND DISCUSSIONS

This chapter describes the effectiveness of fence tags as a device to reduce AVC by using a pre-post analysis on the road segments assigned as treatment and control groups for each of the five study sites and for all five sites combined. Data on AVC from a three-year pre-fence-tag installation period (July 2015 to June 2018) were compared to a three-year post-installation period (July 2018 to June 2021). This chapter also documents changes in UV and blue light intensity emitted by the tags, as well as the fence tag brittleness over time.

Changes in Animal-Vehicle Collisions During the Study Period

A total of 339 AVC were reported on the evaluated segments during the study period from July 2015 through June 2021. This number is broken down into 196 total crashes between July 2015 and June 2018 and 143 between July 2018 and June 2021. A total of 151 AVC occurred on treatment segments where fence tags were installed, and 188 occurred on control segments where fence tags were not installed.

The number of AVC on treatment segments across all five study sites significantly decreased from 88 over years 1–3 to 63 over years 4–6, with an annual average reduction across all five sites of 25.4 percent (ranging from a 50.0 percent reduction to a 12.0 increase; Wilcoxon Signed Rank Test $U = -1.78$, $df = 1$, $P = 0.08$) (Figure 19). The highest reduction, 50 percent, was recorded along I-40 W. The number of AVC in the control segments across all five study sites also significantly decreased from 108 from years 1 to 3 to 80 from years 4 to 6, with an average reduction of 25.8 percent across all five sites (ranging from a 30.1 percent to a 20.0 percent reduction; Wilcoxon Signed Rank Test $U = -1.78$, $df = 1$, $P < 0.01$) (Figure 19). The research team did not detect a significant difference in the reduction of AVC between the treatment segment stretches and the control segment study sites (Wilcoxon Signed Rank Test $U = -0.42$, $df = 1$, $P = 0.68$).

Fluctuations in annual reported AVC were observed over the six-year evaluation period. The highest increase in AVC occurred in Year 2 across both treatment (63 percent) and control (45 percent) segments, followed by a downward trend, except for treatment segments that reported a sudden average increase of 80 percent in Year 6 (Figure 20). All of the test segments combined increased by 80 percent on average from Years 5 to 6. A breakdown by year and road segment are shown in Figures 21 and 22.

The above findings are consistent with results from a similar effort informally conducted by the ADOT North Central District. In that study, reflective tape was installed on the ROW fence in January 2019 along I-40 from Lone Tree Road (MP 196.3) to Butler Avenue (MP 198.3). The research team noted an increase in AVC from 19 over the 2.5 years pre-tape installation, to 22 over the 2.5 years post-tape installation, indicating that the reflective tape's ability to reduce AVC was also inconclusive.

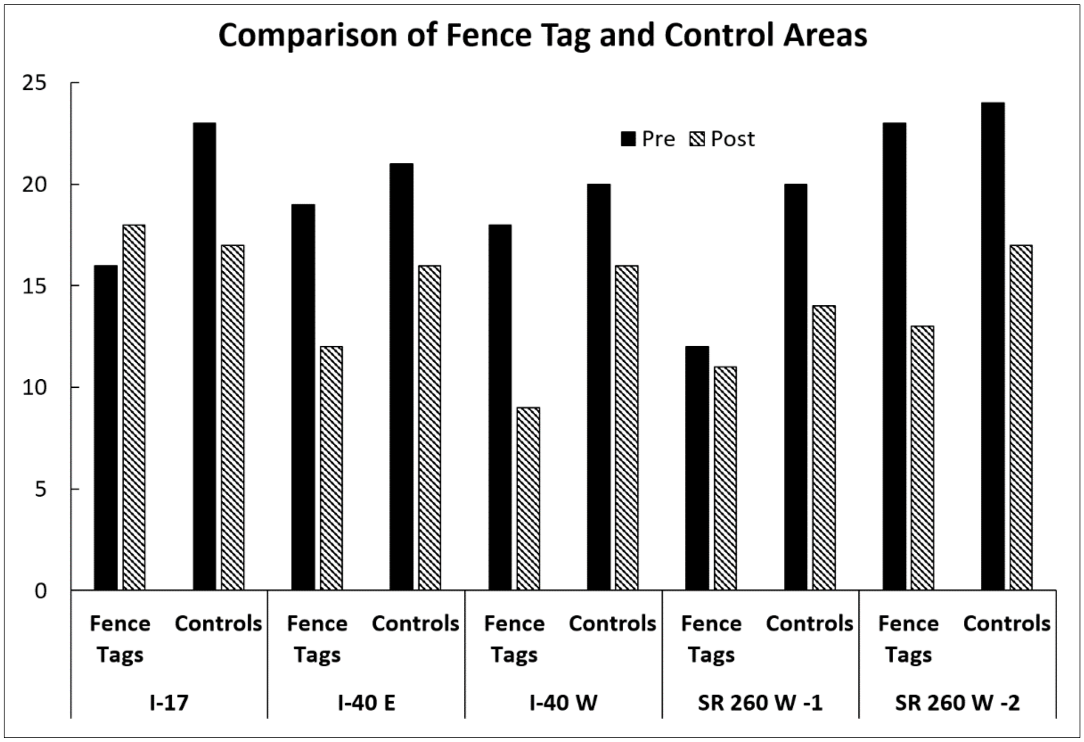

Figure 19. The number of AVC both before and after fence tag installation along treatment and control areas for all five study sites

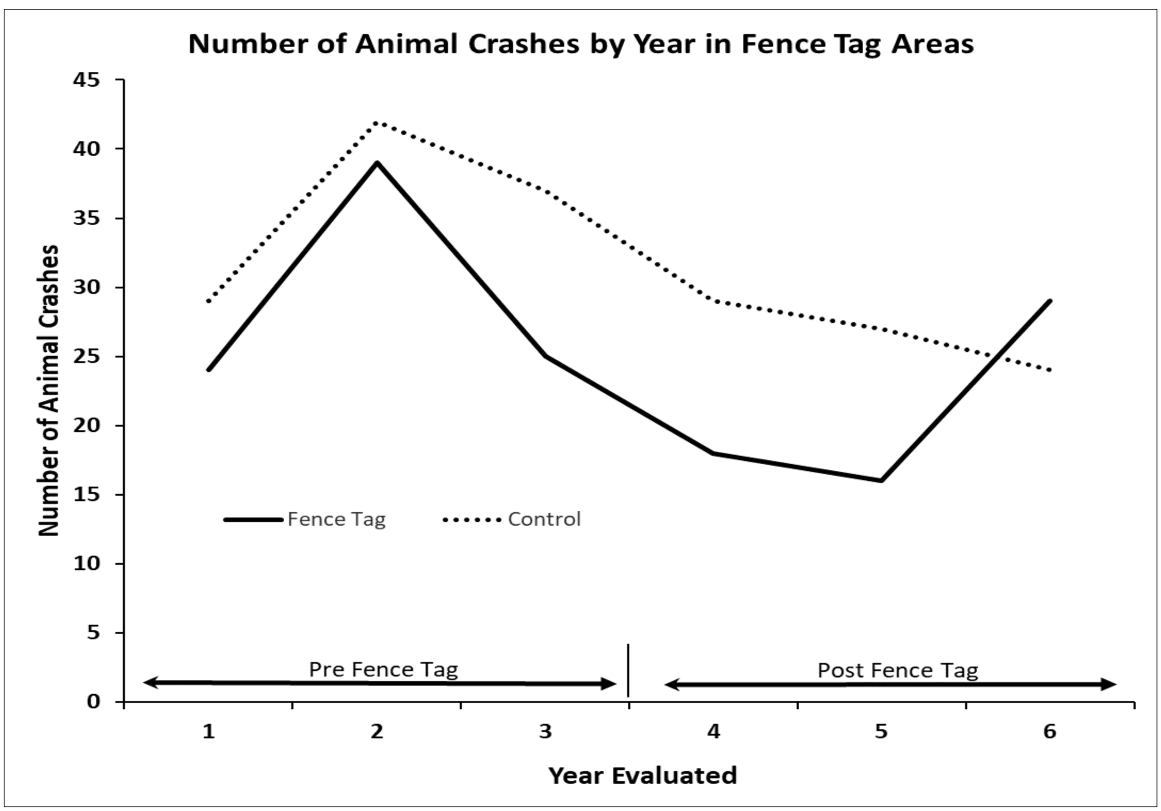

Figure 20. The number of AVC by year along the combined treatment and control areas for all five study sites

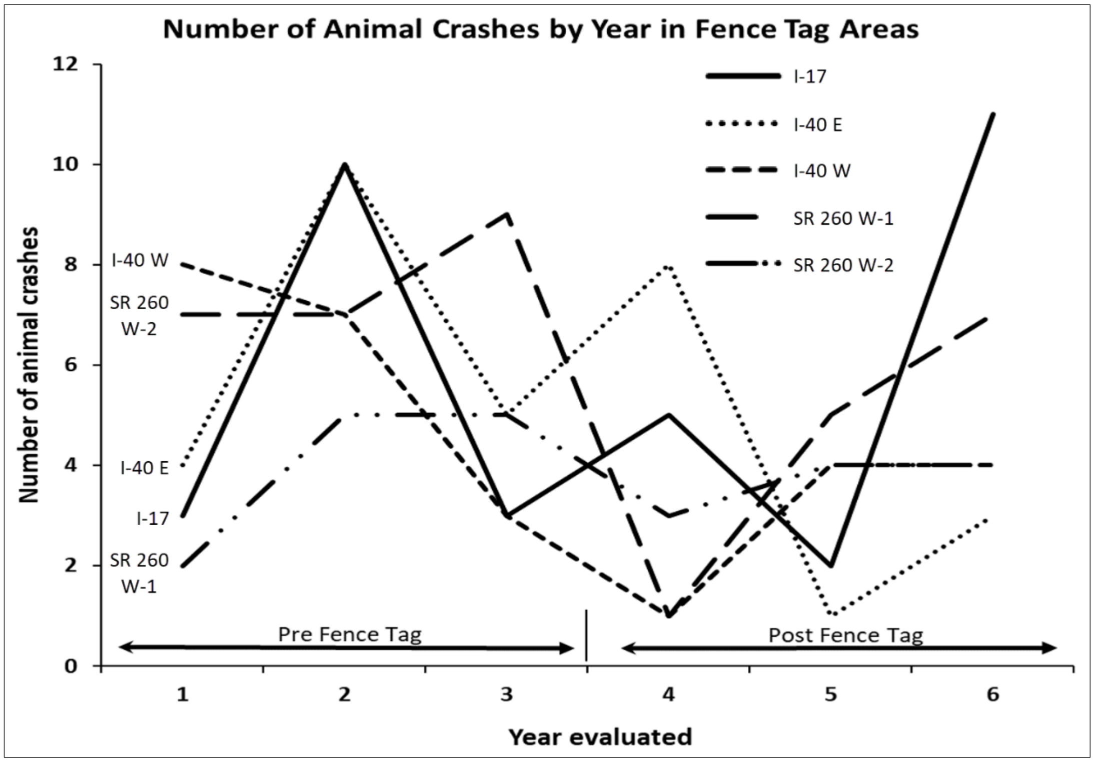

Figure 21. The number of AVC by year along fence tag areas for all five study sites

