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Effects of Wildlife Warning Reflectors ("Deer Delineators") on Wildlife-Vehicle Collisions in Central Wyoming

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DISCLAIMER

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Abstract The purpose of this study was to provide the Wyoming Department of Transportation with information about (1) the effectiveness of Streiter-Lite wildlife warning reflectors that had been installed in three locations within Wyoming’s District 5, and (2) preliminary analysis of patterns of deer-vehicle collisions across Wyoming and the habitat and road variables associated with collision hotspots. We evaluated reflector effectiveness in terms of their ability to reduce deer-vehicle collisions and modify deer road-crossing behavior. Using a series of experimental manipulations of reflectors, we showed that reflectors reduced deer-vehicle collisions by 32 percent and significantly reduced the number of high-risk deer road crossings (those in which deer ran into the road as a car was approaching). However, covering reflectors with white canvas bags – initially done with the intent of creating a control treatment that neutralized the reflectors – proved even more effective than leaving the reflectors exposed. White bags on posts resulted in 33 percent fewer collisions than when reflectors were exposed and significantly reduced the number of high-risk deer road crossings. It is likely that the white bags are more visible or reflective to deer than the red wildlife warning reflectors. A cost-benefit analysis suggests that the benefits of reflectors outweigh their initial materials and installation costs, but may not outweigh the net costs once maintenance is taken into account. Analysis of patterns of deer-vehicle collisions across the state showed that traffic volume, proximity to agricultural land, proximity to deer winter range and migration routes, and high speed limits are all strongly associated with high collision rates. On average, areas with a 55 mph speed limit have 36 percent and 55 percent fewer deer-vehicle collisions than areas with speed limits of 65 and 75 mph, respectively. Reducing nighttime speed limits in high collision areas may be a cost-effective strategy for mitigating deer-vehicle collisions in Wyoming.			
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SI* (MODERN METRIC) CONVERSION FACTORS

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

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

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

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LIST OF ABBREVIATIONS AND SYMBOLS

AIC – Akaike's information criterion
CI – confidence interval
DF – degrees of freedom
DVC – deer-vehicle collision
ESRI – Environmental Systems Research Institute
FLIR – forward-looking infra-red
GIS – geographic information system
GLM – generalized linear model
GPS – global positioning system
KM – kilometers
LRS – linear referencing system
MI – miles
ML – main line
MP – mile post
MPH – miles per hour
NLCD – National Land Cover Database
SEM – standard error of the mean
TSS – Teton Science School
WGFD – Wyoming Game and Fish Department
WVC – wildlife-vehicle collision
WYDOT – Wyoming Department of Transportation
ΔAIC – Change in Akaike's information criterion

CHAPTER 1. INTRODUCTION

WILDLIFE-VEHICLE COLLISIONS IN WYOMING

Wildlife-vehicle collisions (WVCs) pose a serious threat both to highway safety and to wildlife populations.[1,2] In particular, collisions involving large ungulates, such as deer (*Odocoileus* spp.), moose (*Alces alces*), or elk (*Cervus elaphus*), often result in significant damage to the vehicle and injury to its occupants. Across the United States, an estimated 1-2 million wildlife-vehicle collisions (WVC) occur every year, and this number continues to climb as road networks expand and traffic volumes increase.[2]

Predicting and mitigating the occurrence of wildlife-vehicle collisions are high priorities both for the Federal Highway Administration (FHWA) and for State Departments of Transportation. [2] In Wyoming, 2,487 WVCs were reported in 2012 and 2,096 in 2013, accounting for 18 and 14 percent of all reported collisions, respectively.[3,4] However, our analysis of Wyoming Department of Transportation (WYDOT) collision and carcass data (that latter of which is not included in collision statistics) revealed that an average of more than 5,000 wildlife-vehicle collisions have occurred annually over the last three years. This number further underestimates actual collisions, as many animals leave the road right-of-way before dying. The overwhelming majority (>85 percent) of collisions involve mule deer.

These collisions pose a safety hazard and are costly; in addition to causing significant damage to vehicles and injury to their occupants, they are almost always lethal to the animal. WYDOT's estimated costs per reported collision are $11,600 in injury and property damage costs and $4,000 in restitution value (the value, in terms of lost hunter opportunity, of each killed mule deer, according to the Wyoming Game and Fish Department). Taken together, deer-vehicle collisions total approximately $24-29 million per year in Wyoming in injury and damage costs and an additional $20-23 million per year in lost wildlife value.

Highways and vehicle collisions also have a significant negative impact on wildlife populations – reducing their numbers and impeding their movements through their seasonal ranges and along their migratory corridors.[5,6] Where highways create a partial or complete barrier to wildlife movements, they threaten populations by impairing their ability to access the resources they need.[6] In Wyoming, mule deer populations in the state are in decline, as they are across most of the West,[7] and conserving their populations is an extremely high priority for the Wyoming Game and Fish Department (WGFD).[8]

The Wyoming Department of Transportation continues to work extensively to mitigate wildlife-vehicle collisions. Exploring and testing new mitigation strategies and understanding where mitigation measures are most needed are both important parts of achieving WYDOT's strategic goals of keeping people safe on the state transportation system, and exercising good stewardship of our resources.[9] These are particularly important as the human population of Wyoming continues to grow, with corresponding increases in residential development and vehicle traffic.[10]

WILDLIFE WARNING REFLECTORS AS A POSSIBLE MITIGATION METHOD

Wildlife-vehicle collision mitigation measures range from relatively low-cost and frequently-used measures, such as roadside signage, to high-cost, infrequently-used measures such as highway crossing structures. Road signage, as well as a number of other relatively low-cost mitigation methods (e.g. deer whistles, olfactory repellents, mirrors, and model deer in alarm posture) have generally proven ineffective at reducing WVCs.[11-16] Crossing structures (highway under- or over-passes), in combination with fences, typically reduce collisions by 60-90 percent, but can cost millions of dollars to implement.[16-19] Crossing structures have been installed in a number of locations around Wyoming. However, these structures are not suitable or feasible in all locations. Crossing structures rely on extensive roadside fencing to funnel animals to the safe crossing structure and prevent them from entering the roadway in other places. In more developed and populated areas, such "funnel fencing" is not possible due to the large number of road access points that would require gaps in the fence.

Roadside "wildlife warning reflectors" ("deer delineators") are another potential mitigation method. These reflector systems are marketed in the United States as Strieter-Lite Deer and Wildlife Warning Highway Reflectors (Strieter Corporation, Rock Island, Illinois, USA) and in Europe as Swarowarn Wildlife Warning Reflectors (Swareflex GmbH, Vomp, Austria); previously they were marketed in both Europe and the United States as Swareflex Wildlife Warning Reflectors. Reflector systems consists of a series of roadside posts with uniquely manufactured reflectors mounted to face each other across the road (figure 1), or additionally away from the road in specific cases. As vehicles pass with their headlights on, light is meant to reflect in a moving pattern across the road at various angles. The theory is that approaching wildlife will notice the reflected light and halt or flee (away from the road) until the vehicle and lights have passed.

Although wildlife warning reflectors are appealing for their simple technology and moderate cost (compared to crossing structures), their effectiveness has remained the subject of debate. The Strieter-Lite corporation reports a 78-90 percent reduction in deer-vehicle collisions based on a meta-analysis of several individual studies.[20] However, the results of studies within this meta-analysis and in the broader literature are very mixed. Studies in Colorado,[21] Illinois,[22] Ontario,[23] California,[24] Virginia[25] and Wyoming[26] found no effect of reflectors on collision rates. Conversely, studies in Washington,[27] Minnesota,[28] Iowa,[29] and Indiana[30] found that reflectors did reduce deer-vehicle collision rates, although the magnitudes of these reductions were highly variable (ranging from 19-90 percent reductions). The quality of the data and study design are highly variable among these various studies.

Figure 1. Wildlife warning reflectors installed along a stretch of highway.

In one of the few comprehensive studies of the effects of reflectors on deer road-crossing behavior, D'Angelo et al. did not find any significant impact of reflectors on deer road-crossing behavior.[31] In another study, deer were found to react to reflectors initially but to become increasingly habituated over a relatively short period of time (17 days), suggesting no long-term effect of the reflectors on deer behavior.[32] The absence of a mechanism to explain why reflectors would work led them to conclude that reflectors are ineffective. However, the D'Angelo study has been criticized for being performed on a college campus with slow-moving traffic and habituated deer,[33] and other studies have been criticized for using earlier reflector designs or improperly maintaining the reflector system.[34] Thus, there remains much debate about the efficacy of wildlife warning reflectors.

Between 2007 and 2010, WYDOT installed Strieter-Lite® reflectors at five locations in District 5 of Wyoming on a trial basis. These were installed along a total of approximately 19 miles of highway that had been identified as having high rates of deer-vehicle collision. The reflectors were installed in the following locations (figures 2 and 3):

- *Spring 2007*: US 26 mile post 110.5 to 112 and 118.1 to 121.3 (Kinnear reflector area: west of Riverton).
- *Fall 2009*: US 16/20 mile post 196.7 to 202.7 (Basin to Greybull reflector area).
- *January 2010*: US 20 mile post 127.4 to 130.7 (South Thermopolis reflector area: Wind River Canyon to Thermopolis).

- *January 2010*: US 20 mile post 133.3 to 142.2 (North Thermopolis reflector area: Thermopolis to Lucerne).

In this study, we set out to examine the effectiveness of these reflectors. Specifically, our objectives are to:

1. *Understand the degree to which warning reflectors installed along US 20, US 16/20, and US 26 are reducing the number of WVCs along these stretches of highway.*

2. *Examine the effects of reflectors on mule deer road-crossing behavior.*

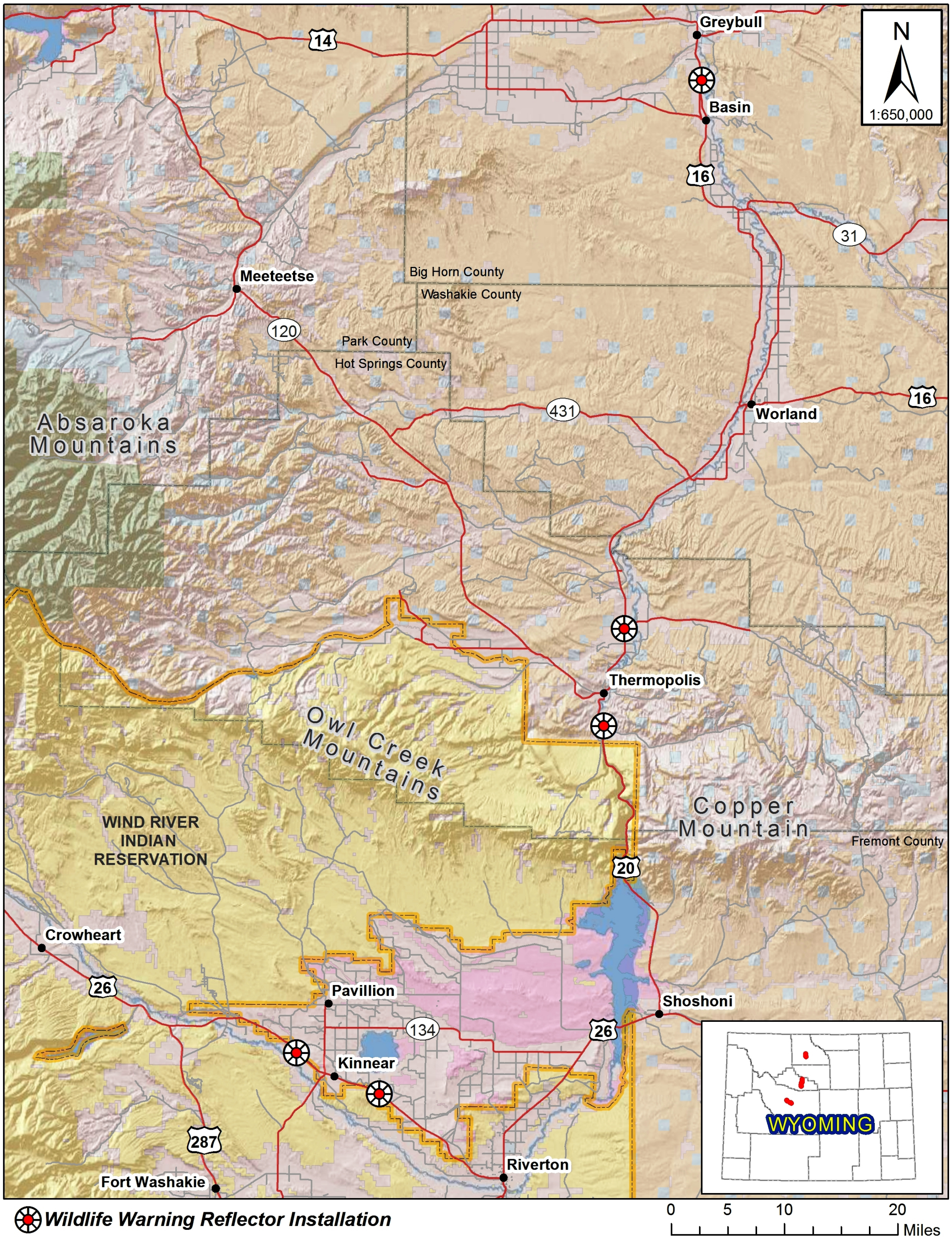


Figure 2. Wildlife warning reflector installations within WYDOT District 5 study area.

a.

b.

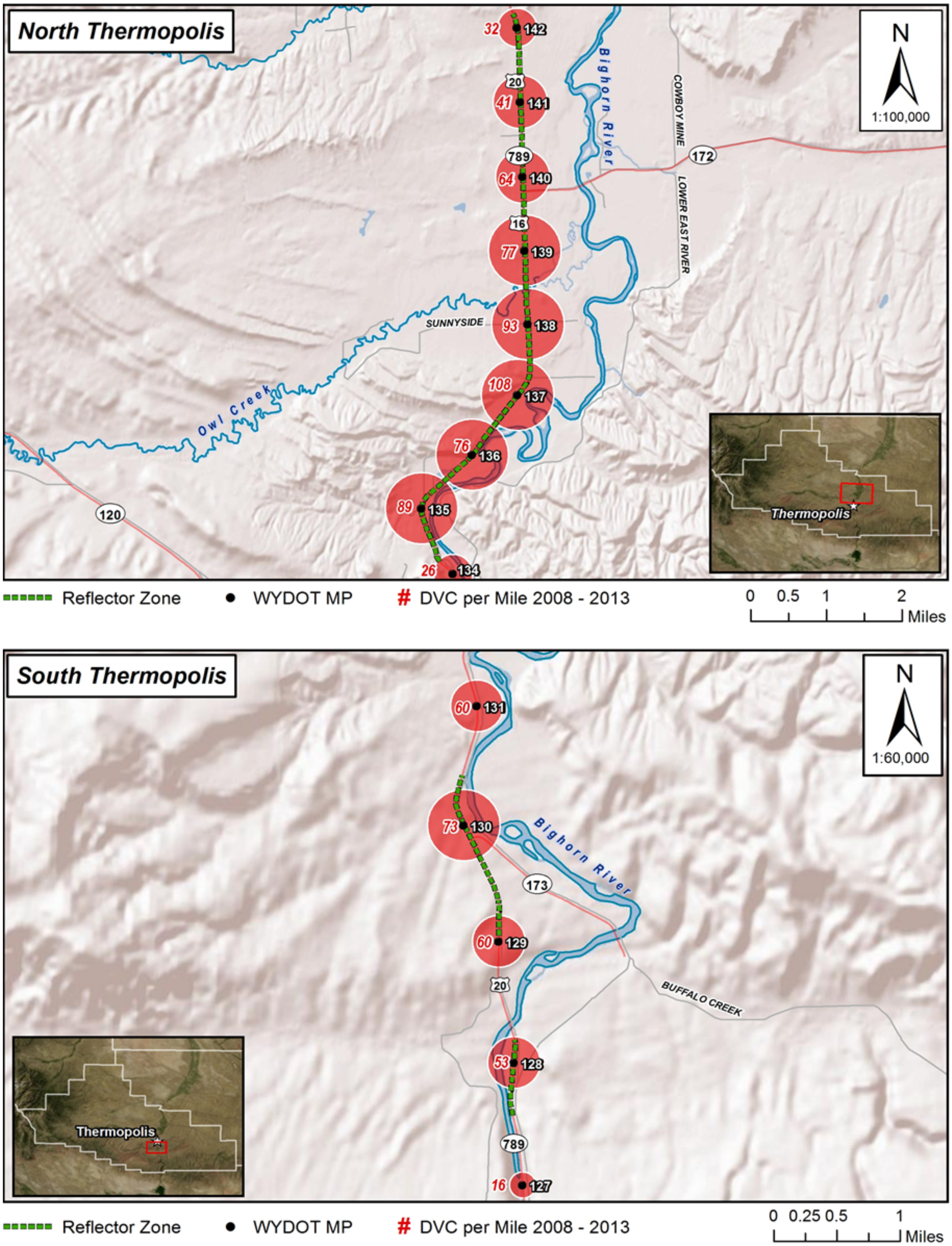
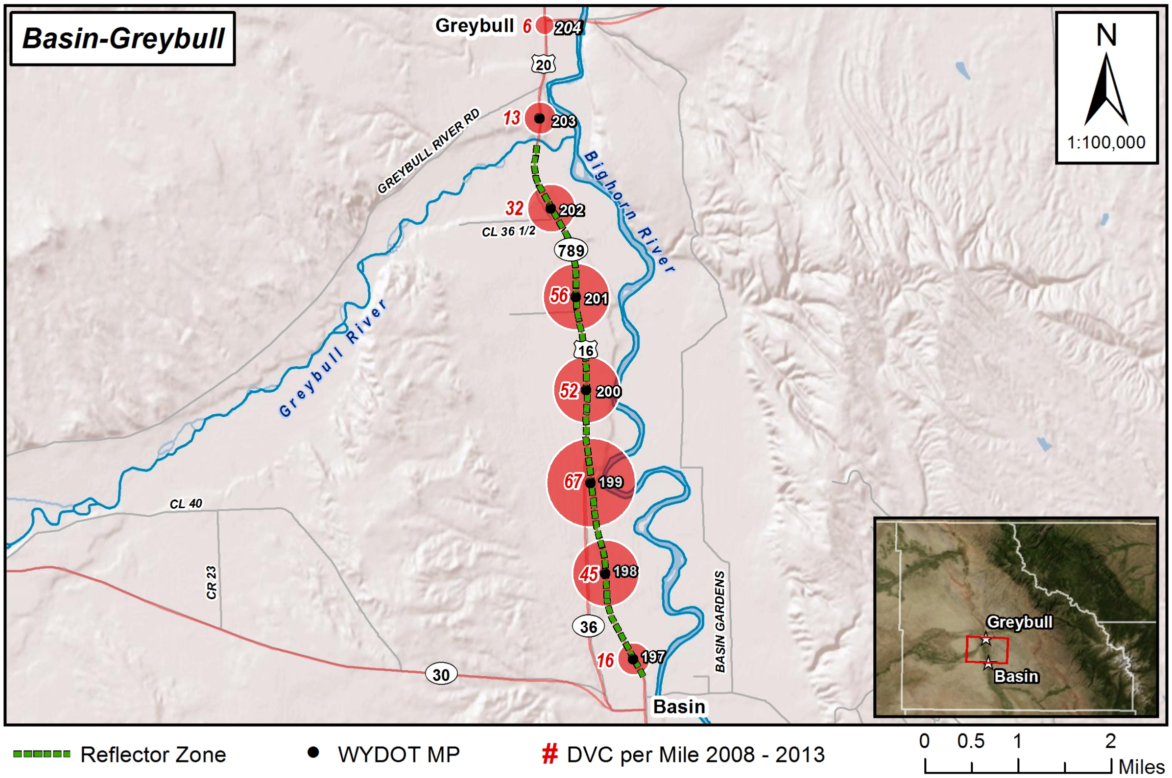


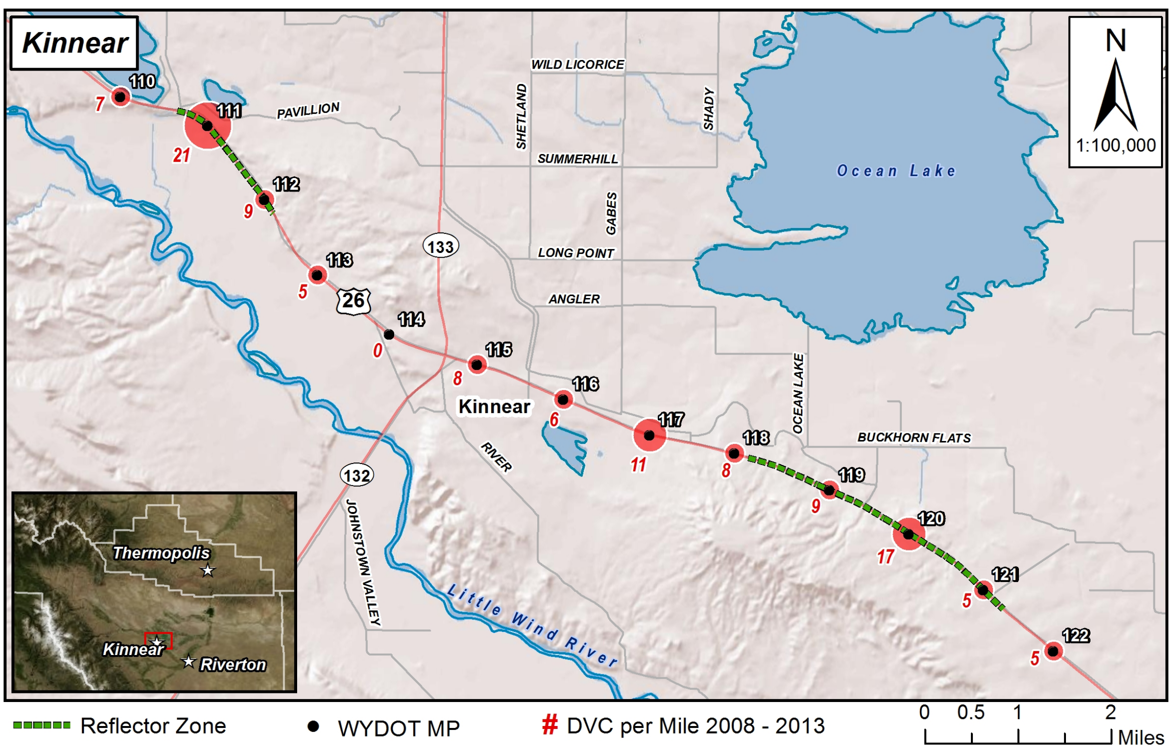
Figure 3. Zoom-in of wildlife warning reflector installations overlain with deer vehicle collisions per mile from 2008-2013 for (a) North Thermopolis (b) South Thermopolis (c) Basin- Greybull and (d) Kinnear.

c.



Basin-Greybull
Greybull
Basin
GREYBULL RIVER RD
CL 36 1/2
CL 40
CR 23
BASIN GARDENS
Bighorn River
Greybull River
N
1:100,000
Reflector Zone
WYDOT MP
DVC per Mile 2008 - 2013
0 0.5 1 2 Miles

d.



Kinnear
PAVILLION
WILD LICORICE
SHETLAND
SHADY
SUMMERHILL
GABES
LONG POINT
ANGLER
OCEAN LAKE
BUCKHORN FLATS
RIVER
JOHNSTOWN VALLEY
Ocean Lake
Little Wind River
Thermopolis
Kinnear
Riverton
N
1:100,000
Reflector Zone
WYDOT MP
DVC per Mile 2008 - 2013
0 0.5 1 2 Miles

SPATIAL PATTERNS OF WILDLIFE-VEHICLE COLLISIONS

Understanding where and why wildlife-vehicle collisions occur is an important step in mitigating the problem. By understanding the spatial patterns of WVCs, transportation managers can make informed decisions about how to prioritize the spatial location and type of mitigation measures and thus maximize the cost-effectiveness of mitigations.[35] An understanding of WVC patterns also helps to identify areas where roads may be impairing landscape connectivity for large mammals. Data on the locations of vehicle collisions with wildlife can be related to habitat and road features to gain insights into why collisions are occurring.[36-38] Habitat features include variables such as land cover type, while road features include variables such as speed limit and traffic volume. By modeling the spatial patterns of WVCs, it is also possible to assess the effects of possible future change in certain variables (e.g. speed limit or traffic volume).

In Wyoming, mule deer home ranges and migration routes crisscross much of the state, intersecting with many of the major highways. Although some areas with high WVC rates are well known, there has not yet been any comprehensive analysis of these patterns or the habitat and road variables associated with them. Here, we set out to examine the spatial patterns of deer-vehicle collisions across Wyoming. Specifically, the third objective of this study was to:

3. *Use WYDOT's carcass and collision databases to identify habitat and road characteristics associated with high WVC rates across Wyoming.*

CHAPTER 2. EFFICACY OF REFLECTORS: COLLISIONS

The Wyoming Department of Transportation collects data on wildlife-vehicle collisions in two ways. First, highway maintenance crews record the locations of all carcasses found along the road right-of-way ("carcass" data). Second, Troopers from the Wyoming Highway Patrol record the locations of any reported wild animal-vehicle crashes ("crash" data). These crashes are restricted to those with a damage value of $1,000 or greater that occurred on public roads and were reported.[39] We used data from both sources to ask whether deer warning reflectors reduced deer-vehicle collision rates.

METHODS

Study Area

All four reflector areas are situated on two-lane highways with speed limits of 65 mph. Adjacent land-cover types consist primarily of sagebrush steppe, saltbush scrub, irrigated hay, cultivated cropland, fenced rangeland, riparian areas, and developed areas. An active railroad runs parallel to US 16 and US 20, ranging from 20 to 400 m (65 - 1,312 feet) in distance from the road. Human population densities are relatively low in all reflector areas except directly north and south of the town of Thermopolis.

Deer population estimates in the study area are conducted annually by the WGFD. They are based primarily on ground and aerial classification surveys in addition to reported hunter success. Budgetary constraints have limited aerial surveys in recent years in some herd units. The absence of a traditional winter range where animals congregate poses an additional challenge in accurately estimating deer herd size. Regardless, the downward population trends indicated by statistical models are consistently corroborated by local ranchers, sportsmen, and wildlife professionals at annual pre-season setting meetings.

Oil, gas, and bentonite mining occur sporadically throughout the study area but primarily occur in historically low quality deer habitat. Of greater concern has been the impact of long-term drought on deer habitat. Consistently dry conditions in already low precipitation zones have not allowed shrubland communities to regenerate at a level sufficient to support stabilization or growth of the deer population toward herd management objectives. Wildfire in the Owl Creek, Meeteetse and Southwest Bighorn herd units over the past two decades has negatively impacted native vegetation and allowed invasive species such as cheatgrass (*Bromus tectorum*) to become established.[40]

Deer populations throughout the study area have increasingly abandoned traditional winter and yearlong range in favor of high quality forage found in agricultural areas. Crop damage from deer is reported as a significant issue across all herd units in the study area. Deer are also attracted to the roadside because adjacent borrow ditches capture moisture runoff from the roads, leading to early spring green up and late fall brown out of vegetation in these ditches.

In a survey of 78 Thermopolis residents conducted by Hot Springs County High School, 70 percent reported negative interactions with deer, 78 percent felt deer were a problem, and 85 percent felt that deer need to be controlled.[41] The most commonly cited problems were damage to yards and landscaping and hostile interactions with dogs and children. Several respondents also reported routinely observing “sick” or “unhealthy” deer within the town of Thermopolis. Deer within the study area have been suspected of die-off from Epizootic Hemorrhagic Disease, Chronic Wasting Disease, and Bluetongue Virus.[42-44]

Reflector Installation and Maintenance

As detailed in Chapter 1, reflectors were installed between 2007 and 2010 in four locations. The West Kinnear section was completed in January 2007 (330 units). The East Kinnear section was completed in May of 2007 (425 units). The Basin-Greybull section was completed in November 2009 (1,064 units). The North and South Thermopolis sections were completed in January 2010 (1,792 units). All installations used Streiter-Lite Reflector Model 7176 and were installed per manufacturer’s recommendations. Depending upon road topography, shoulder slope, or guardrail presence, reflector posts were installed with a horizontal spacing of either 15.24 or 100.48 m (50 or 100 feet), offset from road shoulders by either 1.22 or 6.1 m (4 or 20 feet), 60.9-76.2 cm (24-30 inches) above the crown of the pavement, with one or two reflectors per post. Reflector post embedment depth and reflector spacing were measured by a project engineer. WYDOT Maintenance crews checked installation specifications and repaired or replaced damaged or missing reflectors annually. Maintenance crews also replaced damaged reflectors throughout the duration of the study as needed.

Before-After Comparison

Carcass and crash data were used to make a simple comparison of observed deer-vehicle collision rates before and after reflectors were installed. Although comparison with control sites (in which reflectors were not installed) would have been ideal, suitable control sites could not be located; no roads could be located within reasonable distance of the reflector sites that had comparable habitat conditions and deer abundances or collision rates. We therefore focused on comparing collision rates before and after reflector installation along the four stretches of highway where the reflectors were installed.

Carcass and crash data for District 5 were obtained in both digital (tabular) and paper form for the years 1990-2013. We merged the digital records of all carcasses and crashes and converted this tabular data into a spatially explicit geodatabase (“collision” data). Data referenced to 1/10th mile markers and WYDOT Linear Referencing System (LRS) