MOUNTAIN-PLAINS CONSORTIUM

MPC 15-297 | J.P. Flower and P.C. Cramer

Could Cattle Guards Augmented with Electrified Pavement Prevent Mule Deer and Elk Access to Highways?

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December 2015

Acknowledgements

We would like to thank our funding sources and research partners for making this project possible: the Utah Department of Transportation (UDOT), Utah Transportation Center at Utah State University, and the Utah Division of Wildlife Resources (UDWR). We thank the UDWR for supporting our efforts and for allowing us to conduct research at Hardware Ranch Wildlife Management Area. We especially thank R. Taylor, M. Aldridge, and D. Babcock at UDOT for making our roads safer for people and wildlife. Thanks to the dedicated professionals at UDWR including B. Hunt, K. Pitcher, D. DeBloois, A. Green, S. Walker, P. Kramer, and R. Boswell. Thanks to R. Lampman and B. Truelove at Lampman Wildlife Services for allowing us to test their product. We greatly appreciate assistance from D. Coster for invaluable assistance with experimental design and data analysis. J. Bissonette provided valuable feedback throughout the project. We extend our gratitude to the Utah Division of Wildlife Resources Dedicated Hunter Program and to T. Lowe, T. Wagstaff, C. Peterson, A. Shaw, W. Evans, J. Barratt, C. Snider, S. White, and S. Morgan for field assistance.

ABSTRACT

Motorists and wildlife are at risk when wild animals enter highways at access roads that bisect wildlife exclusion fencing. Cattle guards are common at access roads, but are ineffective wildlife barriers. Electrified pavement is an emerging technology previously untested as an ungulate deterrent. Our objective with this study was to evaluate whether a standard cattle guard augmented with a strip of electrified pavement could reduce mule deer and elk intrusions through fence openings at rates comparable to specialized barriers, but at reduced cost. To determine the efficacy of the augmented guards as a barrier to wildlife movement, a two-part approach was used that included (1) a feeding exclosure trial using augmented guards deployed at entrances to baited wildlife exclosures at the Hardware Ranch Wildlife Management Area in Northern Utah, and (2) a road trial in situ on an access road to Interstate 15 in Southern Utah. Our goal was to provide a rigorous assessment of a cost-effective retrofit to standard cattle guards that could reduce wildlife intrusions to roadways and other protected areas at rates comparable to specialized guards.

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EXECUTIVE SUMMARY

Motorists and wildlife are at risk when wild animals enter highways at access roads that bisect wildlife exclusion fencing. Cattle guards are common at access roads, but are ineffective wildlife barriers. Electrified pavement is an emerging technology previously untested as an ungulate deterrent. We evaluated whether a standard cattle guard augmented with electrified pavement could prevent mule deer (Odocoileus hemionus) and elk (Cervus canadensis) intrusions through openings in wildlife exclusion fencing. To test cattle guards augmented with electrified pavement, we used camera traps to monitor wildlife intrusions into four baited wildlife exclosures with augmented cattle guards and at two exclosures with untreated cattle guards. Cattle guards augmented with strips of electrified pavement (0.91-m to 1.2-m-wide) were >80% effective in excluding mule deer and >95% effective in excluding elk from wildlife exclosures that were constructed in a natural area away from roads. However, when installed into the road surface in front of an existing cattle guard, a strip of electrified pavement (0.91-m-wide) was 54% effective in excluding mule deer from a fenced segment of Interstate 15. Electrified pavement appears to have potential as an effective tool to reduce ungulate access to roadways when deployed at wider dimensions (≥ 1.8-m-wide). To fully assess the viability of electrified pavement for use in excluding wildlife from highways, multi-year monitoring of replicate in-road installations is needed and ongoing.

Roads cover more than 1% of the total land surface of the contiguous United States but affect greater than 20% of the land area ecologically (Foreman 2000). While the effects of these expanding road networks on living systems are diverse, perhaps none are more direct or conspicuous than wildlife mortality due to wildlife-vehicle collisions (Bissonette 2001). In the U.S. alone, an estimated one to two million vehicle collisions with large wild animals occur annually, resulting in approximately 29,000 human injuries and 200 human deaths (Conover et al. 1995, Huijser et al. 2009). When the collective costs due to vehicle damage, human injuries and fatalities, and loss of animal value are combined, the total economic toll imposed by wildlife-vehicle collisions (WVCs) in the U.S. exceeds US$8 billion annually (Huijser et al. 2008).

With an estimated one million vertebrates killed each day on America's highways, WVCs not only pose a threat to the motoring public but can threaten the survival of animal populations (Lalo 1987). Although mortality from vehicle collisions may not pose a significant threat to robust wildlife populations, road mortality can be devastating to small or declining populations (Bennet 1991). For example, road mortality has been identified as a major threat to the survival of 21 federally listed threatened or endangered animal species in the U.S. (Huijser et al. 2008). However, the majority of WVCs involve deer (Odocoileus sp.), with deer-vehicle collisions accounting for ≥ 90% of all WVCs in some U.S. states (Huijser et al. 2008).

The most effective method to reduce vehicle collisions with large ungulates is the placement of wildlife exclusion fencing (2.4 m high) in conjunction with wildlife crossing structures (Hedlund et al. 2004). The main objectives of these structures are to: (1) connect habitats and wildlife populations by providing safe passage for wildlife, (2) reduce wildlife mortality due to WVCs, and (3) increase motorist safety (Beckman et al. 2010). When effectively designed and maintained, wildlife exclusion fencing prevents wildlife access to the roadway and guides animals to crossing structures that facilitate animal passage under or above the road. When combined, these mitigation measures can reduce collisions with large animals by >85% and are the only widely accepted method to effectively reduce WVCs (Hedlund et al. 2004, Huijser et al. 2009).

Management of wildlife intrusions at access roads that bisect wildlife fencing is critical to ensure the success of integrated fence-wildlife crossing structure systems (Peterson et al. 2003). If access roads that bisect fencing are not designed with an effective deterrent to exclude ungulates and other wildlife from the road right-of-way, wildlife crossings and fencing can become ineffective (P. Cramer, Utah State University, personal communication). Standard cattle guards (1.8 m to 2.1 m wide in dimension parallel to vehicle travel) are ubiquitous in the western U.S. and are common at openings in wildlife exclusion fencing. While cattle guards are generally effective at preventing hoofed livestock from accessing highways, they are largely ineffective as barriers to mule deer (Odocoileus hemionus) – the species most often involved in WVCs in much of the western U.S. (Reed et al. 1974, Ward 1982, Flower and Cramer unpublished data). Replacement or upgrade of standard cattle guards with fence-gap mitigation designs that more effectively exclude wildlife can be cost-intensive. Specialized barriers often used to replace or upgrade standard cattle guards, such as double cattle guards (two adjoining standard cattle guards, 3.8 m to 4.8 m wide) or wildlife guards (metal grating, 4.8 m to 6.6 m wide) can effectively prevent deer intrusions (Belant et al. 1998, U.S. Army 2006, Allen et al. 2013, Flower and Cramer unpublished data) but cost approximately US$30,000 to US$60,000 per application, depending on road width (R. Taylor, Utah Department of Transportation, personal communication). These up-front installation costs can be prohibitive when considered at a landscape scale. For example, transportation departments face costs of US$240,000 to mitigate a single highway interchange with four double cattle guards (R. Taylor, Utah Department of Transportation, personal communication).

In this field study, our objective was to evaluate whether a standard cattle guard augmented with a strip of electrified pavement could reduce mule deer (Odocoileus hemionus) and elk (Cervus canadensis) intrusions through fence openings at rates comparable to specialized barriers, but at reduced cost. To determine the efficacy of the augmented guards as a barrier to wildlife movement, we used a two-part approach that included: (1) a feeding exclosure trial using augmented guards deployed at entrances to baited wildlife exclosures at the Hardware Ranch Wildlife Management Area in northern Utah, and (2) a road trial in situ on an access road to Interstate 15 in southern Utah. Our goal was to provide a rigorous assessment of a cost-effective retrofit to standard cattle guards that could reduce wildlife intrusions to roadways and other protected areas at rates comparable to specialized guards.

1. STUDY AREA

We conducted the feeding exclosure trial at fenced wildlife exclosures within the 5,778 ha Hardware Ranch Wildlife Management Area (HRWMA), Cache County, Utah (41o 36' N, 111o 33' W). HRWMA is administered by the Utah Division of Wildlife Resources (UDWR) and serves as wintering habitat for mule deer and elk. Since 1947, a winter elk feeding program has operated at HRWMA and was active during the study from 13 December 2014 to 9 February 2015. Although elk are provided supplemental winter feed (grass hay) at the ranch, mule deer are prevented from accessing feed by socially dominant elk that exclude deer from the feeding area (B. Hunt, UDWR, personal communication, Johnson et al. 2000, Stewart et al. 2002). Habitat within HRWMA includes sagebrush communities, grassland, open woodlands, meadows, and riparian corridors. Dominant vegetation includes sagebrush (Artemisia sp.), conifers (Juniperus sp., Pinus sp.), aspen (Populus tremuloides), and riparian vegetation (UDWR 2012). Depending on winter severity, the number of wintering mule deer within HRWMA ranges from 500 to 1,000 individuals (8.6 to 17.3/km2; Utah Division of Wildlife Resources 2012). The estimated minimum mule deer population in the immediate study area during the evaluation (fall 2014 – spring 2015) was 200 (D. DeBloois, UDWR, unpublished data). The number of wintering elk within HRWMA ranges from 450 to 650 individuals (7.7 to 11.2/km2; UDWR 2012). The estimated minimum elk population in the immediate study area during the study was 600 (D. DeBloois, UDWR, unpublished data).