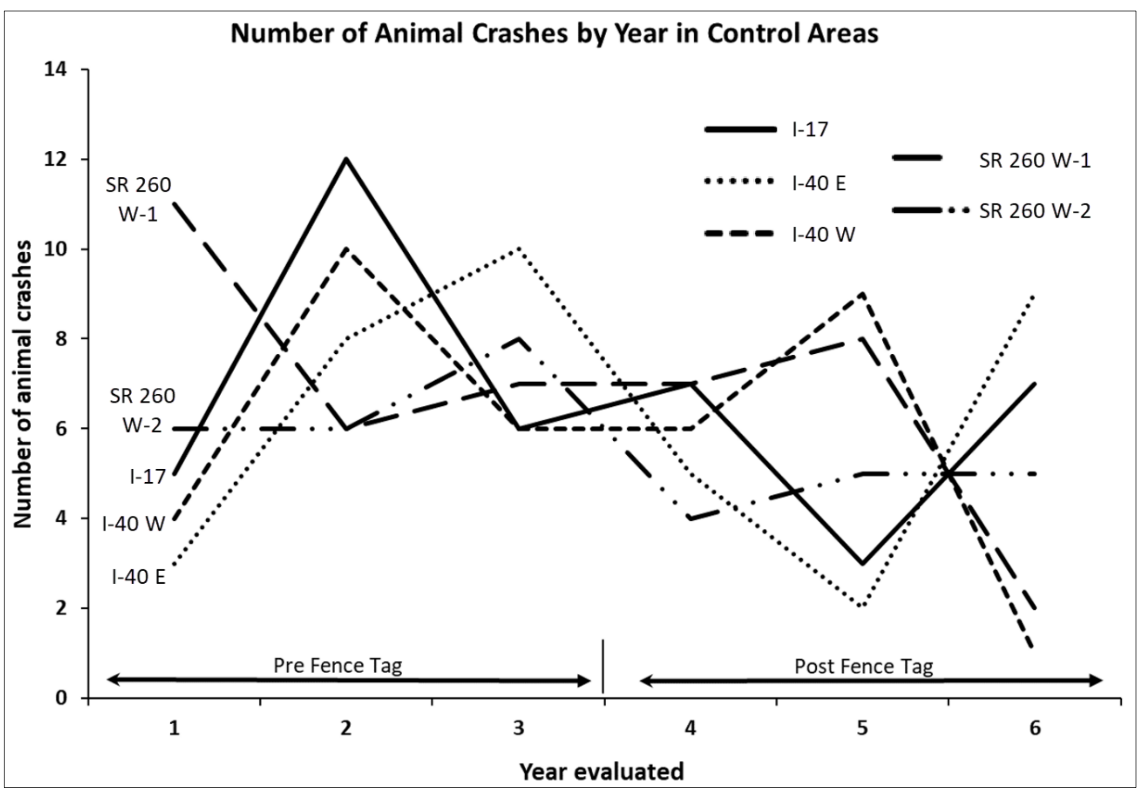

Figure 22. The number of AVC by year along control areas for all five study sites

Fence Tag Light Emission Intensity and Tag Brittleness Over Time

For UV intensity, blue-light intensity, and brittleness tests, the research team used both new tags and tags that had been randomly collected throughout the three years of deployment and kept in an envelope in a climate-controlled environment. The UV and blue-light intensity tests included a combination of over-the-counter and a custom-made monitors that measured UV emittance to as low as one microwatt/cm^2 and blue-light emittance to as low as one hundredth of a microwatt/cm^2. In individual tests, 22 sample tags were separately exposed to three hours of direct sunlight along a fence, and 20 sample tags were placed under a full-spectrum lightbulb in a dark room before taking averaged 30-second readings. The team documented no discernable levels of UV emittance either in new tags or in tags collected from the field. The team also documented minimal discernable levels of blue light emittance in new tags as well as in those collected from the field that had been exposed to sunlight (3 of 22 tags measured 0.01 microwatts/cm^2). Nominal levels of blue light emittance could be detected in the tags exposed to the full-spectrum bulbs at the following average rates:

- New tags: 0.014 microwatts/cm^2
- Tags collected in the first year: 0.016 microwatts/cm^2
- Tags collected in the second year: 0.012 microwatts/cm^2
- Tags collected in the third year: 0.010 microwatts/cm^2

Field evaluations identified that some tags showed erosion where they clipped on to the fence (Figure 7). To test this observation, the brittleness tests employed a weight scale that measured (in pounds) how much perpendicular force can be applied to the tag's fence clip before they came off the fence wire. All five new, unexposed tags bent instead of breaking and came off the fence wire at 49 pounds, on average (46–53 pounds). Of the tags collected during the first year of deployment, one bent at 54 pounds and the other four broke at the weak point without bending between 53 and 75 pounds, at an average of 66 pounds. Of the tags collected in the second year of deployment, all five broke off the fence between 47 and 61 pounds at an average of 49.6 pounds. Of the tags collected in the third year of deployment, all five broke off between 44 and 67 pounds at an average of 54.0 pounds.

Study Results

The research team's evaluation of three years of fence-tag implementation data provided inconclusive results. Although there was a significant reduction of AVC in the areas treated with fence tags, AVC within the control segments showed overall similar reductions. In one instance along I-17, ADOT crash data actually showed an increase in AVC within the treatment segments of the study sites. This outcome implies the following:

- There was not a statistically significant difference in the reduction of AVC between the treatment and control segments.
- External, confounding factors were not considered in the study and may have masked how effective the fence tags were.

Confounding Factors

A multitude of confounding factors may have contributed to the inconclusiveness of the study results. Many of the factors could be animal or environmental in nature, including drought or other climatic variables causing animals to cross roads more or less often. These factors may have also included acclimation by animals to the tags themselves over time. Other possible factors that may have influenced treatment and control segments on the same roadways that registered similar rates of AVC reduction are the presence of construction or maintenance activities during the study period. Furthermore, the application of reflective tape on I-40 may have affected the outcome; however, the use of multiple sites should have helped to mitigate this concern.

Uncommon traffic volume dynamics may also have contributed to changes in AVC during this study. For example, there was a sharp increase in AVC from 2020 to 2021 during the height of the Covid-19 pandemic. Although it may seem counterintuitive, theoretical wildlife-traffic interaction models demonstrated an increase in collisions. As traffic volumes decreased, animals that had been previously deterred from crossing by the presence of traffic now attempted to cross the roads.

Fence Tag Ultra-Violet and Blue Light Intensity

Based on the barely discernable amount of UV and blue-light emittance detected by a custom-built UV detector that was designed to detect as small as one hundredth of a microwatt/cm^2, the researchers expect that wavelength was likely not a factor in success or lack thereof of the tags. If animals were avoiding the fence, then it may have been due to the presence of a white, foreign object on the fence fluttering in the wind and glowing in the visible light spectrum. As the glow-in-the-dark tape is slightly visible to the human eye, it is likely also visible to animals.

Fence Tag Robustness

The fence tags became brittle one year after installation and broke instead of bending as the uninstalled tags did. The weight at which the tags broke was rather high at nearly 50 pounds, but this weight was not a concern due to the extreme unlikelihood of that much force occurring in the field. Due to the sheer number of tags that became dislodged in high-wind areas, it is likely that additional modifications could be made to the fence tag design to address this concern. If a coating is added and modifications are made to enable the tags to endure high winds, then the tags would be considered robust enough to last longer than three years.

RECOMMENDATIONS

This chapter provides recommendations based on the findings presented in the previous chapter.

The research team did not document a detectable rate of change in AVC during this study; however, additional information and discussions may help further explain and enhance the inconclusive results of this study to improve future animal-related studies. These actions include:

- Continued discussion of the study with ADOT
- Implementation of data collection forms that capture specific animal species in AVC data.

Continued Discussions with ADOT

A small reduction in AVC—particularly large animals like elk and deer that pose safety concerns to motorists—could be beneficial to ADOT. The effectiveness of fence tags, if any and however small, may have been masked by confounding external factors, such as changes in data-reporting protocol, variations in AVC reporting, environmental conditions, and road construction. The research team recommends continued discussions with ADOT on the use of fence tags as a mitigating technique. These discussions could include additional data mining and correlations with other available data sources (e.g., condition before, during, and after the fence tag installation for a longer study period; driver behavior; environmental conditions such as construction; crash-data reporting; the impact of changes in crash data collection etc.). New research focused on the study of fence tags' minimum effective size may also be beneficial.

Implement Data Collection Forms that Capture Animal Species

It is possible that different species react differently to the presence of fence tags. For example, deer may have avoided treated fences more than elk, or vice-versa. ADOT's current Arizona Crash Report used by Department of Public Safety and other law enforcement entities combines all animals into a single category called "Animal," which includes wildlife, domestic, and livestock. This combination of animal data does not allow for effective analysis of the type of animals that are hit by vehicles in a given area on ADOT roads. Better classified animal types would further enable ADOT to understand trends in AVC and better plan for future mitigation. For example, the animal crash mitigation required for elk and deer—8-foot high fencing— is quite different than that for horses and burros—standard livestock fencing (Dodd et al. 2012a, Gagnon et al. 2016, Gagnon et al. 2022). Bifurcating the Animal category to collect information that is even slightly more specific, such as several main animal types/species that are regularly hit on ADOT roads, would improve ADOT's mitigation decision-making. As data collection shifts toward digital formats, this additional categorization should not be too cumbersome to include during crash data collection in the field. The ultimate outcome would be a typical ADOT Crash Data query that could be evaluated by animal type/species.

- The research team recommends the inclusion of animal type/species in future data reporting of AVC.

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