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Report No. UT-17.15

TESTING NEW TECHNOLOGY TO RESTRICT WILDLIFE ACCESS TO HIGHWAYS: PHASE 1

Prepared For:

Utah Department of Transportation
Research Division and Region Four

Submitted By:

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Final Report
August 2017

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ACKNOWLEDGMENTS

The authors acknowledge the Utah Department of Transportation (UDOT), and the Utah Transportation Center at Utah State University for funding this research. The following individuals are also acknowledged for helping to guide and complete the research:

- Randall Taylor of Utah Department of Transportation
- Monte Aldridge of Utah Department of Transportation
- John Bissonette, Utah State University Department of Wildland Resources, U.S.G.S. Research Coop Unit
- Dan Coster, Utah State University, Department of Mathematics and Statistics
- Brad Hunt, Utah Division of Wildlife Resources, Hardware Ranch
- Kelly Pitcher Utah Division of Wildlife Resources, Hardware Ranch
- Dave Babcock, Retired, Utah Department of Transportation
- Richard Lampman of Lampman Wildlife Services
- Brad Truelove of Lampman Wildlife Services
- Directors of the Utah Transportation Center, Utah State University –Kevin Heaslip (former co-director) and Paul Barr
- Rhett Boswell of Utah Division of Wildlife Resources
- Ashley Green of Utah Division of Wildlife Resources
- Pam Kramer of Utah Division of Wildlife Resources
- Utah Division of Wildlife Resources Dedicated Hunter Program and N. Madsen, T. Lowe, T. Wagstaff, C. Peterson, A. Shaw, W. Evans, J. Barratt, C. Snider, S. White, S. Morgan.
- Robert Hamlin
- Lauren Flower
- Richard Flower

TECHNICAL REPORT ABSTRACT

1. Report No. UT-17.15	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle TESTING NEW TECHNOLOGY TO RESTRICT WILDLIFE ACCESS TO HIGHWAYS: PHASE 1		5. Report Date August 2017 6. Performing Organization Code
7. Author(s) Patricia Cramer, Joseph Flower		8. Performing Organization Report No.
9. Performing Organization Name and Address Utah State University Department of Wildland Resources Old Main Hill Logan, UT 84322		10. Work Unit No. Region 4 Preconstruction 11. Contract or Grant No. NA
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered Final August 2013- December 2015 14. Sponsoring Agency Code Region 4 Preconstruction

15. Supplementary Notes

Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Wildlife mitigation systems are as good as the weakest link. Often this is the wildlife exclusion barriers at vehicle access points in wildlife exclusion fencing (8 feet, 2.4 m high). The objective of this research was to find new technology solutions to reduce wildlife access to highways at single cattle guard barriers by augmenting the guards with a product that was as effective as the best deterrents, double cattle guards and wildlife guards. The study first looked at effectiveness of existing barriers with camera traps at 14 locations. In the second step, electric pavement strips were placed in front of single cattle guards at six baited wildlife exclosures in a wild area, in widths of three and four feet. Finally, an electric pavement strip, three feet (0.9 m) wide, in front of an existing single cattle guard at a road interchange at I-15, Exit 31 was evaluated. Double cattle guards and wildlife guards were the most effective design at excluding mule deer from entering roadways; effectiveness was 87 -94 percent in deterring the individual animal approaches. Single cattle guards augmented with electric pavement at baited wildlife exclosures were 91 percent effective in deterring mule deer individuals. Electric pavement at the in-road cattle guard was 64 percent effective in deterring individual mule deer approaches. Recommendations include further research on widths of electric pavement in various settings, and standards within UDOT that include double cattle guards and wildlife guards as the current preferred barrier, and escape ramps near all barriers because no barrier is 100 percent effective in keeping wildlife from entering fenced roads.

17. Key Words wildlife, mule deer, elk, ungulates, wildlife-vehicle collisions, animal-vehicle collisions, AVC, WVC, A-V-C, cattle guards, wildlife guards, double cattle guards, electric pavement, access, wildlife crossings, Utah, wildlife fencing, electric mats		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	70	22. Price N/A	

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UNIT CONVERSION FACTORS

Units used in this report and not conforming to the UDOT standard unit of measurement (U.S. Customary system) are given below with their U.S. Customary equivalents:

- 1 centimeter (cm) = 0.393 inches (in)
- 1 meter (m) = 3.28 feet (ft.)
- 1 kilometer (km) = 0.62 mile (mi)
- 1 degree Celsius (C) = 33.8 Fahrenheit (F)

LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
FHWA	Federal Highway Administration
kV	Kilovolt
PDO	Property damage-only crashes
ROW	Road Right of Way
UDOT	Utah Department of Transportation
UDWR	Utah Division of Wildlife
USU	Utah State University
WVC	Wildlife Vehicle Collisions

EXECUTIVE SUMMARY

Mitigation solutions to reduce wildlife-vehicle collisions are only as effective as the weakest link in the infrastructure. In a mitigation system of wildlife crossing structures, wildlife exclusion fencing, wildlife escape ramps, and cattle guards at vehicle access points in the fence, it is often the wildlife deterrent barriers (cattle guards and wildlife guards) that become those weak links. Mule deer (*Odocoileus hemionus*) and other wildlife often find ways to breach these barriers to enter roadways. The goal of this Utah Department of Transportation (UDOT) sponsored study was to find innovative solutions to reduce wildlife access to highways at single cattle guard barriers by augmenting the guards with a product that was as effective as the best deterrents, double cattle guards and wildlife guards.

A three-step study was conducted to evaluate the innovative approach's effectiveness in deterring mule deer from entering the fenced road right-of-way. First, five existing types of wildlife deterrent barrier designs to control mule deer intrusions through fence openings were evaluated to determine the designs with the highest level of effectiveness. Second, the study evaluated whether standard cattle guards augmented with strips of electrified pavement could as effectively deter mule deer and elk (*Cervus canadensis*) intrusions into fenced and baited exclosures in a wild setting as the top wildlife deterrent barrier designs. Third, the study evaluated if an existing single cattle guard augmented with a strip of electrified pavement was as effective in reducing mule deer intrusions into a highway corridor as the most effective wildlife deterrent barriers.

In the initial step of the study, cameras traps were used to evaluate mule deer reactions to single cattle guards with and without excavation pits, electric mats, double cattle guards, and wildlife guards (steel grates the width and length of double cattle guards). Cameras at six single cattle guards documented 619 mule deer approaches. Single cattle guards with excavated pits (n=4) were on average 53 percent effective in deterring mule deer, while the two cattle guards with no excavated pits below were on average 29 percent effective. Two electric mats placed in two different roads had 165 mule deer approaches recorded by cameras, and were effective in deterring 12 percent of the mule deer. Two wildlife guards and four double cattle guards had a combined total of 1,162 mule deer approaches. Wildlife guards were on average 87 percent

effective, and double cattle guards were on average 94 percent effective. Statistical model results confirmed the design of the barrier was the most important predictor of effectiveness.

In step two, single cattle guards augmented with segments of electrified pavement three and four foot-wide (0.9 and 1.2 m) were 91 percent effective in excluding individual mule deer (n=166), and greater than 99 percent effective in excluding individual elk (n=605) from baited wildlife exclosures constructed in a natural area away from roads. In step three, when a three-foot wide (0.9 m) segment of electric pavement was installed into the road surface in front of an existing cattle guard at an access road to Interstate 15, it was found to be 64 percent effective in deterring the 36 individual mule deer approaches.

The discrepancy in electrified pavement efficacy between the wild and in-pavement sites may be due to two primary factors, motivation and insulation. Deer trying to get across I-15 were almost certainly more motivated than deer approaching a new baited exclosure. The electric pavement potential when placed next to earth was different than pavement embedded in asphalt. In the wild setting, the electric pavement potential between the edge of the pavement and the soil was 4-5 kV. The electrical potential in the road setting at I-15 between the pavement and the asphalt was negligible. As a result, photos documented animals in the wild setting detecting and at times being shocked at the edge of the pavement prior to ever placing a hoof on it. At the pavement setting, the photos appeared to show mule deer not detecting an electric shock with their noses or first hoof placement on the first electric pavement panel. It was not until animals straddled the first (negative) and second (positive) panels that they began to receive electric shocks. By the time that occurred, mule deer were already in transit to the road right of way and may have been less apt to turn around and return to the wild area as they belatedly received electrical stimulus through their hooves than they would have been if they received an electrical shock prior to taking their first step. The conditions at the paved road location were more indicative of future installments of electric pavement. Researchers hypothesized the strip of electrical pavement used in the pavement near I-15 may have been too narrow to effectively deter mule deer from moving across. Future wider installations may be more effective.

Recommendations included:

1. Double cattle and wildlife guards should be UDOT's preferred wildlife barrier in fencing.

2. A single cattle guard in the road, augmented with a 3 to 4 foot-wide (0.9 to 1.2 m) strip of electric pavement did not effectively deter mule deer. Research into alternative designs is needed.

3. Single cattle guards augmented with electric pavement will need to be further developed so that the animals receive an electrical current at the leading edge of the electric pavement, or the animals have a greater length of electric pavement to traverse to access the road corridor, both of which would help to deter them from continuing forward.

4. The study found no barrier at vehicle access points is 100 percent effective. Therefore, all wildlife barriers in wildlife exclusion fencing should also be placed with wildlife escape ramps.

5. Wildlife exclusion fence should only be placed with wildlife crossing structures or appropriate existing structures in areas where wildlife need to access both side of the road.

6. Alternative designs of electric pavement, such standalone installations across lanes of traffic at the end of wildlife exclusion fence, and augmented single cattle guards should be further tested.

1 INTRODUCTION

Wildlife mitigation solutions to reduce wildlife-vehicle collisions (WVC) are only as effective as the weakest link in the infrastructure. In a system of wildlife crossing structures, wildlife exclusion fence, escape ramps, and wildlife deterrent barriers such as double cattle guards at vehicle access points, the wildlife deterrent barriers can become those weak links as mule deer (*Odocoileus hemionus*) and other wildlife find ways to breach them to enter roadways. This study evaluated a new approach to augment single cattle guards with electric pavement to increase their effectiveness in deterring mule deer from passing over the guards and entering road rights-of-way. The research was initiated in 2013 as a joint effort between Utah Department of Transportation (UDOT), Utah State University (USU), and the Utah Transportation Center at USU, and completed in 2016. The research was conducted in conjunction with Joseph Flower's master's thesis research, which was funded in part by the Utah Transportation Center at Utah State University. Mr. Flower worked under the supervision of Dr. Cramer. This report was largely taken from Mr. Flower's master's thesis.

1.1 Background Information

Vehicle collisions with wildlife pose safety risks to the motoring public, which lead to significant economic losses, and threaten wildlife populations. In 2015 there were 3,232 WVC reported as crashes to the UDOT (Utah Department of Transportation Numetric Crash Data Website 2016). The accumulated cost to society of these crashes; a single fatality, 19 serious injuries, 81 minor injuries, 127 possible human injuries, and 3,004 property damage only crashes was $66,686,700. This was based on monetary values UDOT estimated for 2015 for the four types of crashes, using traffic safety estimates.

These WVC also affect wildlife populations. The 3,232 reported crashes likely represent only a fraction of the total ungulates (hooved wildlife) killed in collisions. Olson (2013) found that in Utah, carcass numbers collected in his study were 5.26 times higher than reported crashes. Using this conversion factor, Utah's 2015 WVC at minimum killed 17,000 mule deer. While these collisions were found to not significantly affect mule deer populations in Utah (Olson et al.

2015), they ultimately have some negative affect on both mule deer and other wildlife populations across the state.

The most effective method to reduce WVC while providing connectivity for wildlife is to place wildlife crossing structures with wildlife exclusion fencing (Hedlund et al. 2004). Wildlife fence prevents wildlife access to the roadway and guides animals to crossing structures that facilitate safe passage under or above the road. When fencing and structures are working correctly they can reduce WVC on average by 86 percent of pre-construction of fence and wildlife crossing structures numbers (Huijser et al. 2009). A challenge to maintaining effective fencing and wildlife crossing structures is the management of wildlife intrusions at access roads that bisect wildlife fencing. If access roads that bisect fencing are not designed with an effective deterrent to exclude ungulates and other wildlife from entering the road, wildlife crossings and fencing can become ineffective (Peterson et al. 2003, Sawyer et al. 2012, van der Ree et al. 2015). While gates are the best method to exclude large animals from designed openings in wildlife fencing (van der Ree et al. 2015), they are not an option on public roads. Standard cattle guards, eight foot-wide (2.4 m) across as a vehicle travels over them, are ubiquitous in the Western U.S. and are common at designed breaks in wildlife exclusion fencing. While cattle guards are generally effective at preventing hoofed livestock from accessing highways, they are largely ineffective as barriers to deer which are the species that account for the vast majority of WVC in the U.S. (Reed et al. 1974, Ward 1982, Huijser et al. 2008, Sawyer et al. 2012).

1.2 Problem Statement

There is a critical need to upgrade, augment, or replace standard cattle guards with deterrents capable of preventing wildlife, especially deer, from entering fenced highway corridors and other protected areas (Cramer 2012, Randall Taylor, UDOT, personal communication). Previous studies have assessed the effectiveness of double cattle guards, (two adjoining standard cattle guards), wildlife guards (steel grates the width and length of double cattle guards), and electrified mats (composite planks with embedded electrodes (U.S. Army 2006, Seamans and Helon 2008, Allen et al. 2013, Siepel et al. 2013), but efficacy estimates were derived using widely varying methods, rigor, and sample sizes. The combined lack of

scientific knowledge on the efficacy of various wildlife deterrent designs and the high cost of placing double cattle guards and retrofitting single cattle guards resulted in the need for a study on efficacy of existing guards and cost-effective option alternatives to double cattle guards.

In this study researchers explored different types of technologies that could be added to single cattle guards that could further repel animals by possibly acting on their hearing, visual, smell, and other senses. These devices could use electric current, sound, scent, visual barriers, or visual movement that would act to repel approaching animals from trying to jump the single cattle guard. Enhancement of the effectiveness of traditional single cattle guards needs to provide a credible threat to deer and other ungulates to be effective. Deterrent devices designed to simply frighten deer are not effective over extended periods because deer habituate to them (Bombford and O'Brien 1990, Hygnstrom et al. 1994, Curtis 1997, Belant et al. 1998a, b, and c, Beringer et al. 2003). Current deer deterrence research indicates that without a credible threat or some aspect of pain (e.g., electric shock) deer will not alter established usage or movement patterns (Thomas Seamans, United States Department of Agriculture, personal communication). Electricity may offer the most feasible mode of action to deliver a negative reinforcement to animals that attempt to breach animal barriers. Although results from subsequent monitoring of electrified mats on roadways appear mixed (Siepel et al. 2013), the avoidance response observed by Seamans and Helon (2008) indicated that augmenting an existing barrier with an electrical deterrent may minimize the frequency of deer breaching cattle guards.

1.3 Objectives

The goal of the UDOT sponsored portion of the study was to find innovative solutions to reduce wildlife access to highways at single cattle guards by augmenting the guards with a product that was as effective (within five percent) as the best and more expensive deterrents, double cattle guards and wildlife guards. A secondary objective of this study was to determine the average effectiveness of five different types of wildlife barrier designs in use in Utah in preventing mule deer access to highways. The level of effectiveness for most successful types of wildlife deterrents would then serve as a performance measure for evaluating the effectiveness of the augmented single cattle guard. The overall objective was to evaluate whether a standard

cattle guard augmented with a strip of electrified pavement could reduce mule deer and elk (*Cervus canadensis*) breaches over the barrier at rates comparable to double cattle guards and wildlife guards.

1.4 Outline of Report

This report is presented in five chapters and an appendix. In this introductory chapter, the need for this study is introduced. In Chapter 2 the methods used to evaluate the potential to augment existing single cattle guards with electric pavement to deter wildlife are presented in two parts: at an experiential study in the wild at baited feeding exclosures, and at a single cattle guard in an entrance road at Interstate 15. Chapter 3 presents the results of the two parts of the study. In Chapter 4 the discussion and conclusions are presented. The overall recommendations and implementation of this research are presented in Chapter 5. In Appendix A, the evaluation of the efficacy of existing wildlife barrier deterrents is presented.

2 METHODS

Electricity was chosen as the device that could consistently deliver negative reinforcement to wild animals that attempted to breach wildlife deterrent barriers. This was chosen through a review of the existing literature and conversations with wildlife professionals experimenting with methods to deter deer from entering fenced areas, as documented in Flower (2016). At the formation of this research, an independent wildlife deterrent products company, Lampman Wildlife Services, was developing electric pavement to place in vehicle access points along fencing. The researchers worked with this company to test their products in conjunction with single cattle guards.

The study was conducted by placing segments of electric pavement in front of single cattle guards at: the entrances to baited wildlife exclosures at the Hardware Ranch Wildlife Management Area in Northern Utah during a feeding exclosure trial; and in an access road at an interchange of Interstate 15 (I-15) in Southern Utah (Figure 1). Mule deer and elk reactions to the electric pavement were monitored with professional series camera traps.

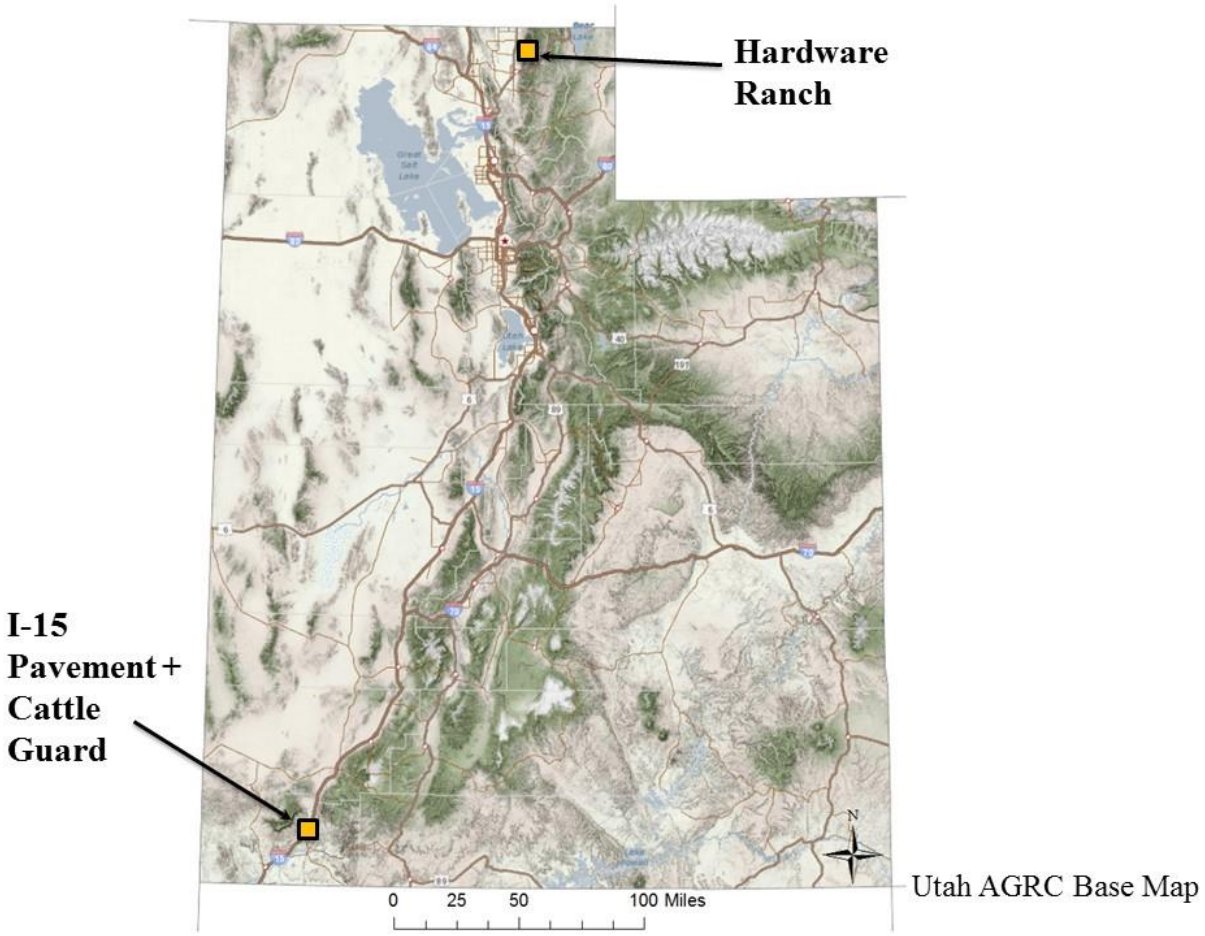

Figure 1. Locations of Study Sites in Utah.

2.1 Feeding Exclosure Trial

The feeding exclosure trials were conducted at fenced wildlife exclosures within the 5,778 ha Utah Division of Wildlife Resources (UDWR) Hardware Ranch Wildlife Management Area (Hardware), in Cache County, in northern Utah. The Hardware serves as wintering habitat for mule deer and elk, where there has been a winter feeding program for elk since 1947. This program was active during the feeding exclosure trials from 13 December 2014 to 9 February 2015. Although elk are provided supplemental grass hay, mule deer are prevented from accessing feed by socially dominant elk that exclude deer from the feeding area (Brad Hunt, UDWR, personal communication, Johnson et al. 2000, Stewart et al. 2002). Wildlife habitat within Hardware includes sagebrush communities, grassland, open woodlands, meadows, and

riparian corridors. Depending on winter severity, the number of wintering mule deer within Hardware numbers from 500 to 1,000 individuals (UDWR 2012). The estimated minimum mule deer population in the immediate study area was 200 during the study from fall 2014 to spring 2015 (Darren DeBloois, UDWR, unpublished data). The number of wintering elk within Hardware ranges from 450 to 650 individuals (UDWR 2012). The estimated minimum elk population in the immediate study area during the evaluation was 600 (Darren DeBloois, UDWR, unpublished data).

The feeding exclosure trial involved six pens, each with wildlife exclusion fences, a single cattle guard at the entrance augmented with an electric strip, food bait, and a camera trap placed in the middle of the pen. Mr. Flower built both the pens and the single cattle guards. Each exclosure was constructed of 6 feet (1.8 m) high woven wire fencing with a single strand of white, braided nylon-copper rope (ElectroBraid Fence Limited) added to the top to increase the fence height to 7.5 feet (2.3 m). The sides of the pens were 30 feet (10 m) long. At a 10 foot-wide (3 m) opening centrally located on one side of each exclosure, Mr. Flower constructed a simulated wooden cattle guard, 10 feet (3 m) by seven feet (2.1 m), and approximately level with the ground, Figure 2. The guard was suspended over a 3-foot deep (0.9 m) excavated pit. Additional cattle guard descriptions are detailed in Flower (2016). The pens were baited with alfalfa pellets to motivate deer and elk to attempt to cross over the experimental guards. The camera trap was placed on a pole in the center of the pen, facing the entrance.

The electrified pavement device (Lampman Wildlife Services, Ontario, Canada) augmented the simulated cattle guards with two different widths. Both pavements were 10-foot long (3 m) and were either 3-foot (0.9 m) or 4-foot wide (1.2 m) (dimension traversed by an animal entering the exclosure). The electrified material was contained by a rectangular plastic board form filled with a black conductive material impregnated with a matrix of stainless steel bits that delivered an electrical potential to the entire surface of the pavement-like segment. An additional yellow plastic board installed lengthwise in the center of the form partitioned it into two sections, with the outermost board charged negative, and the board next to the cattle guard charged positive, Figure 2. The negatively and positively charged surfaces created a difference of electric potential between the two surfaces meant to deliver a high-voltage (9.9 kV), short duration ($<$ 3/10,000 second) shock to animals in simultaneous contact with both surfaces. The

electric pavement was powered by a Stafix X3™ 3-Joule solar-powered energizer (Tru-Test Limited), which delivered a maximum output voltage of 11.4-kilovolts to the conductive segments at approximately 1.5-second intervals. A 40-watt solar panel, solar charge controller, and 12-volt deep-cycle battery were placed within each exclosure and provided continuous power to the system.

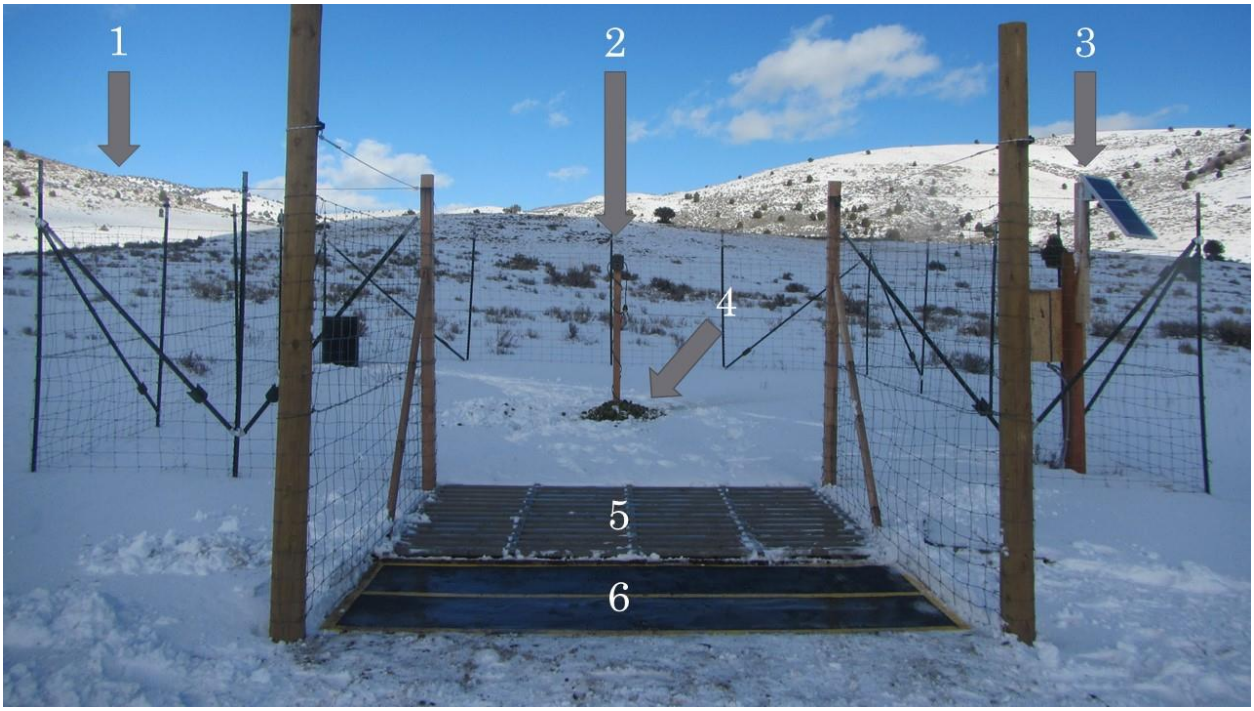

Figure 2. Front View of a 30 by 30 Feet (10 × 10 m) Wildlife Exclosure Used to Test Efficacy Cattle Guards Augmented with Either 9 feet by 4 feet (3 × 1.2 m), Pictured, or 9 feet by 3 feet (3 × 0.9 m) Electrified Pavement as a Wildlife Deterrent Barrier at Hardware Ranch Wildlife Management Area, Utah.

Symbols added to indicate exclosure elements: 1 = 7.5 feet high woven wire fencing, 2 = motion activated camera (Reconyx PC800), 3 = solar panel, 4 = alfalfa feed bait, 5 = simulated cattle guard, and 6 = electrified pavement device, outside panel is negative. Taken from Flower 2016.

The Reconyx Model PC800 motion activated camera was installed on a post 6 feet (1.8 m) high and at the center of each exclosure and positioned to record wildlife approaches and behavioral reactions. Camera settings were programmed for 5 to 10 consecutive photographs rapid fire each time the camera was triggered, with no down time between triggers.

Spacing between exclosures was maximized to reduce interdependence of deer and elk visitation and behavior among the exclosures. Average spacing of exclosures at Hardware was 0.7 miles (1.1 km). The minimum and maximum distance between two exclosures was 0.4 and 1.1 miles (0.6 km and 1.8 km), respectively. All exclosures were located at similar elevations and within comparable habitat. We used a randomized complete block design and partitioned the six experimental units into two separate experimental blocks. Treatment 1 was the 3 foot-wide (.9 m) pavement, Treatment 2 was the 4 foot-wide (1.2 m) pavement, and the control was fitted with just a single cattle guard (Figure 3). Further details are presented in Flower (2016).