We conducted the road trial in situ at mile post 32 on an access road to Interstate 15, near the town of Pintura, Washington County, Utah (37o 20' N, 113o 16' W). Standard cattle guards span access roads on each side of the interchange and are located at openings in continuous wildlife exclusion fencing (2.4 m-high). The segment of Interstate 15 adjacent to the test site is a fenced, four-lane highway, divided by an open median with a posted speed limit of 75 miles per hour (120.7 km/hr) and annual average daily traffic of 21,675 vehicles (UDOT, Transportation Monitoring Unit 2013). A concrete box culvert for reservoir overflow is located 8.5 km north of the interchange, and prior research found occasional mule deer use of the structure (Cramer 2014). 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. Ash Creek and the steep, volcanic slopes of the Black Ridge formation are on the east side of the highway. The interchange is recognized as an area where mule deer often gained access to the highway corridor while traveling seasonally between summer and winter ranges (R. Boswell, UDWR, personal communication, Flower and Cramer unpublished data). Habitat in the area includes sagebrush communities, conifer woodlands, riparian corridors, and small agricultural areas. Dominant vegetation includes sagebrush (Artemisia sp.), conifers (Juniperus sp., Pinus sp.), and riparian vegetation. 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).

2. MATERIAL AND METHODS

2.1 Feeding Exclosure Trial

To motivate deer and elk crossing attempts over experimental guards, we established six wildlife exclosures at Hardware Ranch and baited each with weed-free alfalfa cubes (Intermountain Farmers Association, Salt Lake City, UT, USA). Wildlife exclosures were constructed of 2-m-high woven wire fencing (10 m/side). We added a single strand of white, braided nylon-copper wire rope (ElectroBraid Fence Limited, Lititz, PA, USA) to increase the fence height to 2.3 m. At a 3-m-wide opening centrally located on one side of each exclosure, we constructed a 3 m × 2.1 m simulated wooden cattle guard approximately level with the ground (Figure 2.1).

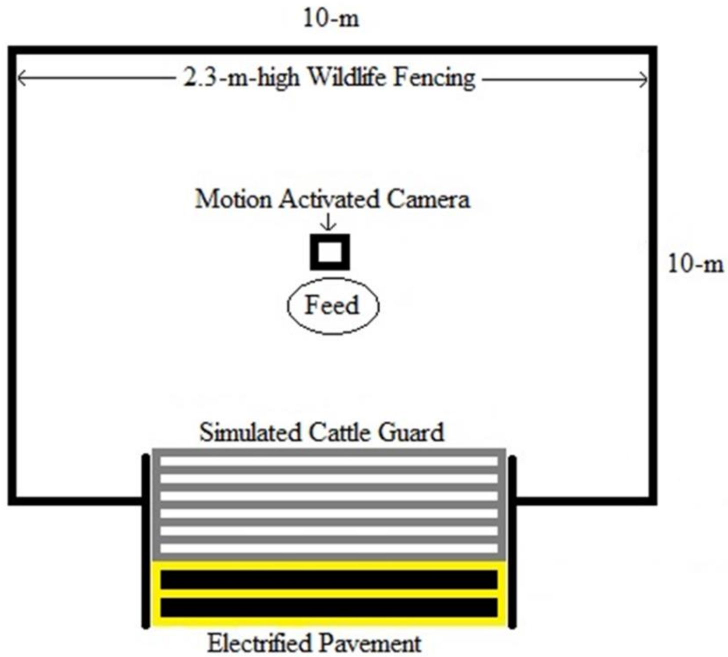

Figure 2.1 Top view of a 10 m × 10 m wildlife exclosure used to test 3 m × 2.1 m cattle guards augmented with either 3 m × 1.2 m (n = 2) or 3 m × 0.91 m (n = 2) electrified pavement as an ungulate barrier at Hardware Ranch Wildlife Management Area, Utah, from mid-Oct 2014 to mid-March 2015. Four sites had cattle guards treated with electrified pavement and two sites had untreated cattle guards.

We constructed simulated cattle guards according to the design and dimensions of standard cattle guards found on Interstate 15. The cattle guard frame consisted of five, 2.1 m × 8.8 cm × 8.8 cm wooden support beams spaced evenly at 72 cm intervals and suspended over a 1-m-deep excavation. We secured 13 rectangular wooden rails measuring 3 m × 6.4 cm × 3.8 cm evenly at 9.5-cm intervals perpendicularly across the support beams and approximately level with the surrounding ground surface. We installed 9.5 cm × 3.8 cm wooden spacer blocks between the rails to prevent animals from stepping on support beams beneath the rails. We extended the fence line along the edges of the guard to prevent animals from accessing the exclosure by traversing along the sides of the guards. We painted all simulated cattle guards with metallic gray latex exterior paint.

The electrified pavement device (EPD; Lampman Wildlife Services, Ontario, Canada) used to augment the simulated cattle guards was constructed at two different widths to investigate if a difference in effectiveness existed between the two dimensions. The overall dimensions of the two EPD's tested were 3-m long by either 0.91-m- or 1.2-m-wide (dimension traversed by an animal entering the exclosure). The electrified material was contained by a rectangular plastic form constructed of 6.3 cm × 14 cm yellow recycled plastic boards (US Plastic Lumber, Chicago, IL, USA). The plastic form was filled with a black, conductive material impregnated with a matrix of stainless steel that delivered an electrical potential to the entire surface of the pavement-like slab. An additional plastic yellow board installed lengthwise in the center partitioned the form into two sections. The bottom of the form was covered with a sheet of 12-mm-thick plastic sheeting to insulate the electrified material from earth ground (Figure 2.2).

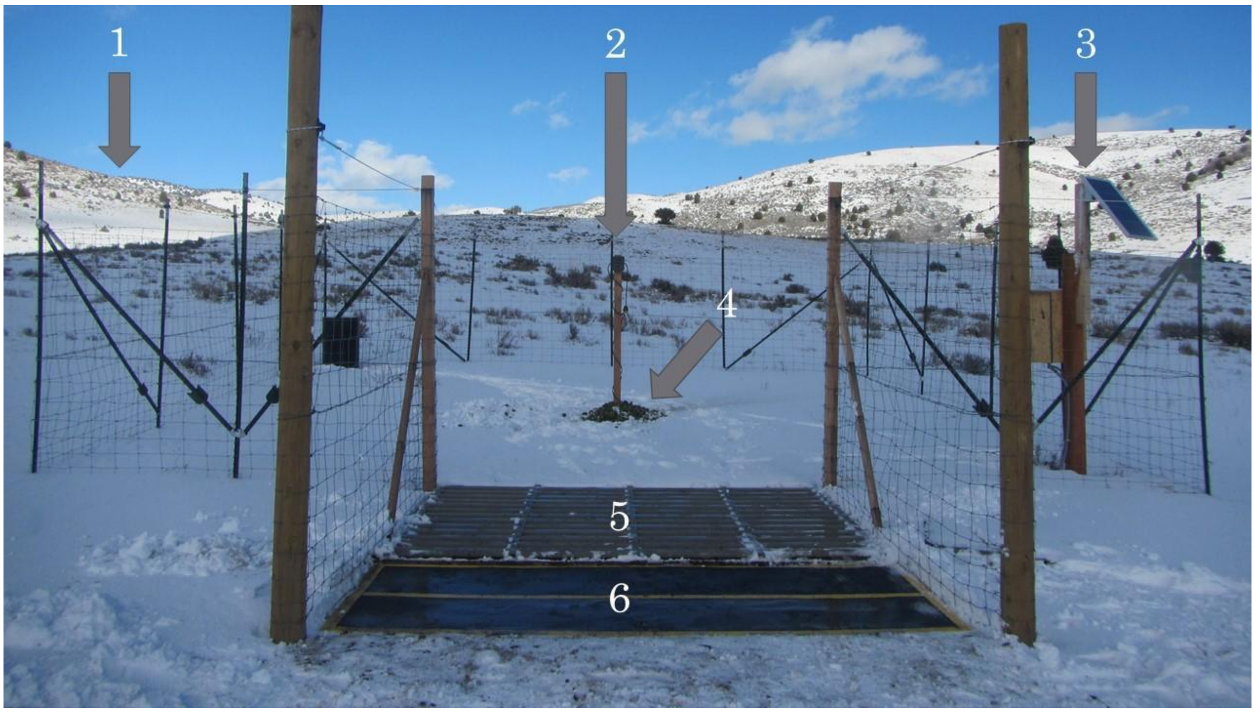

Figure 2.2 Front view of a 10 m × 10 m wildlife exclosure used to test efficacy of 3 m × 2.1 m cattle guards augmented with either 3 m × 1.2 m (n = 2; pictured) or 3 m × 0.91 m (n = 2) electrified pavement as an ungulate barrier at Hardware Ranch Wildlife Management Area, Utah, from mid-Oct 2014 to mid-March 2015. Symbols added to indicate exclosure elements: 1 = 2.3-m-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.

The EPD was composed of two insulated slabs of conductive pavement. 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 (Figure 2.3). Further, the contrasting yellow and black coloration may have acted as aposematic coloring, providing a visual warning cue to animals that approached it (Seamans and Helon 2008). The EPD was powered by a Stafix X3TM 3-Joule solar-powered energizer (Tru-Test Limited, Auckland, New Zealand), which delivered a maximum output voltage of 11.4-kilovolts to the conductive slabs 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 2.3 Close view of a 10 m × 10 m wildlife exclosure used to test efficacy of 3 m × 2.1 m cattle guards augmented with either 3 m × 1.2 m (n = 2; pictured) or 3 m × 0.91 m (n = 2) electrified pavement as an ungulate barrier at Hardware Ranch Wildlife Management Area, Utah, from mid-Oct 2014 to mid-March 2015. Positive and negative symbols added to indicate polarity of electrified pavement.

We installed one motion activated wildlife camera (RECONYX Model PC800 Hyperfire Professional; Holmen, WI, USA) on a post 1.8 m above the ground at the center of each exclosure to record wildlife approaches and behavioral reactions throughout the feeding exclosure trial. We oriented cameras toward the entrance of the exclosure and programmed each to take five to 10 consecutive photographs as fast as possible each time the camera was triggered and to retrigger immediately after detecting motion. The International Animal Care and Use Committee approved our procedures (Protocol #2432).

We maximized spacing between exclosures to reduce interdependence of deer and elk visitation and behavior among the exclosures (Seamans and Helon 2008, VerCauteren et al. 2009). Average spacing of exclosures at HRWMA was 1.09 km. The minimum and maximum distance between two exclosures was 0.57 km and 1.84 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 blocks. We then randomly allocated three treatment levels (control = cattle guard, treatment 1 = cattle guard augmented with 0.91-m-wide EPD, treatment 2 = cattle guard augmented with 1.2-m-wide EPD) to the three experimental units within each of the two blocks (Figure 3.4). Because mule deer tend to avoid areas frequented by elk (Johnson et al. 2000, Stewart et al. 2002), we hypothesized that the three sites within the block closest to the winter elk feeding area (Block 2) would be subject to higher elk visitation rates, and by default, lower deer visitation rates than the three sites farthest from the elk feeding area (Block 1; Figure 2.4). The putative homogeneity of sites within the same block was imparted by differences in elk presence between the two blocks and led us to anticipate that sites within the same block may also have similar responses from deer and elk that visited them (Oehlert 2000).

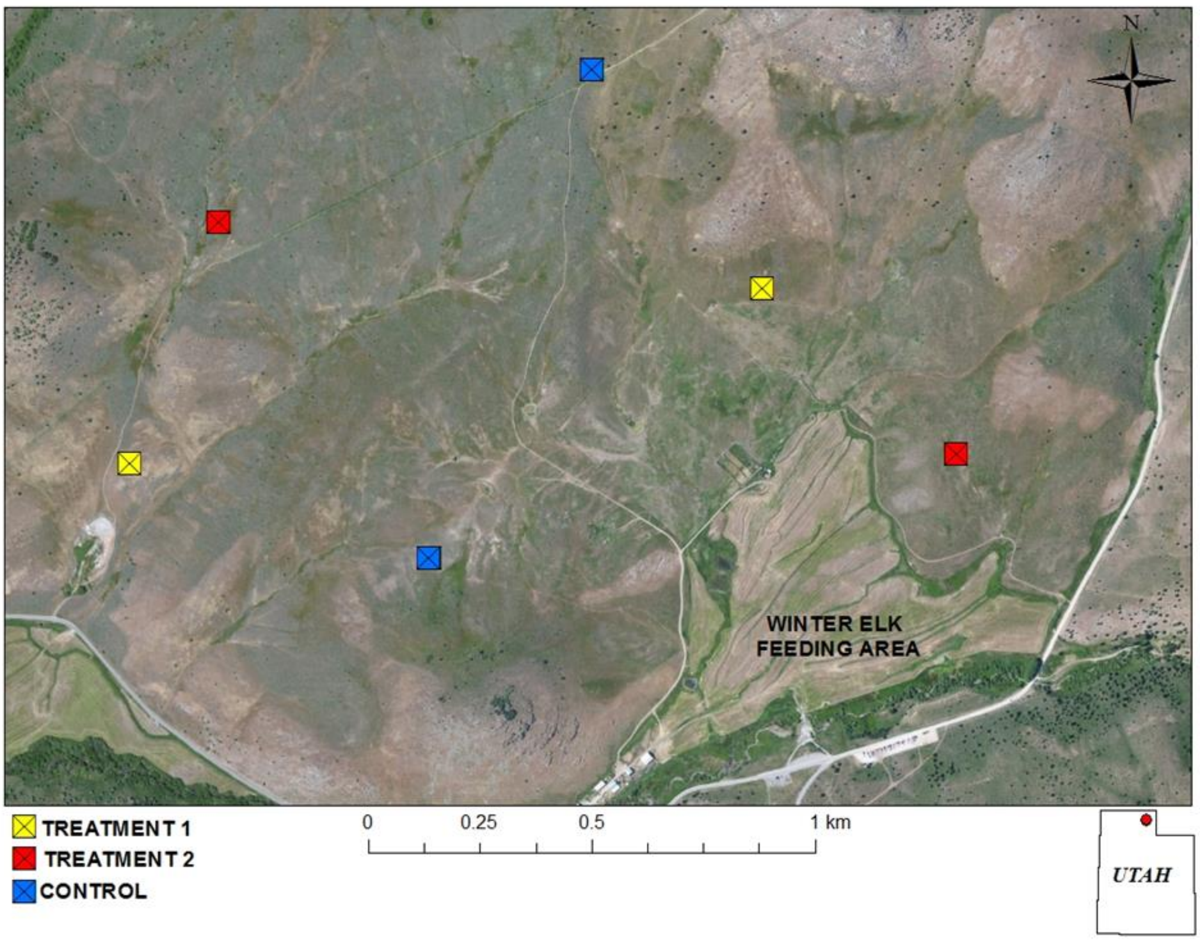

Figure 2.4 Aerial view of wildlife exclosures with entrances treated with cattle guards augmented with either 3 m × 0.91 m electrified pavement (treatment 1, n = 2), 3 m × 1.2 m electrified pavement (treatment 2, n = 2), or cattle guards alone (control, n = 2), Hardware Ranch Wildlife Management Area, Utah, USA. Three stations adjacent to the winter elk feeding area were assigned to block 2 and the remaining three stations were assigned to block 1.

Prior to the start of the feeding trial, we covered the deterrents at all sites with untreated sheets of plywood and 2 cm of soil for a five-week pre-treatment period. The pre-treatment period allowed animals to habituate to the exclosures, find the feed, and establish consistent use of the exclosures (Peterson et al. 2003). We visited sites every other day to maintain a supply of weed-free alfalfa cubes (Intermountain Farmers Association, Salt Lake City, UT, USA) on the ground in the center of each exclosure. We used alfalfa cubes as bait because the feed is occasionally used by local wildlife managers during emergency winter feeding of ungulates near the study area. Further, the nutrient-rich feed was recommended as an attractive food source for ungulates during energetically stressful periods (D. DeBlooise, UDWR, personal communication). During pre-treatment, we also distributed feed atop the covered deterrents and adjacent to the fence opening to encourage animals to establish use of the exclosures. Pre-treatment took place over a five-week period from 13 October to 16 November 2014.

Following the conclusion of the pre-treatment period, we removed the wooden sheets from the deterrents, energized the EPDs, and monitored animal approaches to each site for a 17-week treatment period. During the treatment period, we visited exclosures weekly at minimum to: (1) maintain a constant supply of fresh feed in the center of each exclosure, (2) clear accumulated snow from the surface of the deterrents and solar panels, (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. The treatment period took place between 16 November 2014 and 16 March 2015. In total, we maintained the sites for a total of 22 weeks, from 13 October 2014 to 16 March 2015.

2.1.1 Image Analysis

We examined images of animal approaches to the deterrents and tabulated data gathered from images in a custom database (Access 2013, Microsoft Corporation, Redmond, WA, USA). A single observer analyzed all images to ensure consistency and limit observer bias. Each record in the database comprised an independent event in which one or more animals approached within 2 m of the deterrent. We did not tabulate images of animals recorded more than 2 m distant from the deterrents, because we did not consider those movements indicative of deterrent effectiveness (Allen et al. 2013). Groups of animals traveling together or were present within the same 15-minute interval were treated as a single independent event because the movements of individuals within the same group were likely interdependent (Allen et al. 2013, Schwender 2013). For each event, we considered the outcome either a success (no animals in the event breached the deterrent) or a failure (at least one animal in the event breached the deterrent). For each event, the total number of individuals recorded within 2 m of the deterrent and the total number of individuals that breached the deterrent were also entered. Each individual animal in the event was classified as either moving in parallel to the deterrent, repelling from the deterrent, or crossing the deterrent. Events were classified as behavior with intent to cross the deterrent (crossing behavior) when one or more animals in the event displayed behavior that appeared to indicate an intent to cross the deterrent. Qualifying behavior included, but was not limited to: circling the exclosure, pawing at or stepping on the deterrent, stalling at the fence opening, or by animals that placed their nose to the ground in front of or on the deterrent (Allen et al. 2013). Events were classified as a crossing when one or more animals completely breached the deterrent and gained access to the exclosure. Because we could not distinguish between individual animals during image analysis, it could not be determined whether movement patterns at the exclosures were produced by different groups of animals or by the same groups detected multiple times. For each event, we also recorded the number of days since the start of the treatment period and whether snow was present on the surface of the deterrent during the event.

2.1.2 Effectiveness Estimation

We estimated the effectiveness of each of the three treatments as a barrier to animal movement by addressing the following research questions. First, what is the difference in the total number of weekly deer and elk intrusions across the three treatments? We answered this question by comparing the total number of deer and elk intrusions across the three deterrents for each week of the 17-week treatment period. Second, how effective are the three treatments as a barrier to animals that approached them? We answered this question by calculating the percentage of events that resulted in crossing the deterrent compared with the total number of events in which animals approached within 2 m of the deterrents (Allen et al. 2013). Because not all the animals that approached the deterrents may have intended to cross them, we also considered a subset of the approach events and posed a third research question: how effective are three treatments as a barrier to animals that display behavior to cross the deterrents? We answered this question by calculating the percentage of events that resulted in crossing compared with the total number of events that included crossing behavior (Allen et al. 2013).

In addition to calculating the percentage of independent events that resulted in crossing, we also considered the total number of individual animal approaches within 2 m of the deterrents and the total number of those approaches that resulted in crossing. However, we did not base our inference of guard effectiveness on these metrics for the following reasons: (1) there was evidence from image analysis that movement and behavior between individuals was interdependent, (2) because we could not reliably distinguish between individuals, it was often difficult to reliably estimate the total number of individuals that approached the deterrents, and (3) inability to decipher between individuals likely led to over-counting individuals, which led to overestimates of the total number of individual approaches and resulted in efficacy metrics that were biased high.

Our null hypothesis was that mule deer would be as equally likely to cross cattle guards treated with electrified pavement as untreated cattle guards. Our alternative hypothesis was that mule deer would be less likely to cross treated cattle guards than untreated cattle guards. We posed similar hypotheses for elk. To test these hypotheses, and to examine explanatory variables associated with crossing events, we used generalized linear models to perform logistic regression analyses.

2.1.3 Statistical Model

We used generalized linear models with binomial distributions and logit-links to examine explanatory variables associated with crossing events, defined as an event in which one or more mule deer or elk breached the deterrent and gained access to the exclosure. We performed all analyses using the GLIMMIX procedure in SAS (Version 9.4; SAS Institute Inc., Cary, NC, USA) and cross-validated model output with model output from R (Version 3.1.1; The R

Foundation for Statistical Computing, Vienna, Austria). The response variable was the binary outcome of each event and was assigned as either success (0 = no animals in the event breached the deterrent) or failure (1= at least one animal in the event breached the deterrent). We used a binary response variable rather than considering the proportion of individuals that breached the deterrent out of the total number of individuals that approached the deterrent, because it was often difficult to reliably estimate the total number of individuals involved in an event. We used the categorical explanatory variables of treatment level, block, and whether snow was present on the surface of the deterrent during the event. We also included the continuous explanatory variable of the number of days since the start of the treatment period to determine if the likelihood of crossing varied as the treatment period progressed (Table 2.1).