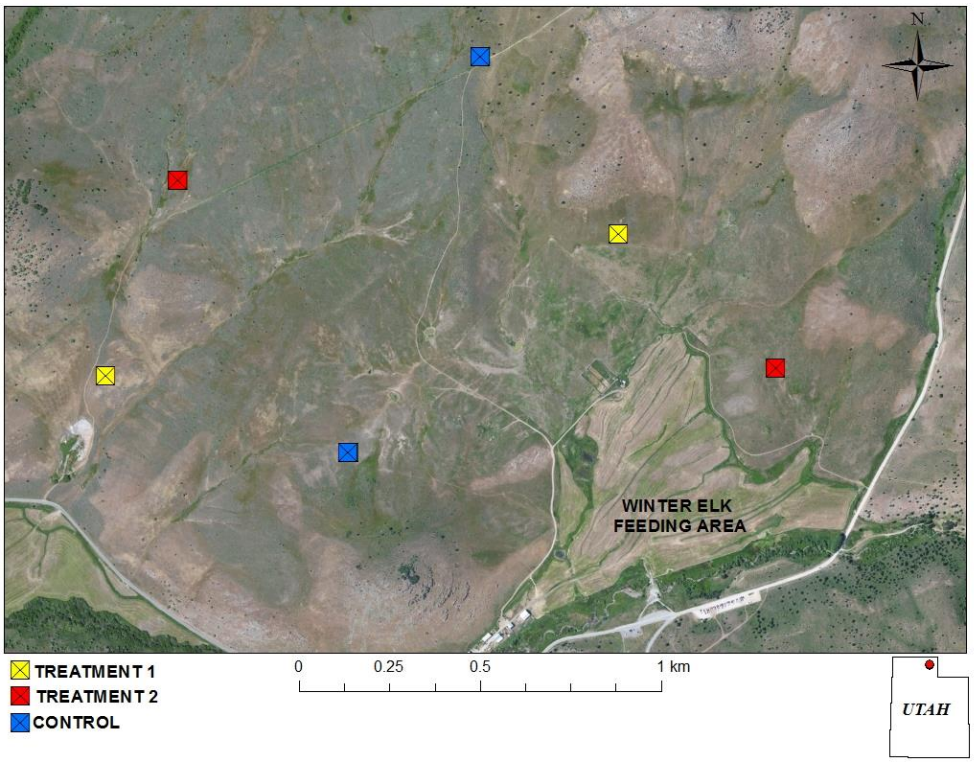

Figure 3. Wildlife Exclosures, Hardware Ranch, Wildlife Management Area, Utah.
Figure taken from Flower 2016.

The experiment was set up as a Before, After, Control, and Intervention (or treatment) (BACI) design (Roedenbeck et al.2007). This allowed for an analysis of the data to truly find if the electric pavements were the reasons for the deterrence of wildlife. The 'before' treatment period was October 13 through November 16, 2015. Mr. Flower placed soil on plywood on top of the pavement and guards and turned off the electricity. Alfalfa pellets were placed in the

exclosures and at the entrances. This allowed animals to habituate to the exclosures, find the alfalfa pellets, and establish consistent use. The sites were checked by Mr. Flower every other day to maintain feed and voltage, and to make sure no animals were trapped in the exclosures.

The treatment period ('After' and 'Intervention' in the BACI) began 16 November, and ran to 16 March 2015. There were no wooden sheets or soil on the deterrents, the pavement strips were energized, and the cameras continued to monitor animal approaches. During those 17 weeks, the exclosures were visited by Mr. Flower weekly at minimum to: 1) maintain fresh feed; 2) clear accumulated snow; 3) maintain continuous operation of the electrified material and cameras; 4) ensure no wildlife had become entangled in the fencing or guards; and 5) estimate snow cover and record snow depth atop the deterrents. In total, the sites were maintained for a total of 22 weeks, from 13 October 2014 to 16 March 2015.

There were two wildlife exclosures with only a single cattle guard and no electric pavement that functioned as the 'control' setting for the experiment. These were treated as the other exclosures, with a 'before' treatment of boards and soil on the guards, then an 'after' period with the boards and soil cleared.

The voltage on the electric pavement was an important factor in the treatment of the deterrents. At treated sites, weekly voltage readings were 9.8 - 9.9 kV, except on one occasion when the voltage dropped below 7.0 kV at one site due to a faulty solar energizer, which was replaced. Electrical potential existed between the negatively and positively charged surfaces of the material (9.9 kV), and between the negatively charged surface of the material on the outside panel and the soil in front of the deterrent (earth ground, 4-5 kV).

2.2 Interstate 15 in-the-Road Trial

The road trial *in situ* was conducted at Exit 31 of I-15 on the western side access road, near the town of Pintura, in southern Utah. This interchange was selected as a test-site due to high mule deer activity documented in the area during pre-electric pavement installation camera monitoring in 2013-2014 (see Appendix A), and low vehicle traffic volume on the access road leading to the interstate. I-15 is a four-lane divided highway at this location, with a posted speed

limit of 75 miles per hour (120.7 km/hour) and annual average daily traffic (AADT) of 21,675 vehicles (Utah Department of Transportation 2015). There are no wildlife crossing structures located on I-15 for miles north and south of this interchange, but the Ash Creek Reservoir Overflow culvert is located 5.2 miles (8.5 km) north. The culvert is 26 foot-high and wide by 135 foot-long (8 x 8 x 41 m), and is placed in a trench of volcanic rock. Cramer (2014) found several to a dozen mule deer successful movements through this structure yearly. The landscape adjacent to the interchange is heterogeneous, with mule deer summer range in the Pine Valley Mountains on the west side of the interstate, and winter range in low-lying valleys and small agricultural areas on the east side. The interchange is recognized as an area where mule deer often gained access to the I-15 right-of-way while traveling seasonally between summer and winter ranges (Rhett Boswell, UDWR, personal communication, data from this study). Habitat in the area includes sagebrush communities, conifer woodlands, riparian corridors, and small agricultural areas. Public lands adjacent to the interchange are under management of the U.S. Forest Service (west side; Dixie National Forest) and the U.S. Bureau of Land Management (east side; Color Country District).

Standard single cattle guards span access roads on the west and east side of the interchange and are located at openings in continuous six foot-high (1.8 m) wildlife exclusion fencing. The west side cattle guard was augmented with electrified pavement that was three foot-wide by 36 foot-long (0.9 m × 11 m) installed along the full length of an existing standard cattle guard 6.8 foot-wide by 36 foot-long (2.1-m × 11-m; Figure 4. Cattle Guard Augmented with Electric Pavement 3 x 36 feet at West Access Road to I-15 at Exit 31, Near Pintura, Utah.

4). The west side single cattle guard was monitored pre-electric treatment from April 2014 into early June 2014, when the electric pavement was installed June 18th, then monitored post treatment June 2014 – March 2015. The single cattle guard on the east side of I-15 at this location was continually monitored during the study, as a control site, both before and after the west side treatment of electric pavement (October 2013 – March 2015).

Materials used in the construction of the electrified pavement here were identical to those used in the feeding exclosure trial. The electrified pavement was powered by components identical to those used in the feeding exclosure trial, and remained at the same voltage, 7,000 to

10,000. However, unlike the electric potential at electric pavements at Hardware, there was no electrical potential between the negative surface of the outside panel of the deterrent and the asphalt surface of the road, and only negligible potential (0.3 kV) between the positive surface of the deterrent and the surface of the road. To deter theft, components were located inside a steel box within an adjacent locked fenced area. A warning sign was installed advising pedestrians to use an adjacent gate in the fence (Figure 4. Cattle Guard Augmented with Electric Pavement 3 x 36 feet at West Access Road to I-15 at Exit 31, Near Pintura, Utah.

4).

Figure 4. Cattle Guard Augmented with Electric Pavement 3 x 36 feet at West Access Road to I-15 at Exit 31, Near Pintura, Utah.
Figure taken from Flower, 2016.

One motion activated camera (Reconyx Model PC85) was placed inside of a utility box on each end of the guard to monitor mule deer and wildlife reactions to the electric pavement and single cattle guard. The cameras faced each other across the guard. Cameras were programmed

to take 3-5 images rapid fire for each motion trigger, with no down time. At the start of the post-electricity monitoring, cameras were programmed to be off from 10 am to 4 pm to prevent power loss from repeated vehicle detections. On November 29, 2014 the inactive period was eliminated and cameras were left on 24 hours after the photo data and camera batteries proved the cameras could be left on at all times. Cameras were checked monthly to download images, change batteries, and ensure operation of the electrified pavement. Cameras continuously monitored wildlife approaches from mid-June 2014 to mid-March 2015.

2.3 Image Analysis

Photographs were analyzed with respect to animal reactions to the various guards and pavement. Reactions were tallied in a custom Access database (Microsoft Corporation 2013). Mr. Flower analyzed all images to ensure consistency and limit observer bias. All unique individual wild animal movements recorded by cameras at each monitoring location were categorized and tallied as follows:

- **Breach** - movements directly over the electric pavement or single cattle guards;
- **Repellency** - movements away from the electric pavement or cattle guard after an interaction that originated outside of the fenced area. An interaction was defined as stepping on, smelling, or looking at the electric pavement or cattle guard with an apparent intent to cross;
- **Parallel** - movements without an interaction within 6 feet (1.8 m) of the electric pavement or cattle guard;
- **Movements** – number of individual mule deer movements within 6 feet (1.8 m) of guard where the animals appeared to interact with the guard, (as defined above in repellency), and equal to the breach movements plus the repellency movements;
- **Edge Breach** - movements over the electric pavement between the fence and the edge of the electric pavement;
- **Inconclusive** – the results of the mule deer approach could not be determined;
- **Percent Effective** - repellency movements divided by movements.

When animals were greater than six feet (1.8 m) from the deterrent, what they did was not considered indicative of interacting with the pavement and their presence was not tabulated, since those movements were not considered indicative of deterrent effectiveness (Allen et al. 2013). Only animal movements that originated from outside of the fenced-highway corridor were included as animal movements. Movements when animals breached or repelled from the guard as they attempted to escape the highway right-of-way were omitted. Animals that breached the guard while escaping the right-of-way were not considered indicative of the effectiveness of the experimental guard because: 1) animals that breached the guard while escaping the right-of-way only encountered the electric deterrent after breaching the cattle guard, 2) animals that attempted to escape the right-of-way may have been more motivated to cross the guard than animals that attempted to gain access to the right-of-way (Allen et. al 2013), and 3) the purpose of the guard was to deter animal entry into the right-of-way, rather than to prevent animal escape from the right-of-way.

2.4 Statistical Models

The null hypothesis was that mule deer would be as equally likely to cross single cattle guards treated with electrified pavement as untreated single cattle guards. The alternative hypothesis was that mule deer would be less likely to cross treated cattle guards than untreated cattle guards. Similar hypotheses were posed for elk. Generalized linear models were used to perform logistic regression analyses on only the Hardware trials to test these hypotheses, and to examine explanatory variables associated with crossing events. Generalized linear models with binomial distributions and logit-links (logistic regression) were used to examine explanatory variables associated with mule deer and elk crossing events, defined as an event in which one or more mule deer or elk breached the deterrent and gained access to the Hardware exclosure. Further details can be found in Flower (2016). The independent variables used for Hardware Ranch trials included: treatment level (3 or 4-foot-wide electric pavement), block (location on Hardware), and whether snow was present on the surface of the deterrent during the event. The number of days since the start of the treatment periods was also included as a continuous explanatory variable to determine if the likelihood of crossing varied as the treatment period progressed. For the logistic regression models, the models only considered events that included

potential crossing behavior. Parallel movements may not have been directly indicative of deterrent effectiveness and were omitted from the models (Schwender 2013). Discounting these movements ensured that only events in which animals appeared to interact with the deterrents were considered in the models.

At Hardware, large groups of mule deer and elk often approached the entrances to the exclosures, and individual animals could not be identified and counted accurately, but nonetheless the best estimates of data are presented from the perspective of individual animal approaches. In the statistical analyses for Hardware, events of groups of animals and the individual animals were analyzed separately. The I-15 Pintura data were presented using individual animal approaches and reactions.

In road trials at the I-15 electric pavement did not have sufficient number of replicates, (only one treatment site), and enough mule deer approaches to conduct rigorous statistical analyses.

3 RESULTS

3.1 Hardware Ranch Feeding Exclosures Electric Pavement and Single Cattle Guards

3.1.1 Electric Pavement and Single Cattle Guard Effectiveness

Cattle guards with fully charged electric pavement at the exclosure entrances were highly effective at deterring individual mule deer movements (n=166) into the exclosures; 90 percent of individual mule deer movements resulted in the animals repelling away. These same electrified pavement and guards were 99 percent effective in deterring individual elk movements (n=605) from entering the exclosures (Table 1). Mule deer and elk were both significantly less likely to cross an electrified pavement and cattle guard than an untreated cattle guard (P<.001, see Flower 2016). Sample photos are presented in Figures 5 through 7.

Table 1. Number and Percentage of Individual Wildlife Approaches to Deterrents Where Animals Displayed Behaviors to Enter Exclosures, and Subsequently Crossed, or Did Not Cross Deterrents at Entrances to Baited Wildlife Exclosures at Hardware Ranch.
Adapted from Flower 2016.

Species	Treatment Level	Number Approached	Number Repelled	Number Breached	Percent Effective
Mule Deer	3 Feet Electric Pavement	52	48	4	92
	4 feet Electric Pavement	114	102	12	90
	Treatments Added Together	166	150	16	91
	Single Cattle Guard - Control	1,417	450	967	32
Elk	3 Feet Electric Pavement	204	202	2	99
	4 feet Electric Pavement	401	397	4	99
	Treatments Added Together	605	599	6	99
	Single Cattle Guard - Control	718	518	200	72

Figure 5. Mule Deer Fawn is Repelled from Electric Pavement at Hardware Ranch, UT.

Figure 6. Mule Deer Doe is Repelled from Electric Pavement at Hardware Ranch, UT.

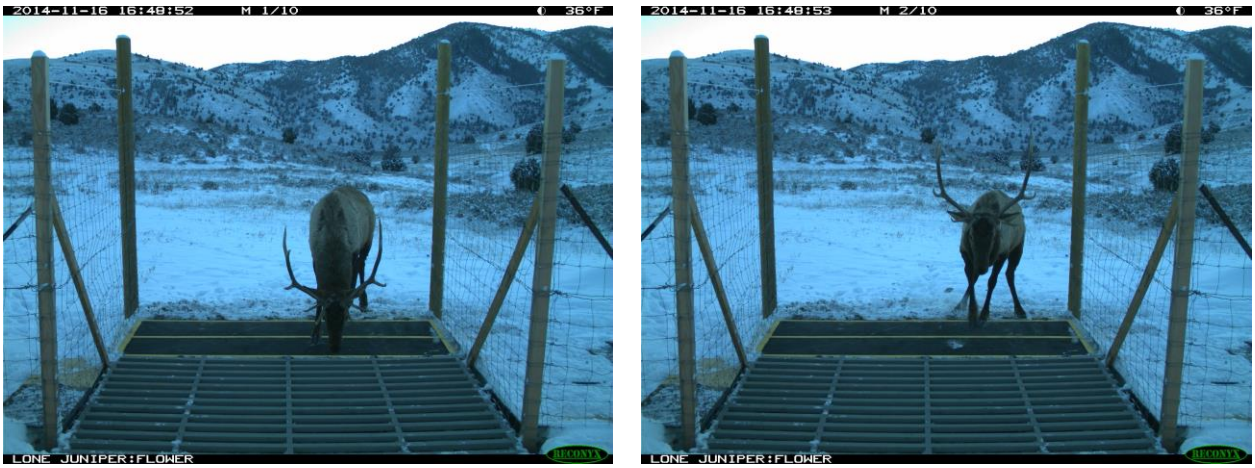

Figure 7. Bull Elk is Repelled from Electric Pavement at Hardware Ranch, UT.

A moose (*Alces alces*) approached and displayed behavior to cross a cattle guard treated with the three-foot wide (0.9 m) electric pavement, but was repelled. The following species were in recorded images at the sites, but due to insufficient sample size (<10 events) the species were not included in the analysis: domestic dog (*Canis lupus familiaris*), common raven (*Corvus corax*), hare (*Sylvilagus* sp.), great horned owl (*Bubo virginianus*), magpie (*Pica hudsonia*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), domestic cattle (*Bos taurus*), and deer mouse (*Peromyscus* species).

Only the metric of effectiveness of the pavement for calculating total *individual* animal's approaches within six feet (1.8 m) and displayed behavioral cues that demonstrated they were interested in breaching the deterrents is presented below. Originally in the overall study reported in Flower (2016), the effectiveness of the electric pavement and cattle guards in deterring mule deer and elk were evaluated based on: 1) all events when animals approached within six feet (1.8 m) of the electric pavement; 2) all individual animals that approached within six feet (1.8 m) of the electric pavement, and 3) all events when animals approached within six feet (1.8 m) of the pavement and displayed behavioral cues that they were interested in breaching the deterrents. For full reporting, the reader is referred to the Flower thesis.

The weather conditions during the winter of 2014-2015 were an integral part of the trial and thus are reported. During the five-week pre-treatment period, mean ambient temperature was 36°F, (2.1°C) and ranged from -6 to 75°F (-21.4 to 23.8°C). During the 17-week treatment period (16 November 2014 to 16 March 2015), mean ambient temperature was 29.7°F (-1.3°C) and ranged from -12.8 to 67.8°F (-24.9 to 19.9°C), (Utah Climate Center 2015). During both periods, observed snow cover on the landscape ranged from 0 to100 percent and recorded snow depth ranged from 0 to 3 inches (0 to 8 cm).

3.1.2 **Electric Pavement and Single Cattle Guard Effectiveness over Time**

During the pre-treatment period for the first five weeks at the beginning of the winter, when electricity was not turned on at the treatment sites, there were limited weekly mule deer intrusions across all sites. During the treatment period when the deterrents were exposed and energized in weeks six to 22 through the fall and winter, mule deer intrusions were virtually

eliminated across all sites until week 12, the end of 2014 and the start of 2015 and the beginning of winter, when intrusions increased dramatically at the control sites only (Figure 8). During the electric pavement treatment period, mule deer breached the electric pavement and single cattle guard sites 16 times, while mule deer breached the single cattle guard control sites 967 times.

Elk appeared to be bold in using the exclosures during pre-treatment, and highly deterred once electricity was turned on in week six. Unlike mule deer, elk regularly entered baited feeding exclosures during the five-week pre-treatment period, with intrusions peaking in week 4 (Figure 9). When the deterrents were exposed in the treatment period, weekly elk intrusions were virtually eliminated at treated sites for the duration of the 17-week treatment period. However, elk intrusions at control sites occurred in nearly every week of the treatment period (Figure 9). During the treatment period, 200 elk intrusions were recorded into control sites compared with six, at treated sites.

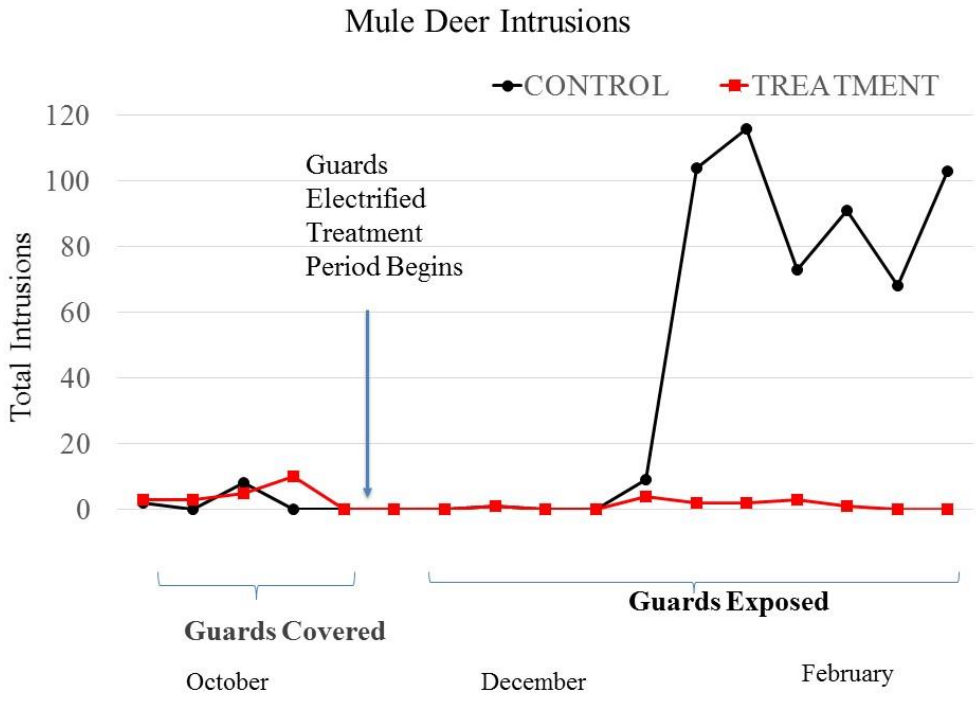

Figure 8. Weekly Mule Deer Breaches into Exclosures during Study.
Figure adapted from Flower, 2016.

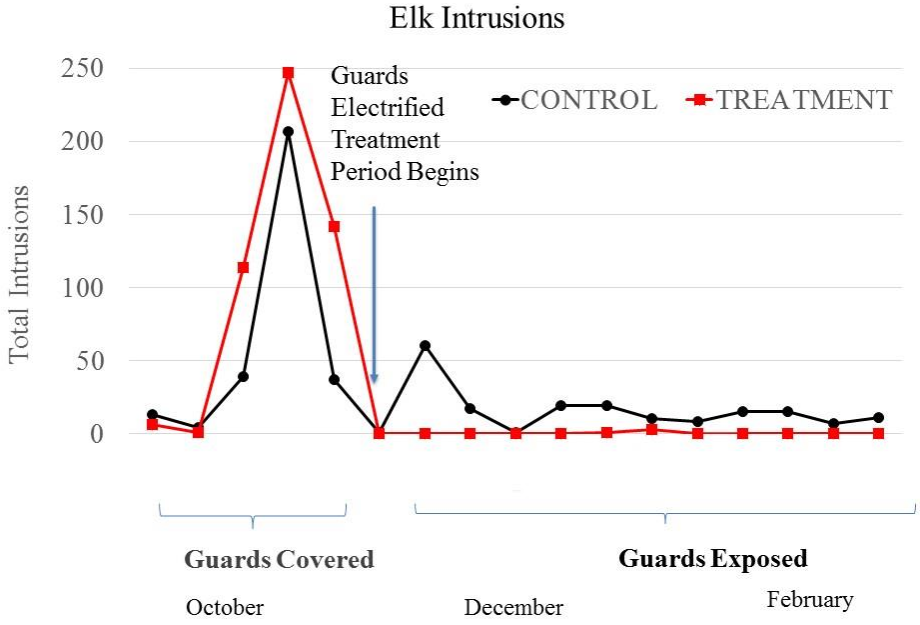

Figure 9. Elk Breaches into Exclosures during Study.
Figure adapted from Flower, 2016.

3.1.3 Statistical Model Results

Mule deer were significantly less likely to breach cattle guards treated with three to four foot-wide (0.9 to 1.2 m) electrical pavement than untreated cattle guards ($P < 0.001$) when considered across all treatment levels and blocks. The likelihood of deer incursion did not differ significantly between the two electrified pavement dimensions ($P = 0.57$). The likelihood of deer incursion at control sites with only cattle guards increased significantly as the treatment period progressed, while it declined, though not significantly, at treated sites. From these results, the null hypothesis that mule deer would be as equally likely to enter control sites as treated sites was rejected, in favor of the alternative that mule deer would be less likely to enter treated sites than control sites.

Model results for elk found three of the four explanatory (independent) variables in the logistic regression model were statistically significant predictors of elk incursion into wildlife exclosures at level $\alpha = 0.05$. These included the electric pavement treatment, block on the landscape, and snow coverage. Additionally, days since the start of the treatment period was

statistically significant when considered at level $\alpha = 0.10$ ($P = 0.06$). When considered across all treatment levels and blocks, elk were significantly less likely to cross cattle guards treated with electrified pavement than untreated cattle guards ($P < 0.001$). The likelihood of elk intrusion was not significantly different between the two electrified pavement dimensions ($P = 0.376$). Snow cover was a highly significant predictor of elk crossing ($P = 0.003$) with elk intrusion significantly more likely when deterrents were snow covered compared with snow-free. Days since the start of the treatment period was a marginally significant predictor of elk crossing ($P = 0.060$) with the likelihood of incursion increasing slightly as the test proceeded. The null hypothesis that elk would be as equally likely to enter control sites as treated sites was rejected in favor of the alternative that elk would be less likely to enter treated sites than control sites.

3.2 Interstate 15 Electric Pavement in-the-Road Trial

During pre-electric treatment of the west cattle guard, the east single cattle guard (the control site), was 62 percent effective in deterring the 74 individual mule deer movements. The west-cattle guard was monitored 2.5 months prior to the installation of the electric pavement on the guard. During that time, twice mule deer approached and were repelled. After the electricity was turned on at the west cattle guard, the east cattle guard was 49 percent effective at deterring the 61 mule deer movements. At the west cattle guard and electric pavement, monitoring from June 2014 to March 2015, 85 individual mule deer movements were documented near the pavement. Two types of behavior were eliminated from the final results at this west guard and electric pavement: animals breaching the electric pavement on the north edge where there was an eight-inch (20 cm) gap in the fencing (Figure 10), and inconclusive results. The electric pavement was then evaluated based on 36 individual mule deer movements. Thirteen times mule deer breached the pavement and guard, and 23 times they were repelled, for an overall effectiveness of 64 percent, see Figures 10 through 12, and Table 2.

Figure 10. Mule Deer Used the Gap in Fencing Along North Side of Electric Pavement to Move to Road Right-of-Way at I-15, Pintura, Utah.

Figure 11. Mule Deer Buck Stood on I-15 Electric Pavement Pintura Site, and was Repelled.

Figure 12. Mule Deer Doe Stood on I-15 Pintura Electric Pavement, and was Repelled.

Table 2. Number Individual Mule Deer Movements at Deterrents Where Animals Displayed Behaviors to Cross and Enter I-15 Right-of-Way, and Percent Effectiveness of Control Single Cattle Guard and Treated Single Cattle Guard, Pre- and Post-Energized Pavement.

Location	Number Movements	Number Repelled	Number Breached	Percent Effective
East Single Cattle Guard Pre-Electricity Treatment	74	46	28	62
East Single Cattle Guard During Electricity Treatment	61	30	31	49
West Cattle Guard Pre-Electricity Treatment	2	2	0	100
West Cattle Guard During Electricity Treatment	36	23	13	64

Mule deer jumped and walked across the electric pavement (Figures 13 through 16, below). It appeared in photos that often the mule deer felt or sensed the electricity, based on sudden jumping up or rearing up behaviors. The four figures below help to evaluate how the electric pavement and asphalt in front of the pavement may have worked.

Figure 13. Two Examples of Mule Deer Does Walking Across I-15 Pintura Electric Pavement.

Figure 14. A Mule Deer Buck Walked Across the I-15 Pintura Pavement, Then Jumped the Single Cattle Guard.

Figure 15. Mule Deer Buck Walked onto I-15 Pintura Electric Pavement, Then Leaped and Moved Across Single Cattle Guard.

Figure 16. Mule Deer Doe Stood on I-15, Pintura Electric Pavement and Then Jumped Single Cattle Guard.

In additional to mule deer, other species were recorded crossing the barrier. These included domestic cats (*Felis catus*), domestic dogs, raccoons, and wild turkeys (*Meleagris gallopavo*). These were not included in the final analysis due to insufficient sample size (≤10 events).

The weather conditions during the winter of 2014-2015 were an integral part of the trial and for comparison with the Hardware Ranch wildlife exclosure portion of the study, and thus are reported. Mean ambient temperature during the 38-week road trial was 56.3°F (13.5°C) and ranged from 14° to 96.6°F (-10.0°C to 35.9°C) (PRISM Climate Group 2014). No wildlife approaches to the experimental guard occurred when snow was present at any period of this study on I-15. Electric pavement voltage readings were 9.8 – 9.9 kV on every site visit except one occasion when the voltage dropped to 7.7 kV. There was no electrical potential between the negative surface of the outside panel of the deterrent and the surface of the road, and only negligible potential (0.3 kV) between the positive surface of the deterrent and the surface of the road

A statistical analysis of the I-15 Pintura electric pavement was not conducted, due to low numbers of deer approaches to the west guard and electric pavement, and the lack of comparison with other units of single cattle guards augmented with electric pavement.

4 DISCUSSION AND CONCLUSIONS

4.1 Summary

The study documented single cattle guards augmented with electrified pavement were 90 percent effective at deterring mule deer from exclosures in a wild setting, and 64 percent effective in a road setting. The study also determined that wildlife guards and double cattle guards currently placed in Utah roads were 87 and 94 percent effective (respectively) in deterring mule deer. The discrepancy in electrified pavement efficacy between the feeding exclosure trial in the wild and the road trial may be due to two primary factors: mule deer motivation and differences in the electrical potential at the two different types of sites.

4.2 Findings

The differences in mule deer reactions to the electric pavement in the wild and road settings may have been due to different levels of motivation to breach the deterrents in the two locations, and the difference in electrical potential between the leading edge of the pavement and the ground or asphalt the animals stood on. Animals at the Hardware Ranch were motivated to access a high-quality food source within the exclosures during winter; the most energetically stressful time of year (VerCauteren et al. 2009, Seamans and Helon 2008). They also could find food on the landscape and had never before used these exclosures as a food source prior to the winter of the study. In contrast, deer in the road trial may have been motivated to cross the deterrent by the need to access food resources in the road right-of-way or on the other side of the highway, because of migration imperatives, to access mates, or to escape predators. When sufficiently motivated, deer can exhibit non-typical behaviors (Reidinger and Miller 2013). This can also be due to the past experiences of the deer near the I-15 single cattle guard. In the past these animals almost certainly used the area to access I-15 right-of-way prior to the study, and in early months of the study when there was a gap in the fencing along the side of the guard and pavement. As a result, they may have had higher confidence in their ability to breach the electric pavement and single cattle guard than the animals that encountered them for the first time at the Hardware Ranch feeding pens. In short, the discrepancy in electrified pavement efficacy may

have been influenced by deer that were more motivated to breach the deterrent at the road than at Hardware Ranch feeding exclosures. Nonetheless, the study was conducted to assist Departments of Transportation to help find an effective deterrent augmentation to single cattle guards in roads, thus the results from the I-15 Pintura mats are far more indicative of future in-road conditions.

Secondly, important differences existed between the electrical contexts of the deterrents in the two locations. At Hardware Ranch, an electrical potential existed between the negatively and positively charged surfaces of the material (9.9 kV), and between the negatively charged surface of the material on the outside panel, and the soil in front of the deterrent (earth ground, 4-5 kV). Animals at Hardware were shocked under certain conditions when in contact with the negative surface of the material and the soil in front of the deterrent. This effect was absent from the road location because road pavement insulated animals from earth ground. That is, there was no electrical potential between the negative surface of the outside panel of the deterrent and the surface of the road, and only negligible potential (0.3 kV) between the positive surface of the deterrent and the surface of the road. The electrical potential was between the negative and positive pavement strips. Another important factor in the electrical potential of the pavement was the animals' hooves. It is possible the hooves of adult deer and elk help to partially insulate the animals from the electrical currents. While Siepel et al. (2013) found electrified mats ineffective at deterring mule deer, they did find one mat deterred a black bear (*Ursus americanus*) from entering the road corridor. Unpublished data from Parks Canada's use of electric pavement found grizzly bear were deterred from wide (> 10 feet, 3 m) strips of electric pavement (Richard Lampman, Lampman Wildlife Services 2014).

A third potential reason for the discrepancy in electric pavement and single cattle guard efficacy between the two areas was the point in time when an animal received the shock when deciding to breach or repel from the pavement-guard location. At the road location, instances were observed of mule deer apparently being shocked while in simultaneous contact with the negatively and positively charged surfaces of the electric pavement, once they had already begun to move across the barrier. Because the mule deer may have already decided to move in the direction of the road when the electrical shock was received, some portion of the mule deer responses was to keep moving in the direction of the highway. At the Hardware Ranch, often animals received shocks prior to moving onto the electric pavement because of the electrical

potential at the soil area at the lip of the pavement. Due to the presence of an earth ground (soil) at Hardware, there were multiple routes for animals to complete the circuit and receive a shock. However, in the road setting, there was a single route for animals to receive a shock at the road – an animal in simultaneous contact with the negatively and positively charged surfaces of the deterrent while they were walking across it. Other studies have demonstrated a similar pattern of effectiveness, Seamans and Helon (2008) and Seipel et al. (2013). Like Seamans and Helon (2008), we found strong effectiveness of an electrified barrier under experimental conditions using feed bait as a reward. However, like Siepel et al. (2013), we found limited effectiveness of the deterrent in a real-world setting along a road with vehicular traffic.

4.3 Limitations and Challenges

Snow also appeared to affect the strength of the electrical charges at the electric pavement. At the Hardware Ranch, a loss of deterrent effectiveness was observed with snow accumulated on the surface of the electrified pavement. Snow was present on the surface of the electrified pavement in all elk breaches, and in most of the mule deer breaches. Based on animal reactions documented in photographs, electrified pavement still delivered a shock to animals through a light layer (half an inch or less, $\leq$ 1.3 cm) of snow. However, we observed sharp declines in effectiveness when approximately two and a half inches (7 cm) of snow accumulated on the electrified surface. At this snow depth, animals appeared to be insulated from the electrified pavement and could stand on the snow-covered deterrent before jumping across the cattle guard. In snowy climates, proactive snow and ice removal would be critical to maintain the effectiveness of electrified pavement.

Given the results and conclusions, it appears that the strip of electric pavement in front of the single cattle guard was too narrow. Increases in the width of the electric pavement would increase the amount of electrical surface potential the animals would encounter and may more successfully deter them from continuing forward to the road right of way area. Further, the study did not evaluate full scale, stand-alone deployments of electrified pavement four-foot wide and greater ($\geq$ 6 feet 1.8 m wide), which may be more effective than the narrower dimensions of

three and four foot-wide (0.9 m to 1.2 m) that were used to augment cattle guards. At wider dimensions, electrified pavement may be more effective in excluding ungulates

Evaluation of the monetary concerns of the comparison of adding an additional cattle guard to an existing single guard, or placing electric pavement in front of the single cattle guard may help DOT personnel make better informed decisions in double cattle guard or electric pavement placement. In 2015, installing an additional standard cattle guard seven-foot by 36-foot (2.1 m × 11 m) to an existing cattle guard cost approximately $32,400 ($900/ft., Randall Taylor, UDOT, personal communication). In contrast, augmenting a standard cattle guard of the same dimension 36 foot-long (11 m) with a strip electrified pavement three-foot by 36-foot (0.9 m × 11 m) cost approximately $27,000 ($750/ft., Randall Taylor, UDOT, personal communication). Based on these cost estimates, electrified pavement yields a total cost-savings of $5,400 when compared to the cost of installing an additional standard cattle guard. However, this research provided evidence that this three-foot wide installation with a single cattle guard does not work as effectively as double cattle guards, so even though there may be a cost savings, the barrier would not be as effective as needed. Also, these initial cost-savings would likely be offset by costs associated with maintenance of the electrified pavement and electrical components over the life of the barrier. In contrast, double cattle guards and wildlife guards require minimal post-installation maintenance.

When costs due to property damage, human injury, human death, and deer loss are combined and averaged, the estimated mean cost of a single deer-vehicle collision ranges from $3,834 (Bissonette et al. 2008, Consumer Price Index Adjustment to 2015 dollars) to $7,593 (Hiujser et al. 2009, Consumer Price Index Adjustment to 2015 dollars). Based on these cost estimates, a double cattle guard or wildlife guard that cost $30,000 to $60,000 would need to prevent four to 16 deer-vehicle collisions over the life of the barrier to justify investment.

The central goal of this research was to provide a rigorous assessment of a cost-effective retrofit to cattle guards that could reduce wildlife intrusions to roadways and other protected areas at rates comparable to double cattle and wildlife guards. The results from the electric pavement installed at single cattleguards in a wild setting at feed exclosures demonstrated the potential for electricity to deter animals from entering an area. The results at the I-15 single cattle

guard with electric pavement showed that installations in an asphalt setting do not work as readily as wild settings, but there is a potential for continued improvements in electric pavement so that it delivers an electric potential at the edge of the pavement when animals have not yet stepped in the direction of the fenced area of highway. If animals can be deterred before they make the decision to begin the crossing, there may be greater potential to keep them off the barrier, as was seen at the wildlife exclosures in the wild area of Hardware Ranch. An electric pavement strip of wider dimensions may be a greater barrier to mule deer and other wildlife than the three to four-foot wide (0.9 to 1.2 m) electric pavement strips mats tested in this study. Further research is needed to determine the efficacy of electrified pavement for use in roadway applications.

5 RECOMMENDATIONS AND IMPLEMENTATION

5.1 Recommendations

The robust design of the experiments in the wild and *in situ* in the road led the researchers to make the recommendations below.

1. Double cattle guards and wildlife guards are the best tested barrier designs for restricting mule deer movement into roads at vehicle access points, and should be the preferred barrier used in wildlife exclusion fencing. The 87 to 94 percent effectiveness rate of these two barriers should be used as the standard performance measure for future barrier designs.

2. A single cattle guard in the road, augmented with a 3 to 4-foot wide (0.9 to 1.2 m) strip of electric pavement did not prove to deter mule deer at rates comparable to double cattle guards (80 percent or greater). Further research into alternative designs is needed to develop a system that is as effective as double cattle guards and wildlife guards.

3. Single cattle guards augmented with electric pavement will need to be further developed so that the animals receive an electrical current at the very edge of the electric pavement, when they are first deciding to breach or repel from the site.

4. The study found no barrier at vehicle access points is 100 percent effective. Therefore, all wildlife deterrent barriers in wildlife exclusion fencing should also be placed with wildlife escape ramps within 300 feet (91 m) to allow animals that have accessed the roadway a safe escape to the wild side of the fencing.

5. Wildlife exclusion fence in areas where mule deer and other wildlife need to access both side of the road should only be placed in conjunction with wildlife crossing structures or other existing appropriate bridges and culverts. If animals need to cross the road to survive, then a fence and guards at vehicle access points become significantly less effective if the animals'

motivation to get across them is high. Ecologically, connectivity needs to be provided along wildlife exclusion fencing, otherwise wildlife populations' survival could be negatively affected.

6. Alternative designs of electric pavement, specifically standalone installations such as those across lanes of traffic at the end of wildlife exclusion fencing, should be tested as well as single cattle guard augments, to evaluate the potential of this concept that it could be used in place of double cattle guards.

5.2 Implementation Plan

The results of this study help UDOT, other transportation agencies, and wildlife agencies to make more informed decisions on the best deterrent barriers to keep mule deer and other hooved wild animals (ungulates) out of fenced areas, and the potential for electricity to be added to pavement to help deter ungulates from entering road area.

1. UDOT can create a standard of double cattle guards and wildlife guards as the only choices for vehicle access point barriers in wildlife exclusion fencing. Electric mats (study results presented in Appendix A) and single cattle guards do not deter mule deer at rates above 50 percent and should not be considered to do so.

2. UDOT and manufacturers of electric pavement will need to experiment with different widths of electric pavement in the road to deter mule deer from entering fenced areas. At the writing of this report, UDOT had installed six foot-wide (1.8 m) electric pavement across a highway at the end of wildlife exclusion fencing at two locations. A second phase of this study (Phase 2) was underway with camera traps at these locations to determine the efficacy of this barrier at the writing of this report. That phase of the overall study will help UDOT make decisions regarding the usability of this design in deterring mule deer from entering fenced highway areas.

3. UDOT has become an innovator in wildlife mitigation designs and research. Continued designing, building, monitoring, and adaptively managing future infrastructure will assist UDOT in creating the most effective and cost-effective structures, fencing, barriers, and escape ramps for wildlife. Other states and countries will also benefit from the results of these efforts.

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APPENDIX A: THE EFFECTIVENESS OF FIVE WILDLIFE DETERRENT BARRIER DESIGNS USED TO RESTRICT MULE DEER ACCESS TO HIGHWAYS

Abstract

Five types of wildlife deterrent barriers used on Utah roads at vehicle access points along wildlife exclusion fences (8 feet, 2.4 m high) were monitored with camera traps to gauge their effectiveness in restricting mule deer access to highways. The 14 wildlife deterrent barriers monitored included: 1) two single cattle guards without excavated pits beneath, 2) four single cattle guards suspended over excavated pits, 3) four double cattle guards over excavated pits, 4) two wildlife guards (the size of double cattle guards with steel mesh rather than steel bars) over excavated pits, and 5) two electrified mats embedded in the road surface. The objectives of the study were to determine the best designs in restricting mule deer access to roads, and to examine explanatory variables associated with events in which deer crossed the barriers.

Cameras captured 1,946 individual mule deer movements near the barriers where animals were within 6 feet (1.8 m) of the barrier and approached it. There were 581 breaches to the 14 barriers. Double cattle guards were most effective: they deterred on average 94 percent of all individual mule deer movements (n= 783) from becoming breaches. Wildlife guards worked second best, on average they were 87 percent effective in deterring mule deer movements (n=339). In contrast, individual deer movements were deterred at the other barrier types at the following rates: single cattle guards with excavated pits were on average 53 percent effective (n=139), single cattle guards with no excavated pits were overall on average 28 percent effective (n=403), and electric mats were on average 11 percent effective (n=161).

Generalized linear models used to examine explanatory variables associated with events in which mule deer crossed over the barriers indicated the design of the wildlife deterrent barrier was the most important predictor of whether mule deer crossed over them. Although double cattle guards and wildlife guards did not entirely eliminate deer access to roadways, both designs were significant obstacles to mule deer and consistently prevented intrusions through designed openings in wildlife fencing for this species. Double cattle guards and wildlife guards both with excavation pits are recommended as the most effective means to exclude mule deer from highways.

Introduction

Vehicle access points along wildlife exclusion fencing are often fitted with double cattle guards to help reduce mule deer and other wildlife intrusions into the road. Other methods to prevent wildlife access to the road area include single cattle guards, wildlife guards – steel grates of approximately six inches (15 cm) square grids over excavated pits, electric mats – plastic planks with metal electrodes placed along their length that conduct electricity, and painted parallel white lines that mimic single cattle guards. Although standard cattle guards are likely ineffective deer barriers (Reed et al. 1974, Ward 1982), they are ubiquitous in the Western U.S. and can become integrated as part of a wildlife exclusion fencing system when additional fencing is placed on top of existing four feet (1.2 m) right-of-way fencing that originally was never intended to restrict wildlife access.

Departments of transportation have a need to evaluate the efficacy of the double cattle guard and other wildlife deterrent barriers to make cost-effective decisions on how to reduce wildlife intrusions onto roadways at vehicle access points in wildlife exclusion fencing. Placing the most effective wildlife deterrent barrier at vehicle access points in turn will help wildlife mitigation reduce the number of wildlife-vehicle collisions (WVC). These efforts will also help make roads safer for the motoring public as the risk of WVC is reduced. Despite their expense and essential role in the function of integrated fence-wildlife crossing mitigation, no study has directly compared the effectiveness of these wildlife-specific barriers as impediments to mule deer movement *in situ* on roadways using consistent methods.

Objectives

Five wildlife deterrent barriers types used on Utah roads in areas with wildlife exclusion fencing (8 feet, 2.4 m high) were monitored to gauge their efficacy in restricting mule deer access to Utah highways. The objectives were to evaluate if there were differences in the efficacy in these five designs in restricting mule deer access to roads and to examine explanatory variables associated with events in which deer crossed the barriers.

Methods

This study was conducted in Utah on four major highways: U.S. Highway 91 (US 91) in northern Utah, U.S. Highway 6 (US 6) in central Utah, and U.S. Highway 89 (US 89) and Interstate 15 (I-15) in southern Utah (Figure 17). Fourteen wildlife deterrent barriers were monitored and located on lateral access roads that bisect continuous wildlife exclusion fencing constructed on both sides of roadways. The roads were from 2-lane (US 6 and US 89) to 4-lane (US 91) US highways, and an interstate (I-15). Additional wildlife mitigation measures present along the highways ranged from no wildlife crossing structures within 5 miles (I-15 sites), to sites with existing culverts that could be used by mule deer within two miles (I-15 MP 31 near Pintura, and US 6 MP 236 near Helper), to locations within two miles of wildlife crossings structures (US 89 in southern Utah, and US 91 in northern Utah).

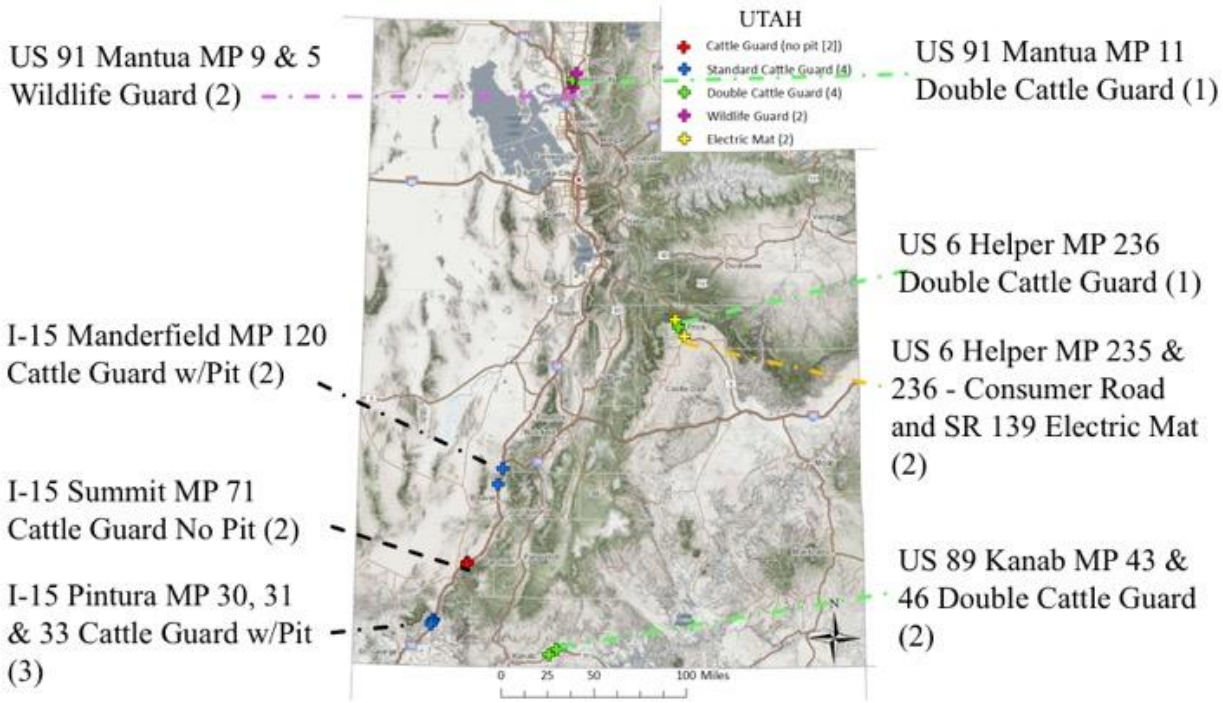

Figure 17. Locations of Wildlife Deterrent Barriers (N=14) Along Fenced Sections of US 91, US 6, I-15, and US 89 in Utah. Location is to the Nearest Town and Mile Post (MP).

Figure adapted from Flower 2016.

Wildlife deterrent barriers were monitored for their effectiveness in restricting mule deer access to highway with motion activated cameras, Reconyx Model PC85 or PC800. These cameras were placed at 14 vehicle access points in wildlife exclusion fencing at: cattle guards with no excavation pits (*n*=2, Figure 18), cattle guards with excavation pits (n=4, Figure 19), double cattle guards with excavation pits (*n*=4, Figure 20), wildlife guards with excavation pits (*n*=2, Figure 21), or electrified mats placed in the road surface (*n*=2, Figure 22), see Table 3. All sites were in areas with wildlife exclusion fencing and were selected because: the sites were the only locations with these wildlife deterrent barriers as was the case for the wildlife guards; these were sites where the barriers were known to be in working order, as was the case on US 6 for the electric mats; these were the only known sites with wildlife exclusion fencing and single cattle guards where mule deer carcasses were recorded along the highway as was the case for the I-15 sites; and these were typical double cattle guards placed near other structures that were being monitored in this and a concurrent study (US 89 Kanab-Paunsaugunt Study, Cramer and Hamlin 2016), as was the case for the double cattle guards on US 89, US 6, and US 91. UDOT and UDWR personnel also helped select the most appropriate sites (Rhett Boswell, UDWR and Randall Taylor UDOT, personal communication).

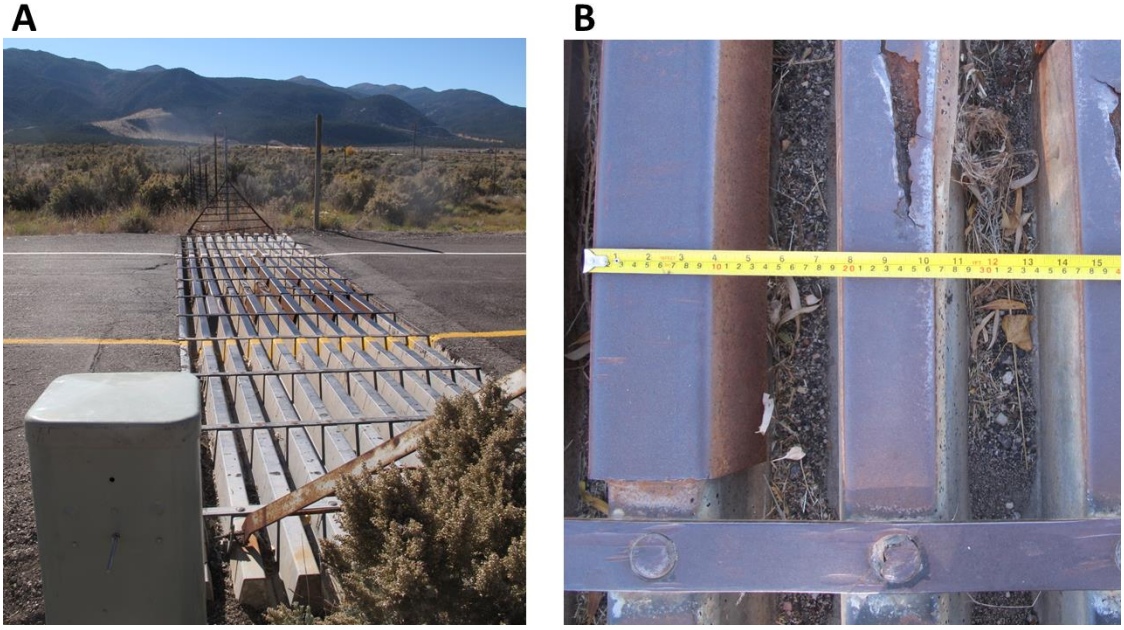

Figure 18. Cattle Guard (6.2 feet by 31.8 feet, 1.9 m × 9.7 m) With No Excavation Pits, (A) and Close View of Cattle Guard Rails (B), on an access road to Interstate 15, MP 71, Near Summit, Utah.

Taken from Flower 2016.

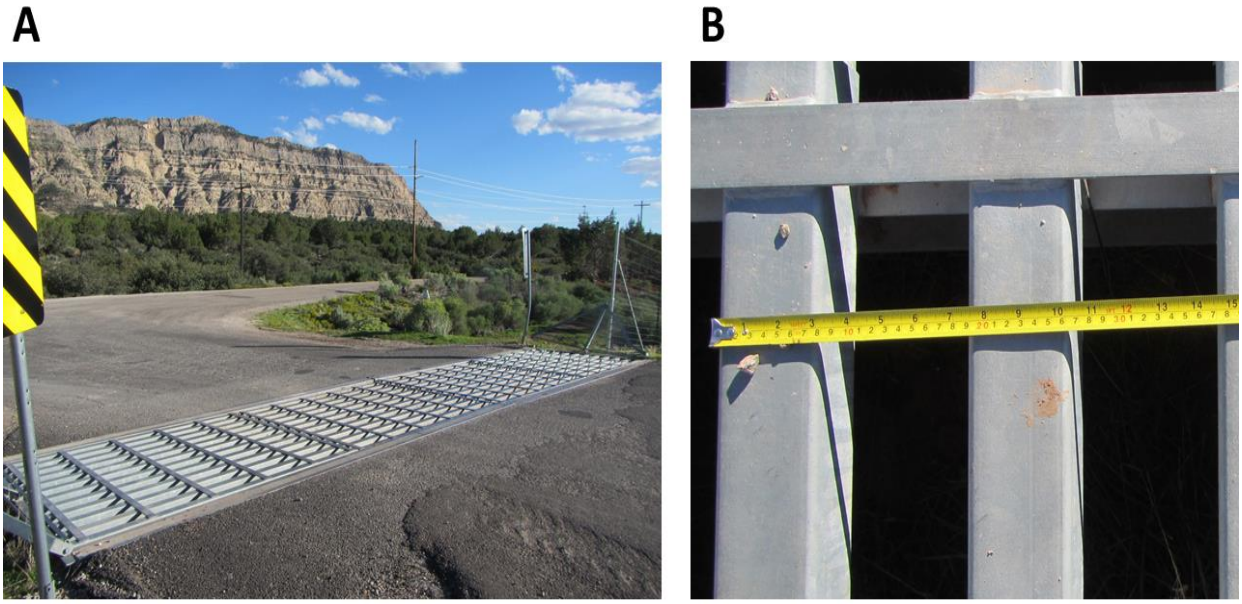

Figure 19. Standard Cattle Guard, 6.9 feet x 36 feet (2.1 m × 11 m), over Excavation Pit (A), and Close View of Cattle Guard Rails (B) on an Access Road to Interstate 15, MP 31, Near Pintura, UT.

Taken from Flower 2016.

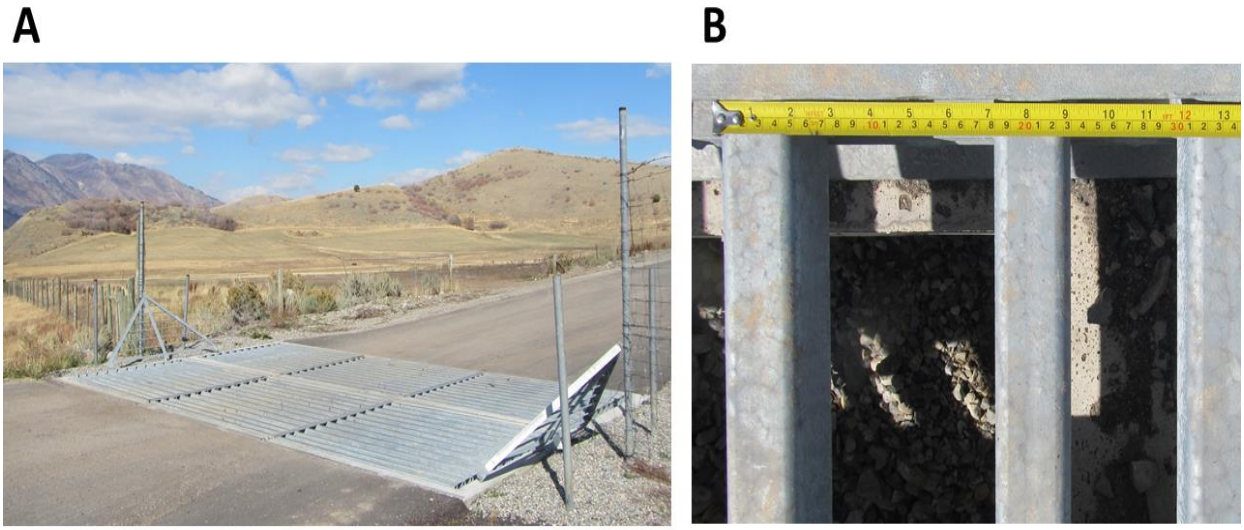

Figure 20. Double Cattle Guard (15 feet by 33 feet, 4.6 m × 7 m) Suspended over Excavation Pit (A), and Close View of Cattle Guard Rails (B), on an Access Road to U.S. Highway 91, MP 11, North of Mantua, Utah.

Taken from Flower 2016.

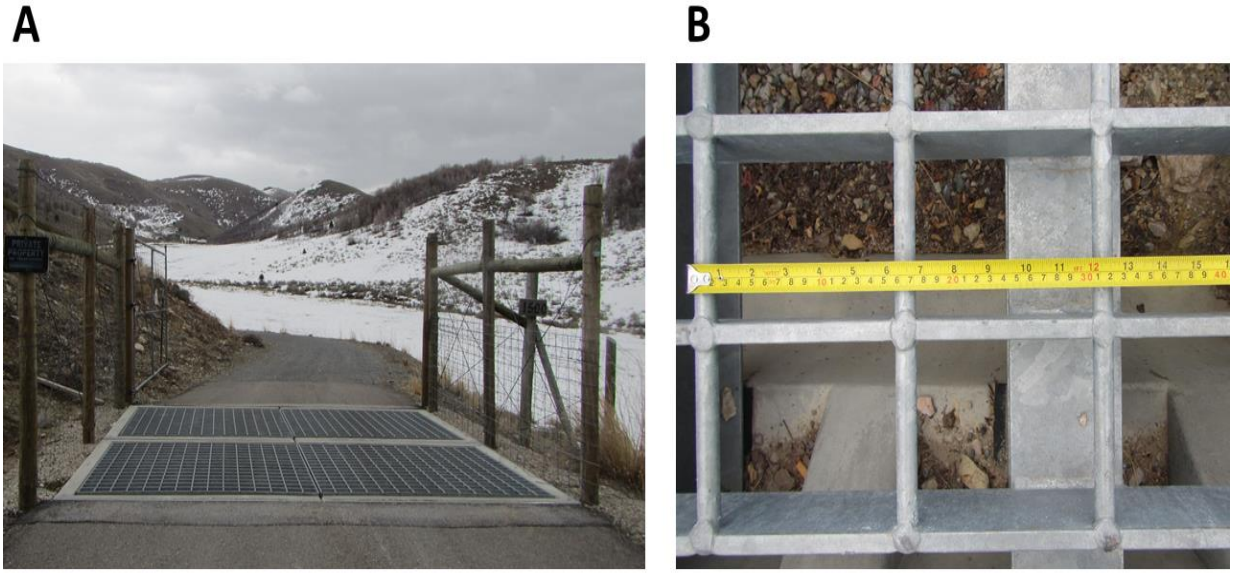

Figure 21. Wildlife Guard (16 by 16 feet, 4.9 m × 4.9 m) Suspended Over Excavation Pit (A), and Close View of Steel Grating (B) on an Access Road to U.S. Highway 91, MP 6, near Mantua, Utah.

Taken from Flower 2016.

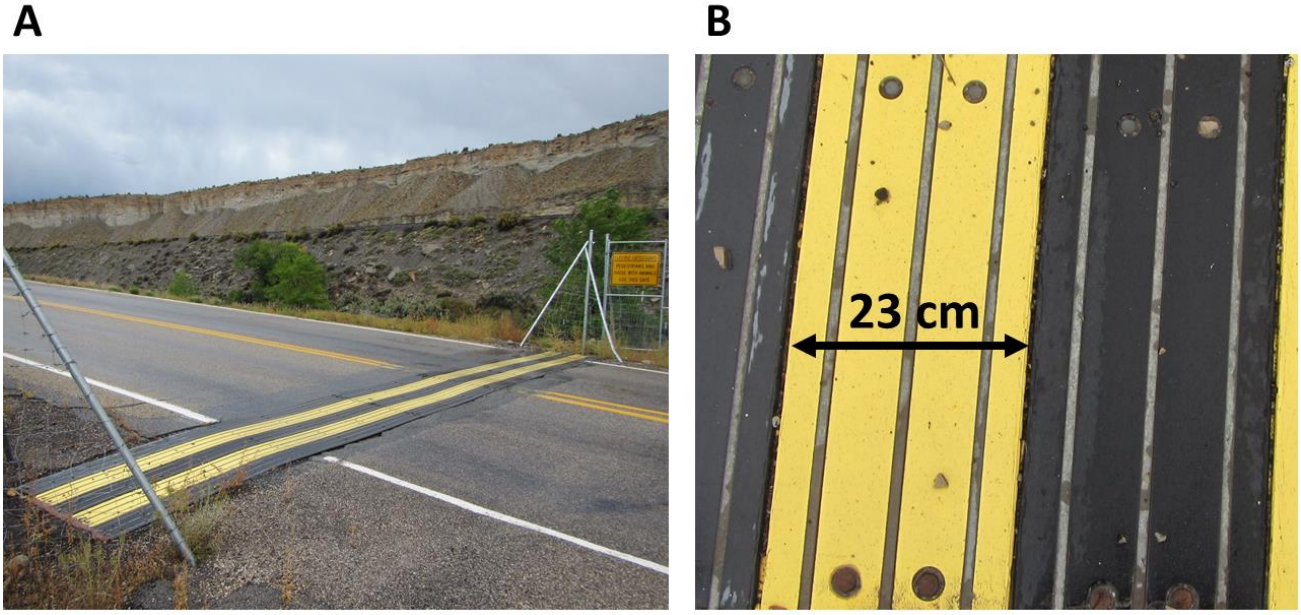

Figure 22. Electrified Mat (4 feet by 36 feet, 1.2 m × 11 m, A) and Close View of Composite Planks with Embedded Metal Electrodes (B), on an Access Road to U.S. Highway 6, MP 236, Near Helper, Utah.

Taken from Flower 2016.

Table 3. Wildlife Deterrent Barrier Location, Dimensions (m), Traffic Volume (AADT), and Approximate Date Installed for all Studied Sites.

Table adapted from Flower 2016.

Barrier Design	Location	Width	Length	Road AADT[a]	Date Barrier Installed
Cattle Guard (no pit)	I-15 exit 71 NE	1.8	9.7	20,575	Pre-2000
	I-15 exit 71 SE	1.9	9.7	20,575	Pre-2000
Standard Cattle Guard with pit	I-15 exit 120	2.1	7.3	17,605	Pre-2000
	I-15 exit 33	2.1	13.7	21,685	Pre-2000
	I-15 exit 31	2.1	11.0	21,675	Pre-2000
	I-15 exit 30	2.1	11.0	21,845	Pre-2000
Double Cattle Guard with pit	U.S. 91 MP 10.8	4.6	7.0	16,460	1995
	U.S. 6 MP 235.8	4.8	26.2	10,980	2008
	U.S. 89 MP 43	4.3	4.8	1,850	2013
	U.S. 89 MP 45.5	4.4	4.8	1,850	2013
Wildlife Guard with pit	U.S. 91 MP 5.8	4.8	4.8	17,865	2011
	U.S. 91 MP 9.1	4.8	4.8	16,460	2012
Electric Mat	U.S. 6 & S.R. 139	1.2	12.8	10,980	2008
	U.S. 6 & Consumer Rd.	1.2	10.6	10,980	2008

[a] AADT = Annual Average Daily Traffic from UDOT 2015. Table adapted from Flower 2016.

All cameras were deployed in September 2013, except for one camera placed on the US 91 wildlife guard in December of 2011 prior to the start of this study. Most cameras were maintained continuously until late April 2015. Some cameras were still in place at the time of this writing: one single cattle guard on I-15 Pintura Exit 31; two double cattle guards on US 89; and one wildlife guard on US 91. Cameras were checked and photo data downloaded monthly. Cameras were set to rapid fire, and took photos as long as there was detected motion. Typical camera programming was one to five images per trigger. Cameras at sites with over 200 vehicles passing the camera per day were programmed to detect motion from dusk to early morning hours when mule deer were most active and vehicle numbers were lowest. This helped the cameras to

remain powered for the month between researcher visits, otherwise the photographing of vehicles would have drained batteries within two weeks.

Photographs were analyzed with respect to animal reactions to the various guards and pavement. Reactions were tallied in a custom Access database (Microsoft Corporation 2013). Mr. Flower analyzed all images to ensure consistency and limit observer bias. Where possible, the method used by each animal to breach the barrier (e.g. jumped, walked, breached at the barrier edge, or unknown), was recorded. All unique individual wild animal movements recorded by cameras at each monitoring location were categorized and tallied as follows:

- **Breach -** movements directly over the barrier;
- **Repellency -** movements away from the barrier after an interaction. An interaction was defined as stepping on, smelling, or looking at the barrier with an apparent intent to cross;
- **Parallel -** movements without an interaction within 6 feet (1.8 m) of the barrier;
- **Movements** – number of individual mule deer movements within 6 feet (1.8 m) of barrier where the animals appeared to interact with the guard, (as defined above in repellency), and equal to the breach movements plus the repellency movements;
- **Inconclusive** – the results of the mule deer approach could not be determined;
- **Rate of Effectiveness** – total repellency movements divided by total movements.

When animals were greater than six feet (1.8 m) from the deterrent, what they did was not considered indicative of interacting with the pavement and their presence was not tabulated, since those movements were not considered indicative of deterrent effectiveness (Allen et al. 2013). A range of levels of effectiveness was given, by first considering all inconclusive approaches were repelled as a high value, and then as if all inconclusive approaches were breaches, for the low value.

The following were recorded to help examine explanatory variables associated with events in which mule deer crossed the barriers: 1) The annual average daily traffic (AADT) on the highway adjacent to the lateral access road (Utah Department of Transportation 2015); 2) Number of days that each barrier was monitored by cameras; and 3) The distance (in road miles)

to the nearest culvert or bridge mule deer could use to cross beneath the highway, this included wildlife crossing structures and multipurpose structures.

Generalized linear models with binomial distributions and logit-links (logistic regression) were used to examine explanatory variables associated with mule deer breach *events*, defined as an event in which one or more deer in a group, breached the barrier and gained access to the fenced highway corridor. Reporting of mule deer rates of effectiveness represented the effectiveness of guard types at repelling *individual* animal approaches. Statistical model assumptions of independence could not be met with analyses of individuals, so the results of events were analyzed. All analyses used the GENMOD procedure in the statistical software SAS (Version 9.4; SAS Institute Inc.) and model output was cross-validated with model results from R statistical software (Version 3.1.1; The R Foundation for Statistical Computing). The response (dependent) variable was the outcome of each event: either success (0 = no deer breached the barrier) or failure (1= one or more of the deer in a group, or single deer breached the barrier). The categorical explanatory variable was the wildlife deterrent barrier design type. The continuous explanatory variables were: 1) AADT on the highway segment adjacent to the access road, 2) number of days that our cameras monitored each barrier, and 3) distance in road miles to the nearest culvert or bridge that mule deer could use to cross beneath the roadway, which were wildlife crossing structures or multipurpose structures.

For the logistic regression model, only events where behavior that was interpreted as intent to breach the structure were considered for analyses. Parallel movements may not have been directly indicative of deterrent effectiveness, and so were removed from the model (Schwender 2013). This was important in places where barriers had been installed for several years and the deer had already stopped trying to breach the barriers and moved past them. Similarly, events in which deer breached the barriers when they were snow-covered were not included in statistical models. Snow coverage negatively affected barrier effectiveness and was a source of variation unequally distributed across the monitoring locations. Omitting these events ensured that only events that were directly indicative of barrier effectiveness were considered in the model.

Results

Effectiveness of Wildlife Deterrent Barrier Designs

A total of 1,946 individual mule deer movements where animals displayed interactive behaviors were recorded at the 14 monitoring locations. The range of effectiveness for each type of barrier is presented in Table 4. Double cattle guards had the highest effectiveness rate, on average 94 percent (783 movements used in calculation). Wildlife guards were the second highest effective barrier design, with an effectiveness rate of 87 percent (339 movements used in calculation) (Figure 23). Single cattle guards over excavated pits were on average 53 percent effective (using 122 movements for calculation). Single cattle guards without excavation pits and electrified mats were least effective (on average 29 percent and 12 percent, respectively)

Table 4. Results of Individual Mule Deer Movements at 14 Wildlife Barriers in Utah.
Table taken from Flower 2016.

Location	Movements	Breached	Percent Breached	Inconclusive *	Percent Effective
Cattle Guard (no pit)					
I-15 exit 71 NE	340	216	63.5	47	23 – 37
I-15 exit 71 SE	135	72	53.3	25	28 – 47
Total	**475**	**288**	**60.6**	**72**	**24 – 39**
Standard Cattle Guard					
I-15 exit 120	8	1	12.5	0	88
I-15 exit 33	14	8	57.1	0	43
I-15 exit 31	117	47	40.2	20	43– 60
I-15 exit 30	5	2	40	2	20 – 60
Total	**144**	**58**	**40.3**	**22**	**44 – 60**
Double Cattle Guard					
U.S. 91 MP 10.8	55	9	16.4	19	49 – 84
U.S. 6 MP 235.5	71	2	2.8	5	90 – 97
U.S. 89 MP 42.3	501	11	2.2	3	97 – 98
U.S. 89 MP 45.5	186	26	14.0	3	84– 86
Total	**813**	**48**	**5.9**	**30**	**90 – 94**
Wildlife Guard					
U.S. 91 MP 5.8	159	29	18.2	1	81 – 82
U.S. 91 MP 9.1	190	15	7.9	9	87 – 92
Total	**349**	**44**	**12.6**	**10**	**85 – 87**
Electric Mat					
U.S. 6 & S.R. 139	18	15	83.3	0	17
U.S. 6 & Consumer Rd.	147	128	87.1	4	10 – 13
Total	**165**	**143**	**86.7**	**4**	**11 – 13**
GRAND TOTAL	**1,946**	**581**	**30**	**138**	**63 – 70**

* Inconclusive = It could not be determined if deer crossed or did not cross the barrier.

Figure 23. Mule Deer Approached a Wildlife Guard on US 91, and Repelled.

Mule deer methods of breaching barriers occurred by the animals jumping over, walking across, or by moving along the edge of the barrier, where adjacent wildlife exclusion fencing formed a junction with the barrier (Figures 24-27). Walking across barriers was the most common method of breaching barriers, with 264 individual mule deer breaches recorded with this method. Most deer that breached double cattle guards and electrified mats walked across them (52 percent and 98 percent, respectively). The second most common method to breach barriers was through jumping over the barrier (n=232). Eighty percent of all recorded jumps by individuals occurred at the single cattle guards without excavation pits. Much less common were where individuals walked along the edge of barriers (n=43) or method of breaching was inconclusive (n=42). However, nearly 25 percent of recorded deer breaches at standard cattle guards occurred at the barrier edge, where guard apron wings were common (triangular metal structures installed at the margins of cattle guards). Similarly, most mule deer that breached wildlife guards (52 percent) crossed at the barrier edge, often on a narrow concrete frame exposed between the steel grid and the adjacent wildlife fencing, see Table 5.

Breaches during snowy conditions were less common, with only 22 individuals recoded moving over the double cattle guards and wildlife guards during those conditions. Of the 48 recorded deer breaches over double cattle guards, 8 (16.6 percent) occurred when the barriers were covered in snow. At wildlife guards, ~32 percent of recorded deer breaches were influenced by accumulated snow on the surface or margins of the barrier, Table 5.

Figure 24. Mule Deer Breached US 91 Wildlife Guard by Walking on the Cross Bars and Support Beams.

Figure 25. Mule Deer Walked Across Double Cattle Guard on US 6, Left, and Jumped Across Single Cattle Guard on I-15, Pintura, Right.

Figure 26. Mule Deer Walked Along Edge of Wildlife Guard on US 91, Left, and Walked Across Top of Electric Mats near US 6, Right.

Table 5. Number of Individual Mule Deer Breaches and Resulting Method of Breaching at Wildlife Barriers in Utah.

Table taken from Flower 2016.

Location	Jumped	Walked	Breached Edge[a]	Unknown[b]	Snow[c]
Cattle Guard (no pit)					
I-15 exit 71 NE	136	61	4	15	0
I-15 exit 71 SE	50	15	1	6	0
Total	**186**	**76**	**5**	**21**	**0**
Standard Cattle Guard					
I-15 exit 120	0	1	0	0	0
I-15 exit 33	4	3	1	0	0
I-15 exit 31	19	11	13	4	0
I-15 exit 30	1	1	0	0	0
Total	**24**	**16**	**14**	**4**	**0**
Double Cattle Guard					
U.S. 91 MP 10.8	0	4	1	4	4
U.S. 6 MP 235.5	0	2	0	0	0
U.S. 89 MP 42.3	2	8	0	1	4
U.S. 89 MP 45.5	5	11	0	10	0
Total	**7**	**25**	**1**	**15**	**8**
Wildlife Guard					
U.S. 91 MP 5.8	12	3	13	1	8
U.S. 91 MP 9.1	1	4	10	0	6
Total	**13**	**7**	**23**	**1**	**14**
Electric Mat					
U.S. 6 & S.R. 139	0	15	0	0	0
U.S. 6 & Consumer Rd.	2	125	0	1	0
Total	**2**	**140**	**0**	**1**	**0**
GRAND TOTAL	**232**	**264**	**43**	**42**	**22**

[a] Breached Edge = Total number of mule deer breaches that occurred at guard apron wings (triangular metal structures commonly installed at cattle guard edges) or on exposed concrete ledges that framed wildlife guards.
[b] Unknown = Total number of mule deer breaches in which the method of crossing could not be determined.
[c] Snow = Subset of mule deer breaches that occurred when the wildlife barrier was snow covered.

Statistical Model Results

Three of the four explanatory variables entered into the logistic regression model were statistically significant at level $\alpha = 0.05$. Significant predictors of whether mule deer breached the barriers included: 1) barrier design (double cattle guards and wildlife guards being the most effective designs), 2) AADT volume on the highway segment adjacent to the access road (higher traffic volumes were associated with lower effectiveness designs), and 3) distance to the nearest culvert or bridge that mule deer could use to cross beneath the roadway (areas with wildlife crossings nearby had higher likelihoods of being breached). Additional statistical information is available in Flower 2016.

The likelihood of mule deer breaching a barrier differed, but not significantly, between cattle guards with and without excavations pits ($P = 0.06$). The likelihood of mule deer breaching cattle guards without excavations was more similar to the likelihood of breaches at electrified mats, with the differences in effectiveness not significant ($P = 0.10$). However, mule deer were significantly more likely to cross single cattle guards than either double cattle guards ($P = 0.04$,) or wildlife guards ($P = 0.01$). Double cattle guards and wildlife guards did not differ significantly in likelihood of a mule deer breaching them, ($P = 0.8$). In contrast, mule deer were significantly more likely to cross electrified mats than either double cattle guards ($P < 0.001$) or wildlife guards ($P < 0.00$). The null hypothesis that the likelihood of mule deer crossing over a barrier would be equal among the five designs was rejected in favor of the alternative that the likelihood of mule deer crossing would differ among the five barriers (at least one significant difference in barrier effectiveness among the five designs).

Wildlife Deterrent Barrier Effectiveness for Other Wildlife

In addition to mule deer, 18 events were recorded in which coyotes (*Canis latrans*) approached within six feet (1.8 m) of double cattle guards and eight (44.4 percent) events resulted in the animal crossing. Images were recorded but did not include, the following species in analysis due to insufficient sample size (≤10 events): American badger (*Taxidea taxus*), black-tailed jack rabbit (*Lepus californicus*), bobcat (*Lynx rufus*), cottontail rabbit (*Sylvilagus spp.*), deer mouse (*Peromyscus spp*.), domestic cow (*Bos taurus*), elk (*Cervus canadensis*), gray

fox (*Urocyon cinereoargenteus*), gray wolf (*Canis lupus*), mountain lion (*Puma concolor*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), ring-tailed cat (*Bassariscus astutus*), striped skunk (*Mephitis mephitis*), wild turkey (*Meleagris gallopavo*), and ground squirrel (*Urocitellus spp*).

Discussion and Conclusions

In this study, double cattle guards and wildlife guards had the highest efficacy rates for excluding mule deer from roads: double cattle guards were on average 94 percent effective and wildlife guards were on average 87 percent effective. The least effective wildlife deterrent barrier designs for mule deer were electric mats, single cattle guards without excavation pits, and single cattle guard with excavation pits. The statistical models suggested the design of the barrier was the most important predictor of whether mule deer crossed. Mule deer were significantly less likely to breach double cattle guards and wildlife guards when compared with any other barrier design evaluated. Statistics determined there was no significant difference in barrier effectiveness between double cattle guards and wildlife guards.

In addition to the wildlife deterrent barrier design, AADT on the highway segment adjacent to the access road emerged as a significant predictor of barrier effectiveness. Although the effect was small, we detected a statistically significant effect of AADT on the likelihood of deer crossing over a barrier. Contrary to our expectation, the significant positive relationship between the variables suggested that barriers on access roads adjacent to highways with high traffic volume tended to have a *higher* likelihood of being breached by deer. Rather than representing a causal relationship between the variables however, the effect was likely an artifact of the spatial distribution of the barriers across Utah. Importantly, all single cattle guards had a high likelihood of being breached by deer and were concentrated along I-15, the highway with the greatest AADT volume in the study ($\bar{x}$ > 17,500 vehicles/day). In contrast, double cattle guards were the most effective barriers monitored and two of the four of them were adjacent to U.S. Highway 89, which had the lowest AADT volume of any highway in the study ($\bar{x}$ = 1,850 vehicles/day).

Contrary to the positive relationship found here between AADT and the likelihood of deer crossing, several studies suggest that roads with high traffic volume may act as more severe movement barriers to several species than roads with low traffic volume (Huijser et al. 2008, Jaarsma and Willems 2002, Seiler 2003). For example, Rost and Bailey (1979) demonstrated that mule deer and elk appeared to avoid high traffic roads when compared with low traffic roads in Colorado, USA. Mueller and Berthoud (1997) developed models that suggested highways with 4,000 to 10,000 AADT were strong movement barriers to wildlife and may become absolute barriers when traffic exceeds 10,000 AADT. Mule deer may have also been accessing I-15 in this study to graze on vegetation in the right-of-way rather than attempting to cross the interstate. This was especially true for the location where the single cattle guards with no pits were located (Exit 71 near Summit). Mule deer were photographed repeatedly crossing the cattle guard from both the wild side and the highway side, often within hours of each crossing type.

In our model, the distance to the nearest culvert or bridge mule deer could use to cross beneath the roadway also emerged as a significant predictor of barrier effectiveness. We detected a significant inverse relationship between the distance to the nearest culvert or bridge and the likelihood of deer crossing over a barrier. The relationship indicated that barriers closer to potential wildlife crossing structures had a *higher* likelihood of being breached by deer. This unexpected result was likely driven by the spatial distribution of wildlife deterrent barriers and wildlife crossing opportunities in our study area. For example, while the electrified mats adjacent to U.S. Highway 6 had a high likelihood of being breached by deer, the deterrents were also in close proximity to a highway bridge that mule deer could use to cross beneath the highway (Makeda. Hanson, UDWR, personal communication).

Another major factor in this unusual relationship was that wildlife mitigation fencing, wildlife deterrent barriers, and wildlife crossing structures were placed in Utah in areas where mule deer have a strong migratory need to move to seasonal ranges. Single cattle guards studied were in areas where no mitigation was placed and there have not been as large of herds or migratory linkages in these areas of Utah along I-15 where these were, as compared to mule deer movements and needs across US 89 in southern Utah and US 91 in northern Utah where the double cattle guards and wildlife guards were placed.

Another pattern that was not taken into account for the statistical analysis was the time since placement of the wildlife deterrent barriers. In the US 89 southern Utah sites, the double cattle guards monitored were placed just several months prior to this study. Initially the Paunsaugunt mule deer herd that migrates twice a year over US 89 at these locations was heavily motivated to breach the barriers because a portion of the animals did not have knowledge of wildlife crossing structures and culverts nearby that they could use. In the two and a half years since this study initiated, mule deer approaches and mule deer breaches have decreased drastically, as mule deer find those wildlife crossing structures. Statistical analyses on the dates since placement of the barriers could not be conducted because the exact dates of placement for the majority of the 14 sites were not known.

We suspect that the time since the installation of the wildlife barrier may have been an important determinant of efficacy. Based on observations from UDOT staff, electrified mats on US 6 appeared to be effective mule deer barriers in the months immediately following initial installation (Dave Babcock, UDOT retired, personal communication). However, our data indicate that, currently, electrified mats are poor deer barriers and suggest that mat efficacy may have attenuated over time. In contrast, the effectiveness of the double cattle guards monitored on US 89 may have increased over time. While the number of days that our cameras monitored the barriers did not emerge as a significant predictor of barrier effectiveness, we suspect that the effectiveness of a barrier may attenuate or increase over longer temporal scales as deer learn to defeat or avoid barriers.

Although double cattle guards were a substantial barrier to mule deer, the design was approximately 55 percent effective for coyotes, the only species other than mule deer for which we had a sufficient sample, and in general, none of the barrier designs evaluated were significant obstacles to carnivore movement. For example, we recorded several events in which a mountain lion crossed over a double cattle guard and a wildlife guard on US 91. Several events were recorded in which gray foxes traversed standard cattle guards as did red fox, and we captured one event of a wolf walking over a double cattle guard on US 89.

This research found the electric mats to be ineffective. Like Siepel et al. (2013), this study found two electrified mats deployed along US 6 to be poor barriers to mule deer

movement. The two electrified mats monitored were confirmed operational during monitoring and in use according to the manufacturer recommended pulse-rate settings (1.5-seconds between electrical pulses). Although Seamans and Helon (2008) found strong effectiveness of electrified mats under experimental conditions using feed bait as a reward, this study's results corroborate those from Siepel et al. (2013) and suggest limited effectiveness of electrified mats in a real-world setting along a road with over 10,000 AADT.

Recommendations and Implementation

1. Choose Double Cattle Guards and Wildlife Guards - This study's test of five wildlife deterrent barrier designs found that double cattle guards and wildlife guards were the most effective mitigation options for vehicle access points along wildlife exclusion fencing, with both designs consistently deterring mule deer from accessing fenced highway corridors. The 87 to 94 percent effectiveness rate of these two barriers should be used as the standard performance measure for future barrier designs.

2. Adaptively Manage and Retrofit Double Cattle Guards, Wildlife Guards, and Fencing - Although this study's data suggest that double cattle guards and wildlife guards can limit mule deer intrusions to highways, neither design represents an absolute barrier to mule deer. The majority of deer that breached the wildlife guards did so by walking on a 6 inch (15 cm) wide concrete frame exposed between the steel grating and the adjacent wildlife exclusion fencing. Installing additional fencing at an angle to obstruct the concrete frame or extending wildlife fencing over the frame may mitigate this problem and enhance the efficacy of wildlife guards. Additional adaptive management techniques include the installation of rubber "bumper" strips to fence posts or the addition of fence coils that may prevent deer from walking on the concrete frame (Pat Basting, formerly of Montana Department of Transportation, currently with JACOBS Engineering Group Inc., personal communication). Similarly, replacing guard apron wings (triangular metal structures installed at the margins of cattle guards) with additional wildlife fencing that overlaps the edge of the cattle guard would likely increase the effectiveness of this design for mule deer. Finally, retrofitting or replacing flat cattle guard rails with round or angular

rails may increase the effectiveness of these barriers for deer (Kelly McAllister, Washington Department of Transportation, personal communication).

3. Mule deer do jump double cattle guards and wildlife guards and need escape routes - While deer may be capable of running broad jumps of nearly 30 feet (9 m) (Severinghaus and Cheatum 1956), none of the mule deer that breached double cattle guards or wildlife guards in this study did so by jumping over the barriers in a single bound. However, mule deer were photographed completely clearing standard cattle guards and electric mats in a single jump. Cameras also recorded instances of deer that became entangled in cattle guards and wildlife guards while attempting to cross and instances of deer landing awkwardly in the guards while attempting to jump across. Providing additional earthen escape ramps in the vicinity of a wildlife barrier may reduce entanglements by allowing animals trapped within a fenced road corridor to escape safely (see Bissonette and Hammer 2000 for details).

Overall, this study provided clear results that can be used in to inform the planning and placement of wildlife barriers at vehicle access points along wildlife exclusion fences. The results also can be used as performance measure standards for future experimental designs of alternative wildlife barriers.