Table 2.1 Measured variables included in logistic regression models used to examine explanatory variables associated with mule deer and elk intrusions into experimental feeding stations at Hardware Ranch Wildlife Management Area, Utah, USA.

Variable Type	**Variable Name**	**Variable Description**
Response	Cross Code	0 = non-crossing event, 1 = crossing event
Explanatory	Treatment Level	0 = cattle guard (control)
		1 = cattle guard with 0.91-m-wide electric pavement
		2 = cattle guard with 1.2-m-wide electric pavement
	Block	1 = block 1, 2 = block 2
	Snow	0 = no snow present, 1 = snow present on deterrent
	Day	Days since the start of the treatment period (0 – 119)

For the logistic regression models, we only considered events that included potential crossing behavior, where one or more animals in the event displayed behavior that was translated as intent to cross the deterrent and gain access to the exclosure. Events where potential crossing behavior was absent were defined as events where animals passed within 2 m of the deterrent, but did not display behavior that indicated intent to enter the exclosure. Because these “parallel” movements may not have been directly indicative of deterrent effectiveness, we omitted them from the models (Schwender 2013). Discounting these movements ensured that only events in which animals appeared to attempt to breach the deterrents were considered in the models.

2.2 Road Trial

On an access road on the west side of Interstate 15, a strip of electrified pavement (0.91 m × 11 m) was installed along the full length of an existing standard cattle guard (2.1 m × 11 m; Figure 2.5). The EPD was installed on the highway-entry side of the guard to prevent wildlife that originated from outside of the fenced highway corridor from gaining access to the highway corridor. The interchange was selected as a test site due to high mule deer activity documented in the area during pre-installation camera monitoring in 2013-2014, and low vehicle traffic volume on the access road leading to the interstate. The cattle guard consisted of 12 rectangular steel rails measuring 7.6 cm × 11 m spaced evenly at 10.1 cm intervals. The steel rails were suspended over a 30.4-cm-deep excavation, approximately level with the surrounding pavement. Materials used in the construction of the EPD road trial were identical to those used in the feeding exclosure trial. The width of the EPD was identical to that of the narrower pavement dimension in the feeding exclosure trial (0.91-m-wide, treatment level 1). Installation took place over a six-day period from 12-18 June 2014. The deterrent was energized on 29 July 2014. The EPD was powered by components identical to those used in the feeding exclosure trial (3-Joule solar-powered energizer, 40-watt solar panel, solar charge controller, and 12-volt deep-cycle battery). To deter theft, components were located inside a steel box within a fenced area adjacent to the EPD. A warning sign was installed advising pedestrians to use an adjacent gate in the fence (Figure 2.5).

Figure 2.5 Cattle guard (2.1 m × 11 m) augmented with electrified pavement (0.91 m × 11 m) on access road to Interstate 15 (background), near Pintura, Utah, USA.

To determine the effectiveness of the experimental guard, we installed one motion-activated wildlife camera (RECONYX Model PC85; Holmen, WI) on each end of the guard on 16 June 2014. We oriented cameras to face each other and programmed each to take three to five images as fast as possible for each motion trigger. To prevent power loss from repeated vehicle detections, we programmed cameras to be inactive from 10 a.m. to 4 p.m. at the start of the trial (16 June 2014 to 29 November 2014). After we learned that cameras would remain powered between checks, we eliminated the inactive period and programmed cameras to be active for all hours (29 November 2014 to 22 April 2015). We visited cameras monthly to download images, change batteries, and ensure operation of the electrified pavement. Cameras continuously monitored wildlife approaches from mid-June 2014 to late-April 2015.

We used identical image analysis methods in the road trial and the feeding exclosure trial. In our final analysis, we only included animal movements that originated from outside of the fenced-highway corridor and omitted animal movements in which animals crossed the guard to escape the highway right-of-way (ROW). We did not consider animals that breached the guard while escaping the ROW as indicative of the effectiveness of the experimental guard for the following three reasons: (1) animals that breached the guard while escaping the ROW only encountered the electric deterrent after breaching the cattle guard, (2) animals that attempted to escape the ROW may have been more motivated to cross the guard than animals that attempted to gain access to the ROW (Allen et. al 2013), and (3) the purpose of the guard was to deter animal entry into the ROW, rather than to prevent animal escape from the ROW.

3. RESULTS

3.1 Feeding Exclosure Trial

During the five-week pre-treatment period at Hardware Ranch when the deterrents were covered, mean ambient temperature was 2.1°C and ranged from -21.4 to 23.8°C. During the pre-treatment period, observed snow cover ranged from 0 – 100% and recorded snow depth ranged from 0 to 8 cm. When the sheeting was removed and deterrents were exposed during the 17-week treatment period, mean ambient temperature was 1.3°C and ranged from -24.9 to 19.9°C (Utah Climate Center, Utah State University). During the treatment period, observed snow cover ranged from 0 – 100% and recorded snow depth ranged from 0 to 8 cm.

3.1.1 Difference in Weekly Wildlife Intrusions: Control vs. Treatment

When the deterrents were covered in weeks 1 to 5, we observed limited weekly mule deer intrusions across all sites ($\bar{x}$ = 6.2/week, min. = 0, max. = 13, Figure 6). During this pre-treatment period, average weekly mule deer intrusions at controls sites ($\bar{x}$ = 2/week) were similar to those at treated sites (treatment level 1, $\bar{x}$ = 2.2/week; treatment level 2, $\bar{x}$= 2/week). When we exposed the deterrents in the treatment period in weeks 6 to 22, mule deer intrusions were virtually eliminated across all sites until week 12, when intrusions increased dramatically at the control sites only (Figure 3.1). During weeks 12 to 22 of the treatment period, we recorded at least 55 deer intrusions at the control sites every week ($\bar{x}$ = 56.5/week, min. = 55, max. = 139), but never greater than 4 intrusions per week at treated sites during the same period ($\bar{x}$ = 1.0/week, min. = 0, max. = 4). Weekly deer intrusions at treated sites never exceeded weekly intrusions at controls sites and were lower at the treated sites in a total of 12 of 17 weeks during the treatment period (Figure 3.1). In total, we recorded 983 mule deer intrusions into all sites during the treatment period. Of these, 967 (98.4%) were into control sites and 16 (1.6%) were into treated sites.

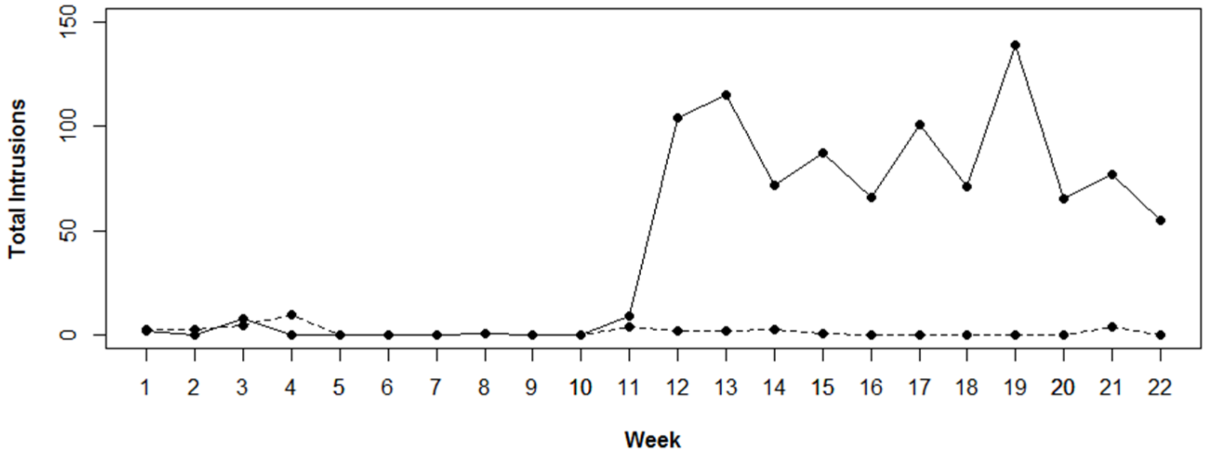

Figure 3.1 Weekly mule deer intrusions into two baited wildlife exclosures with entrances treated with simulated cattle guards (control, solid line) and into four exclosures treated with simulated cattle guards augmented with electrified pavement (treatment, dashed line) over the 22-week study period (mid-Oct 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah. Deterrents were covered in weeks 1 to 5 and exposed in weeks 6 to 22.

Unlike mule deer, elk regularly entered the feeding stations during the five-week pre-treatment period, with intrusions peaking in week 4 (Figure 4.2). During pre-treatment (deterrents covered) average weekly elk intrusions were somewhat lower at sites treated with the narrower pavement dimension (treatment level 1, $\bar{x}$ = 45.2/week) when compared with sites treated with the wider pavement dimension (treatment level 2, $\bar{x}$ = 56.8/week) and control sites ($\bar{x}$ = 60/week). When we exposed the deterrents in the treatment period, weekly elk intrusions were virtually eliminated at treated sites ($\bar{x}$ = 0.35/week, min. = 0, max. = 3) for the duration of the 17-week treatment period. However, elk intrusions at control sites occurred in nearly every week of the treatment period ($\bar{x}$ = 11.76/week, min. = 0, max. = 60; Figure 4.2). Weekly elk intrusions at treated sites never exceeded weekly intrusions at controls and were lower in virtually every week of the treatment period (Figure 3.2). In total, we recorded 206 elk intrusions into all sites during the treatment period. Of these, 200 (97.1%) were into control sites compared with 6 (2.9%) at treated sites.

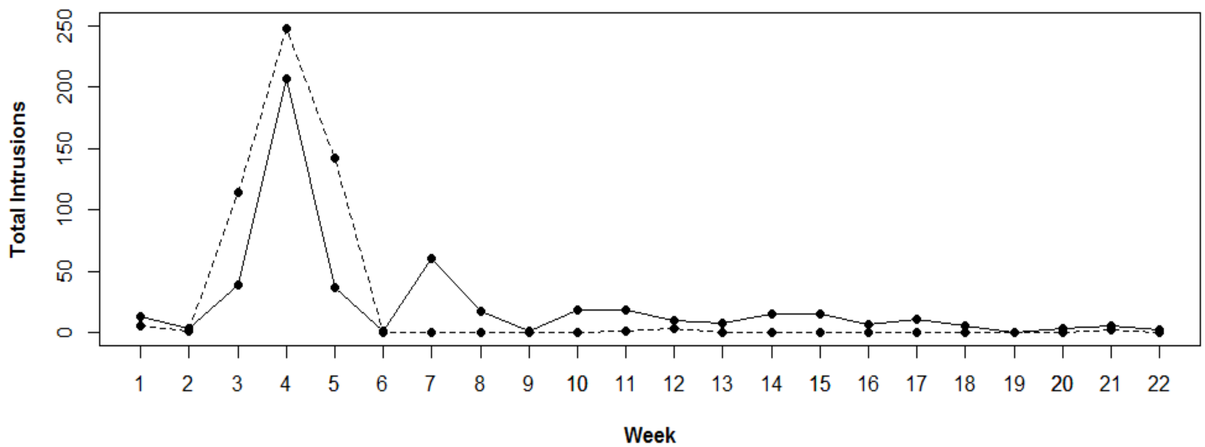

Figure 3.2 Weekly elk intrusions into two baited wildlife exclosures with entrances treated with simulated cattle guards (control, solid line) and into four exclosures treated with simulated cattle guards augmented with electrified pavement (treatment, dashed line) over the 22-week study period (mid-Oct 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah. Deterrents were covered in weeks 1 to 5 and exposed in weeks 6 to 22.

3.1.2 Effectiveness of Treatments as Barriers to Approaching Animals

Across all sites treated with electrified pavement (treatments 1 and 2 combined), we observed 166 independent events in which mule deer approached within 2 m of the deterrents during the treatment period (Table 3.1). Of these, 13 events (7.8%) resulted in a crossing event, in which one or more mule deer completely breached the deterrent and gained access to the fenced exclosure. Of the 13 deer crossing events at treated sites, 7 (53.8%) occurred when snow covered the electrified surface of the deterrents. Across the sites with only cattle guards (controls), there were 533 events in which mule deer approached the deterrents and 424 (79.5%) resulted in crossing. Out of 262 events in which elk approached treated sites, 5 events (1.9%) resulted in crossing, all of which occurred when snow covered the deterrents. In contrast, 130 of the 204 elk approach events (63.7%) resulted in crossing at the control sites.

Table 3.1 Number and percentage of independent events in which animals approached (within 2 m) and subsequently crossed, or did not cross, deterrents at entrances to baited wildlife exclosures during the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah.

Species	Treatment Level	Approached	Crossed	% Crossed	Did not cross	% Effective
Mule Deer	Treatment 1[a]	74	4	5.4	70	94.6
	Treatment 2[b]	92	9	9.8	83	90.2
	Treatments Combined	166	13	7.8	153	92.2
	Control[c]	533	424	79.5	109	20.5
Elk	Treatment 1[a]	130	1	0.8	129	99.2
	Treatment 2[b]	132	4	3.0	128	97.0
	Treatments Combined	262	5	1.9	257	98.1
	Control[c]	204	130	63.7	74	36.3

[a] = cattle guard augmented with 0.91-m-wide electric pavement

[b] = cattle guard augmented with 1.2-m-wide electric pavement

[c] = cattle guard

We also considered the total number of individual wildlife approaches within 2 m of the deterrents and the total number of those approaches that crossed, or did not cross the deterrents (Table 3.2). However, we did not base our inference on these metrics because guard effectiveness was likely biased high. Of the 363 total individual mule deer approaches at treated sites, a total of 16 deer (4.4%) crossed. Similarly, of the 1069 total individual elk approaches at treated sites, 6 animals crossed (0.6%).

Table 3.2 Number and percentage of individual wildlife approaches (within 2 m) that crossed, or did not cross, deterrents at entrances to baited wildlife exclosures during the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah.

Species	Treatment Level	Approached	Crossed	% Crossed	Did not cross	% Effective
Mule Deer	Treatment 1[a]	161	4	2.5	157	97.5
	Treatment 2[b]	202	12	5.9	190	94.1
	Treatments Combined	363	16	4.4	347	95.6
	Control[c]	1914	967	50.5	947	49.5
Elk	Treatment 1[a]	432	2	0.5	430	99.5
	Treatment 2[b]	637	4	0.6	633	99.4
	Treatments Combined	1069	6	0.6	1063	99.4
	Control[c]	974	200	20.5	774	79.5

[a] = cattle guard augmented with 0.91-m-wide electric pavement

[b] = cattle guard augmented with 1.2-m-wide electric pavement

[c] = cattle guard

3.1.3 Effectiveness of Treatments as Barriers to Animals Attempting to Cross

We then considered only events in which animals displayed behavioral cues to gain access to the fenced exclosures, which was a subset of the number of approach events (Table 3.3). Out of 82 events in which mule deer displayed behavior to access the exclosures, 13 events (15.9%) resulted in animals crossing at the treated sites. In contrast, 424 out of 488 mule deer events (86.9%) resulted in an intrusion at controls sites. Of the 199 elk events at the treated sites, 5 events (2.5%) resulted in animals crossing. Across the control sites, 139 out of 204 elk events (69.1%) resulted in crossing. We also considered the total number of individual wildlife approaches that included behavior to access the exclosures and the total number of these approaches that crossed, or did not cross the deterrents (Table 3.4).

Table 3.3 Number and percentage of independent events in which animals approached (within 2-m) and displayed behavior to cross and subsequently crossed, or did not cross, deterrents at entrances to baited wildlife exclosures during the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah.

Species	Treatment Level	Approached	Crossed	% Crossed	Did not cross	% Effective
Mule Deer	Treatment 1[a]	33	4	12.1	29	87.9
	Treatment 2[b]	49	9	18.4	40	81.6
	Treatments Combined	82	13	15.9	69	84.1
	Control[c]	488	424	86.9	64	13.1
Elk	Treatment 1[a]	96	1	1.0	95	99.0
	Treatment 2[b]	103	4	3.9	99	96.1
	Treatments Combined	199	5	2.5	194	97.5
	Control[c]	188	130	69.1	58	30.9

[a] = cattle guard augmented with 0.91-m-wide electric pavement

[b] = cattle guard augmented with 1.2-m-wide electric pavement

[c] = cattle guard

Table 3.4 Number and percentage of individual wildlife approaches (within 2 m) that displayed behavior to cross and subsequently crossed, or did not cross, deterrents at entrances to baited wildlife exclosures during the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah.

Species	Treatment Level	Approached	Crossed	% Crossed	Did not cross	% Effective
Mule Deer	Treatment 1[a]	52	4	7.7	48	92.3
	Treatment 2[b]	114	12	10.5	102	89.5
	Treatments Combined	166	16	9.6	150	90.4
	Control[c]	1417	967	68.2	450	31.8
Elk	Treatment 1[a]	204	2	1.0	202	99.0
	Treatment 2[b]	401	4	1.0	397	99.0
	Treatments Combined	605	6	1.0	599	99.0
	Control[c]	718	200	27.9	518	72.1

[a] = cattle guard augmented with 0.91-m-wide electric pavement

[b] = cattle guard augmented with 1.2-m-wide electric pavement

[c] = cattle guard

3.1.4 Model Results

For mule deer, none of the explanatory variables (treatment level, block, snow cover, and days since the start of the treatment period) entered into the logistic regression model were statistically significant predictors of deer incursion at level $\alpha = 0.05$. However, we detected a highly significant interaction between treatment level and the number of days since the start of the treatment period ($P < 0.001$; Table 3.5). We therefore excluded the snow cover variable from the model and ignored inference on the main effects of days since the start of the treatment period and treatment level. There was a significant block effect when considered at level $\alpha = 0.10$ ($P = 0.0731$; Table 3.5). Model fit, as measured by the proportion of deviance explained by the fitted logistic regression model (D2), was 0.398. The residual deviance of 376.88 was less than the 564 deviance degrees of freedom, indicating that over-dispersion was absent.

Table 3.5 Type III test of fixed effects including degrees of freedom, F-statistics, and P-values from a generalized linear model used to examine explanatory variables associated with mule deer intrusions into baited wildlife exclosures at Hardware Ranch Wildlife Management Area, Utah, USA.

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Block	1	564	3.23	0.0731
Treatment Level	2	564	0.19	0.8251
Day	1	564	2.34	0.1265
Day × Treatment Level	2	564	11.95	<0.0001

When considered across all treatment levels and blocks, mule deer were significantly less likely to breach cattle guards treated with 0.91-m-wide electrical pavement (treatment level 1) than untreated cattle guards ($P < 0.001$; Table 3.6). Similarly, mule deer were significantly less likely to breach cattle guards treated with 1.2-m-wide electrical pavement (treatment level 2) than untreated cattle guards ($P < 0.001$). However, the likelihood of deer incursion did not differ significantly between the two electrified pavement dimensions ($P = 0.571$). The likelihood of deer incursion at control sites increased significantly as the treatment period progressed and declined, though not significantly, at treated sites (Figure 3.3, Figure 3.4, Table 3.7). We rejected our null hypothesis that mule deer would be as equally likely to enter control sites as treated sites, in favor of the alternative that mule deer would be less likely to enter treated sites than control sites.

Table 3.6 Differences of treatment level least squares means for mule deer. Variable coefficients, standard error, degrees of freedom, t-statistic, and P-values for a logistic regression model used to examine explanatory variables associated with mule deer intrusions into baited wildlife exclosures at Hardware Ranch Wildlife Management Area, Utah, USA.

Treatment Level	**Estimate**	**SE**	**DF**	***t*-value**	***P*-value**
Control vs. Treatment 1	4.3336	0.6827	564	6.35	<.0001
Control vs. Treatment 2	3.9083	0.4242	564	9.21	<.0001
Treatment 1 vs. Treatment 2	-0.4253	0.7504	564	-0.57	0.5711

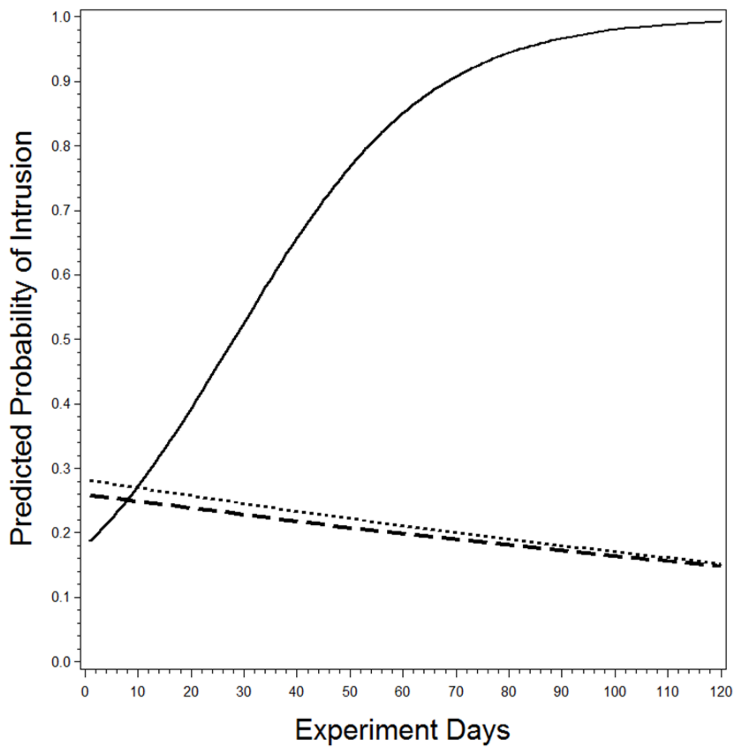

Figure 3.3 Effect of experiment day on the predicted probability of mule deer intrusion over the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah, USA. Results from logistic model using observations from exclosures within block 1 during snow and snow-free conditions. As the feeding trial progressed, the likelihood of deer intrusion into exclosures treated with cattle guards increased significantly (control, solid line). Intrusion likelihood declined, though not significantly, at exclosures treated with cattle guards augmented with 0.91-m-wide electric pavement (treatment 1, dotted line) or 1.2-m-wide electric pavement (treatment 2, dashed line). The likelihood of deer intrusion did not differ among treatments 1 and 2, but was significantly higher at controls when compared with either treatments.

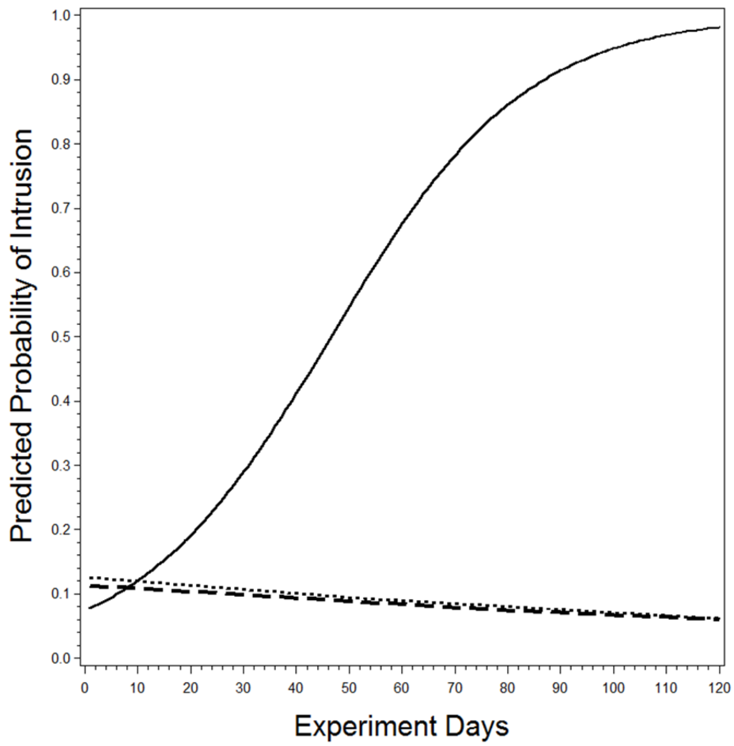

Figure 3.4 Effect of experiment day on the predicted probability of mule deer intrusion over the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah, USA. Results from logistic model using observations from exclosures within block 2 during snow and snow-free conditions. As the feeding trial progressed, the likelihood of deer intrusion into exclosures treated with cattle guards increased significantly (control, solid line). Intrusion likelihood declined, though not significantly, at exclosures treated with cattle guards augmented with 0.91-m-wide electric pavement (treatment 1, dotted line) or 1.2-m-wide electric pavement (treatment 2, dashed line). The likelihood of deer intrusion did not differ among treatments 1 and 2, but was significantly higher at controls when compared with either treatments.

Table 3.7 Variable coefficients, standard error, degrees of freedom, t-statistics, and P-values for a logistic regression model used to examine explanatory variables associated with mule deer intrusions into baited wildlife exclosures at Hardware Ranch Wildlife Management Area, Utah, USA. Results from block 1 only. Block 2 results showed similar relationships.

Label	Estimate	SE	DF	t-value	P-value
Control Intercept	-1.5274	0.4972	564	-3.07	0.0022
Control Slope	0.05441	0.008370	564	6.50	<.0001
Treatment 1 Intercept	-0.9364	1.1480	564	-0.82	0.4150
Treatment 1 Slope	-0.01319	0.01837	564	-0.72	0.4729
Treatment 2 Intercept	-1.0506	0.8667	564	-1.21	0.2259
Treatment 2 Slope	-0.00579	0.01132	564	-0.51	0.6095
Control - Treatment 1 Slope	0.06760	0.02018	564	3.35	0.0009
Control - Treatment 2 Slope	0.06020	0.01408	564	4.27	<.0001
Treatment 1 - Treatment 2 Slope	-0.00741	0.02158	564	-0.34	0.7315

For elk, three of the four explanatory variables entered into the logistic regression model were statistically significant predictors of elk incursion at level $\alpha = 0.05$. These included the treatment level, block, and snow coverage (Table 3.8). Additionally, days since the start of the treatment period was statistically significant when considered at level $\alpha = 0.10$ ($P = 0.0603$; Table 4.8). Model fit, as measured by the proportion of deviance explained by the fitted logistic regression model (D2), was 0.483. There was no evidence of model over-dispersion as the residual deviance of 257.64 was less than the 379 deviance degrees of freedom.

Table 3.8 Type III test of fixed effects including degrees of freedom, F-statistics, and P-values from a generalized linear model used to examine explanatory variables associated with elk intrusions into baited wildlife exclosures at Hardware Ranch Wildlife Management Area, Utah, USA.

Effect	Numerator DF	Denominator DF	***F*-value**	***P*-value**
Block	1	379	6.92	0.0089
Treatment Level	2	379	32.64	<.0001
Snow	1	379	8.84	0.0031
Day	1	379	3.55	0.0603

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 ($P < 0.001$; Table 3.9). However, 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 phase was a marginally significant predictor of elk crossing ($P = 0.0603$) with the likelihood of incursion increasing slightly as the test proceeded (Figure 3.5, Figure 3.6). We rejected our null hypothesis that elk would be as equally likely to enter control sites as treated sites, in favor of the alternative that elk would be less likely to enter treated sites than control sites.

Table 3.9 Differences of treatment level least squares means for elk. Variable coefficients, standard error, degrees of freedom, t-statistic, and P-values for a logistic regression model used to examine explanatory variables associated with mule deer intrusions into baited wildlife exclosures at Hardware Ranch Wildlife Management Area, Utah.

Treatment Level	Estimate	SE	DF	*t*-value	*P*-value
Control vs. Treatment 1	5.7198	1.0473	379	5.46	<.0001
Control vs. Treatment 2	4.6931	0.6951	379	6.75	<.0001
Treatment 1 vs. Treatment 2	-1.0268	1.1606	379	-0.88	0.3769

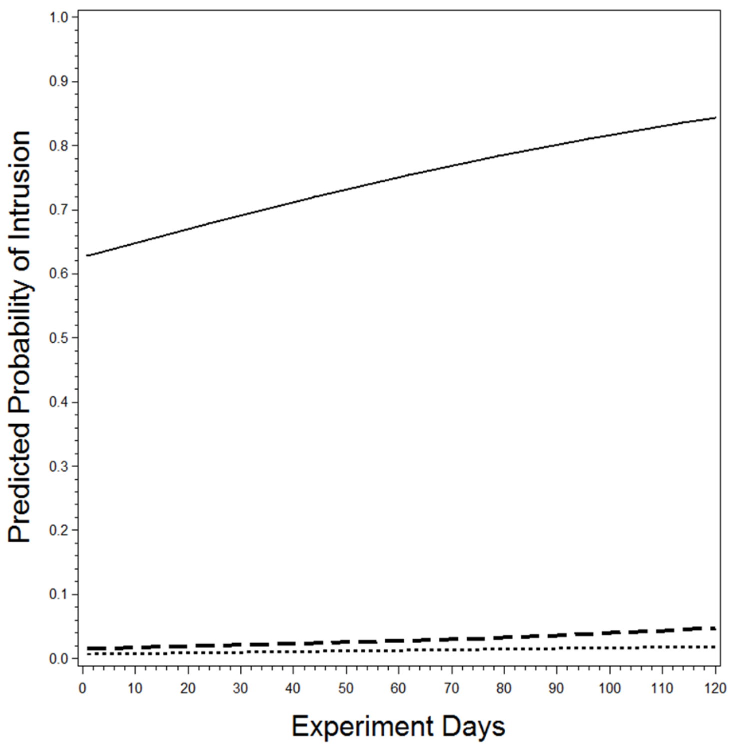

Figure 3.5 Effect of experiment day on the predicted probability of elk intrusion over the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015) at Hardware Ranch Wildlife Management Area, Utah, USA. Results from logistic model using observations from exclosures within block 2 during snow-free conditions. As the feeding trial proceeded, the likelihood of elk intrusion increased, though not significantly, at exclosures treated with cattle guards (control, solid line) and at exclosures with cattle guards treated with either 0.91-m-wide (treatment 1, dotted line) or 1.2-m-wide (treatment 2, dashed line) electric pavement. The likelihood of elk intrusion did not differ among treated exclosures, but was significantly higher at controls when compared with either treatments.

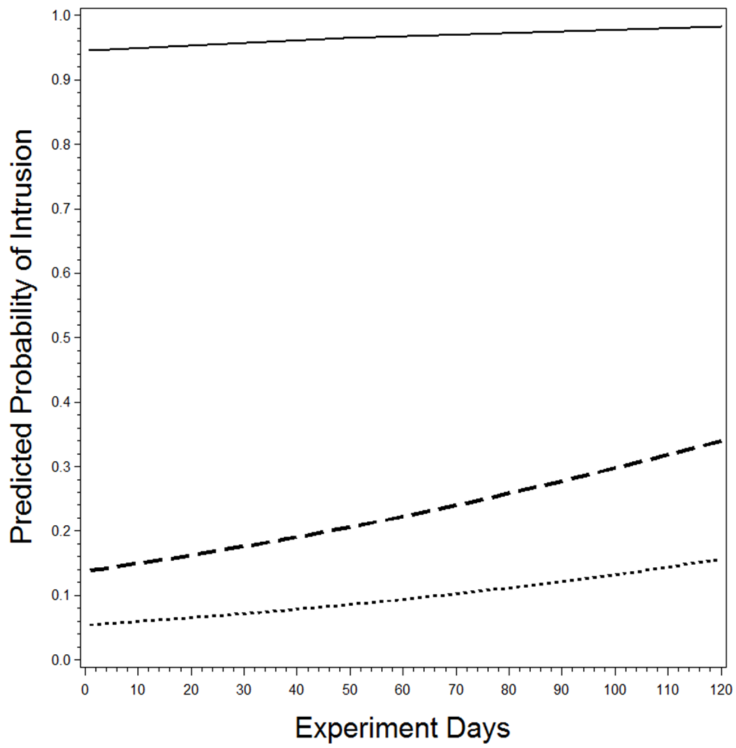

Figure 3.6 Effect of experiment day on the predicted probability of elk intrusion at Hardware Ranch Wildlife Management Area, Utah, USA over the 17-week treatment period (mid-Nov 2014 to mid-Mar 2015). Results from logistic model using observations from exclosures within block 2 during under snowy conditions. As the test proceeded, the likelihood of elk intrusion increased, though not significantly, at exclosures treated with cattle guards (control, solid line) and at exclosures with cattle guards treated with either 0.91-m-wide (treatment 1, dotted line) or 1.2-m-wide (treatment 2, dashed line) electric pavement. The likelihood of elk intrusion did not differ among treated exclosures, but was significantly higher at controls than at either treatments.

In week 17, the control site in block two was destroyed by two bull elk that jumped the cattle guard and subsequently fought within the exclosure. We censored observations after the exclosure was destroyed and ended data collection at the site six days later. We also documented and repaired damage to fences at control sites on two occasions and on three occasions at treated sites. At the control site in block one, we repaired fence damage on two occasions that indicated mule deer had jumped the fence to gain access to the exclosure. We did not find any evidence of animals jumping the fence at the other control site or at any of the treated sites. We censored a limited number of observations at one of the control stations when it appeared that deer had jumped the fence to gain access to the exclosures.

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 that we replaced. We also replaced a battery after observing complete power loss at one site after snow obscured the solar array for approximately 60 hours. We checked voltage at the treatment sites on two occasions in the pre-dawn hours and observed lower battery voltage, but no decrease in deterrent voltage.

We recorded one event in which a moose (Alces alces) approached and displayed behavior to cross a cattle guard treated with 0.91-m-wide electric pavement. The animal was subsequently repelled from the deterrent and did not gain access to the exclosure. We recorded images of, but did not include, the following species in analyses due to insufficient sample size (≥10 events): 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 sp.).

3.2 Road Trial

Mean ambient temperature during the 38-week road trial was 13.5°C and ranged from -10.0°C to 35.9°C (PRISM Climate Group, Oregon State University). Although snow cover ranged from 0 – 100% during the test, we observed no wildlife approaches to the experimental guard when snow was present. Voltage readings were 9.8 – 9.9 kV on every visit except one occasion when the voltage dropped to 7.7 kV.

We observed 61 independent events in which mule deer approached within 2 m of the cattle guard augmented with a strip of 0.91-m-wide electrified pavement. Of these, 37 events (60.7%) resulted in a crossing event in which one or more mule deer completely breached the guard and gained access to the fenced highway segment (Table 3.10). However, 31 of 37 (83.7%) crossing events occurred when deer breached through a 20-cm-wide gap between the edge of the electrified pavement and the fence that was left unmitigated when the deterrent was installed. Further, we were unable to decipher whether deer crossed, or did not cross, in 24.6% of the events. We incorporated uncertainty from these inconclusive events into an estimate of the upper and lower range of effectiveness of the experimental guard. We calculated the lower effectiveness estimate by assuming that all the inconclusive events resulted in crossing. For the upper estimate, we assumed that none of the inconclusive events resulted in crossing (Table 3.10). In total, we observed 91 individual mule deer approaches within 2 m of the guard. Of these, 55 (60.4%) crossed the guard and gained access to the fenced highway segment (Table 3.11).

Table 3.10 Number and percentage of independent events in which mule deer approached (within 2 m) and subsequently crossed, or did not cross, a 2.1 m × 11 m cattle guard augmented with 0.91 m × 11 m electrified pavement near Pintura, Utah, USA, during the study period (late-Jul 2014 to late-Apr 2015).

Species	Approached	Crossed	% Crossed	Did not cross	Inconclusive*	% Effective
Mule Deer	61	37	60.7	9	15	14.8 – 39.3

* Inconclusive = events in which it was uncertain if deer crossed, or did not cross, the deterrent.

Table 3.11 Number and percentage of individual mule deer approaches (within 2 m) that crossed, or did not cross, a 2.1 m × 11 m cattle guard augmented with 0.91 m × 11 m electrified pavement near Pintura, Utah, USA, during the study period (late-Jul 2014 to late-Apr 2015).

Species	Approached	Crossed	% Crossed	Did not cross	Inconclusive*	% Effective
Mule Deer	91	55	60.4	22	14	24.2 – 39.6

* Inconclusive = approach in which it was uncertain if deer crossed, or did not cross, the deterrent.

We then considered only events in which deer displayed behavioral cues to cross the guard, which was a subset of the number of the approach events. Out of 53 events in which deer displayed behavior to cross the guard, 37 (69.8%) resulted in a crossing event (Table 3.12). Most crossing events (83.7%) occurred when deer crossed through the unmitigated fence gap on one end of the guard. Eight of the 53 events (15.1%) were inconclusive and were used to calculate an effectiveness range for the guard. In total, we observed 85 individual mule deer approaches that displayed behavior to cross the guard. Of these, 55 (64.7%) crossed the guard and gained access to the fenced highway corridor (Table 3.13).

Table 3.12 Number and percentage of independent events in which mule deer displayed behavior to cross and subsequently crossed, or did not cross, a 2.1 m × 11 m cattle guard augmented guard augmented with 0.91 m × 11 m electrified pavement near Pintura, Utah, USA, during the study period (late-Jul 2014 to late-Apr 2015).

Species	Approached	Crossed	% Crossed	Did not cross	Inconclusive*	% Effective
Mule Deer	53	37	69.8	8	8	15.1 – 30.2

* Inconclusive = events in which it was uncertain if deer crossed, or did not cross, the deterrent.

Table 3.13 Number and percentage of individual mule deer approaches (within 2 m) that displayed behavior to cross and subsequently crossed, or did not cross, a 2.1 m × 11 m cattle guard augmented with 0.91 m × 11 m electrified pavement near Pintura, Utah, USA, during the study period (late-Jul 2014 to late-Apr 2015).

Species	Approached	Crossed	% Crossed	Did not cross	Inconclusive*	% Effective
Mule Deer	85	55	64.7	21	9	24.7 – 35.3

* Inconclusive = approach in which it was uncertain if deer crossed, or did not cross, the deterrent.

Because events in which deer breached the unmitigated gap between the deterrent and the fence may not have been directly indicative of guard effectiveness, we also examined a subset of the 53 events in which deer displayed behavior to cross the guards. Out of the 53 events, there were 13 events in which deer attempted to cross the deterrent surface of the guard directly, rather than by circumventing the deterrent by crossing through the unmitigated fence gap. Of the 13 events in which deer challenged the guard directly, 6 (46.1%) resulted in crossing. Deer jumped the guard in 4 of 6 (66.6%) crossings. The remaining 2 crossings (33.3%) were the result of deer that walked across the deterrent. In total, we recorded 18 individual approaches by mule deer that appeared to challenge the guard directly and 6 mule deer (33.3%) crossed.

In additional to mule deer, we also recorded domestic cats (Felis catus), domestic dogs (Canis lupus familiaris), raccoons (Procyon lotor), and wild turkeys (Meleagris gallopavo) crossing the experimental guard from the highway entry side while it was energized, but we did not include them in the final analysis due to insufficient sample size (≤10 events).

4. DISCUSSION

Regardless of the dimension of the electrified pavement, simulated cattle guards augmented with the material were >80% effective in excluding mule deer and >95% effective in excluding elk from baited wildlife exclosures. However, when applied to an existing standard cattle guard spanning an access road to Interstate 15, we found the material no more than 54% effective in preventing mule deer access to the highway. Although we demonstrated that cattle guards augmented with electrified pavement were effective barriers to deer and elk movement under the conditions of the feeding exclosure trial, we found the design only marginally effective at securing the highway right-of-way from deer intrusions during the road trial.

While snow coverage emerged as a highly significant predictor of elk intrusion in our feeding trial model, the variable was not a predictor of deer intrusion. The lack of significance was likely the result of numerous deer intrusions across simulated cattle guards at control exclosures in both snow and snow-free conditions. During the feeding exclosure trial, we observed a loss of deterrent effectiveness when snow accumulated on the surface of the electrified pavement. Snow was present on the surface of the electrified pavement in all the elk crossing events, and in most of the mule deer crossing events. Based on animal reactions documented in photographs, electrified pavement was capable of delivering a shock to animals through a light layer (≤ 1.3-cm) of snow. However, effectiveness declined sharply when approximately 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. Snow melting technologies already incorporated into subsequent designs may mitigate this problem (R. Lampman, Lampman Wildlife Services, personal communication). However, snow melt capabilities would increase the cost of the device and would require either a direct power connection or on-site power generation.

The highly significant interaction between treatment level and the number of days since the start of the treatment period indicated that the effect of the treatments on the likelihood of deer intrusion depended on the number of days the deterrents were exposed. As the feeding trial progressed, the likelihood of deer crossing untreated guards increased significantly, but declined (though not significantly) at treated cattle guards. This result suggests that as the winter progressed and natural forage availability declined, deer became increasingly motivated to access feed within the exclosures and learned to defeat untreated cattle guards. Simultaneously, deer learned to avoid the negative reinforcement administered by electrified pavement at treated guards. Future monitoring of new electrified pavement installations may reveal a similar trend in which the barrier effect of the deterrent increases over time as animals respond to aversive conditioning. For elk, the marginally significant predictor of days since the start of the test indicated that, when considered across all treatments, the likelihood of elk intrusion increased slightly (though not significantly) as the test proceeded. This result was likely driven by elk intrusions into control exclosures and was not indicative of a decline of treatment effectiveness over time.

The marginally significant block effect indicated that mule deer intrusions were less likely to occur at exclosures within block 2, where elk presence tended to be higher, when compared with block 1, where elk presence tended to be lower. In contrast, the significant block effect for elk indicated that elk were more likely to enter exclosures within block 2, when compared with block 1. These results confirmed our a priori designation of blocks during experimental design based on spatial differences in elk presence between the two blocks.

We believe the discrepancy in electrified pavement efficacy between the feeding exclosure trial and the road trial were due to two primary factors. First, animals may have been subject to different levels of motivation to breach the deterrents in the two trials. Animals in the feeding exclosure trial were motivated to access a high-quality food source within our exclosures during winter—the most energetically stressful time of year (VerCauteren et al. 2009, Seamans and Helon 2008). It is possible that elk were less motivated to access feed within our exclosures due to the presence of supplemental grass hay available to them during the winter elk feeding program, which operated during weeks 9 to 18 of the feeding exclosure trial. However, because deer were excluded from supplemental grass hay by elk, we believe deer remained motivated to access alfalfa within our exclosures throughout the trial, despite the presence of grass hay provided to elk at the winter elk feeding area outside of our exclosures. In contrast, deer in the road trial may have been motivated to cross the deterrent by migration imperatives, to access mates, or to escape predators. When sufficiently motivated, deer can exhibit non-typical behaviors (Reidinger and Miller 2013). In short, the discrepancy in electrified pavement efficacy between the two trials may have been influenced by deer that were more motivated to breach the deterrent in the road trial than in the feeding exclosure trial.

Second, important differences existed between the electrical contexts of the deterrents in the two trials. In the feeding exclosure trial, an electrical potential existed between the negatively and positively charged surfaces of the material (9.9 kV), but also between the negatively charged surface of the material and the soil in front of the deterrent (earth ground, 4-5 kV). Animals in the feeding exclosure trial 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 trial because road pavement insulated animals from earth ground. That is, there was no electrical potential between the negative surface 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. In the road trial, we observed instances of deer being shocked while in simultaneous contact with the negatively and positively charged surfaces of the deterrent. However, deer did not react when in simultaneous contact with the negative surface of the deterrent and the road pavement in front of the deterrent. Due to the presence of an earth ground (soil) in the feeding exclosure trial, there were multiple routes for animals to complete the circuit and receive a shock. However, there was a single route for animals to receive a shock in the road tria—an animal in simultaneous contact with the negatively and positively charged surfaces of the deterrent. In short, the presence of soil in front of the deterrent in the feeding exclosure trial acted as a de facto extension of the negative surface of the deterrent, thereby expanding the total width of the active deterrent surface.

Seamans and Helon (2008) evaluated an electrified mat consisting of metal electrodes implanted into alternating yellow and black plastic planks. The design was 95% effective at reducing white-tailed deer (Odocoileus virginianus) intrusions into feeding stations, although some deer jumped over the mat. However, in a subsequent field test of four electric mats along Highway 101 in California, Siepel et al. (2013) documented mule deer crossing the mats in 54 out of 63 events (14.3% effective). While Siepel's work found that electric mats did deter a black bear (Ursus americanus) from entering the road corridor, the authors suggested the design should be modified to more effectively exclude mule deer. Like Siepel et al. (2013), we found two electrified mats deployed along U.S. Route 6 in Utah to be poor barriers to mule deer movement, with deer crossing the mats in 67 out of 85 events (17.6% – 21.2% effective, Flower and Cramer, unpublished data). The results we present here from cattle guards augmented with electrified pavement suggest a similar pattern of effectiveness as demonstrated in work by Seamans and Seipel. 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 busy roadway.

Recently, Allen et al. (2013) evaluated two wildlife guards deployed along U.S. Highway 93 in Montana. The guards consisted of a steel bridge grating (6.6 m × 6.8 m) suspended over 45-cm-deep pits. The wildlife guards were >90% effective for mule deer that displayed behavior to cross them (n = 21 events), but were less effective for black bear and coyotes (33% and 55%, respectively). In other work, we found two similar, but smaller, wildlife guards (4.8 m × 4.8 m) adjacent to U.S Highway 91 in Utah to be ≥80% effective for mule deer that displayed behavior to cross them (n = 179 events, Flower and Cramer, unpublished data). Under the conditions of the feeding exclosure trial, cattle guards augmented with electrified pavement in this study were slightly less effective for mule deer than the wildlife guards tested by Allen et al. (2013), but were as effective as wildlife guards we monitored in Utah. However, when tested under in-road conditions, the augmented cattle guards were approximately 35% less effective in excluding mule deer from the highway than the wildlife guards in Allen's study.

In Utah, the most common method to increase the effectiveness of standard cattle guards is to install an additional cattle guard adjacent to the existing guard, thereby increasing the total width of the deterrent surface to 3.8-m-wide to 4.8-m-wide. The Utah Department of Transportation and the U.S. Army have each monitored one of these double cattle guards and estimated they were 90% to 95% effective for mule deer and 60% to 70% for elk, although these unpublished, short-term monitoring efforts lacked consistent methods and replication (D. Babcock, UDOT, personal communication, U.S. Army 2006). Belant et al. (1998) found that a similar, 4.6-m-wide simulated cattle guard with round bars reduced white-tailed deer crossings through fence openings by >95%. In other work, we evaluated four double cattle guards deployed along Utah's highways. The design was a significant barrier to mule deer and successfully secured gaps in wildlife fencing in >80% of recorded events (n = 337, Flower and Cramer, unpublished data). Results from the feeding exclosure trial indicate that cattle guards augmented with electrified pavement excluded mule deer at rates comparable to that of double cattle guards (>80% effective). However, results from the road trial suggest that the augmented cattle guard was substantially less effective for mule deer (54% effective) when compared with a double cattle guard (>80% effective).

In this study, our objective was to evaluate whether a standard cattle guard augmented with a strip of electrified pavement could reduce wildlife intrusions at rates comparable to specialized guards, but at reduced cost. Installing an additional standard cattle guard (2.1 m × 11 m) to an existing cattle guard costs approximately US$32,400 (US$900/ft., R. Taylor, Utah Department of Transportation, personal communication). In contrast, augmenting a standard cattle guard of the same dimension (11-m-long) with a strip electrified pavement (0.91 m × 11 m) costs approximately US$27,000 (US$750/ft., R. Taylor, Utah Department of Transportation, personal communication). Based on these cost estimates, electrified pavement yields a total cost savings of $5,400 when compared with the cost of installing an additional standard cattle guard. However, 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.

Although the cost of electrified pavement is forecast to decrease in the future (R. Lampman, Lampman Wildlife Services, personal communication), at present, a standard cattle guard augmented with a strip of the material does not appear to offer substantial cost savings when compared with the cost of an additional standard cattle guard. When costs due to property damage, human injury, human death, and deer loss are combined, the estimated mean cost of a single deer-vehicle collision ranges from US$3,834 (Bissonette et al. 2008, Consumer Price Index Adjustment to 2015 dollars) to US$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 US$30,000 to US$60,000 would only 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. Based on strong results from the feeding exclosure trial, electrified pavement appears to have potential as an effective tool to reduce ungulate access to roadways when deployed at wider dimensions. Moreover, the material may offer a mitigation option for locations unsuitable for double cattle guards and wildlife guards, such as at end points in wildlife exclusion fencing and/or across roads with annual average daily traffic of greater than 500 vehicles. However, mixed results from the road trial suggest that further research is needed to determine the efficacy of electrified pavement for use in roadway applications. Monitoring replicated installations of electrified pavement over multi-year time spans would likely yield a comprehensive assessment of the material under different roadway scenarios and may improve the essential function of this innovative emerging technology to reduce risk for motorists and wildlife along our highways.

5.1 Limitations

Our feeding exclosure trial was modeled after existing ungulate deterrence research (VerCauteren et al. 2009, Seamans and Helon 2008, Peterson et al. 2003). We believe the evaluation provided a robust estimate of deterrent effectiveness under the conditions in which we tested. However, our in-road results were derived from a limited number of useful observations (n = 13) from a single field site. Further, we did not evaluate full scale, stand-alone deployments of electrified pavement (≥1.8-m wide) that may be more effective than the narrower dimensions (0.91-m-wide to 1.2-m-wide) we used to augment cattle guards. At wider dimensions, electrified pavement may be more effective in excluding ungulates and could offer a method to close the 15% to 20% effectiveness gap that exists between specialized guards (≥80% effective) and an absolute wildlife barrier (100% effective). Further, electrified pavement may represent a promising mitigation option for wildlife species with non-hoof foot morphology, such as canids, felids, and ursids, which may be more susceptible to electric shock than cervids.

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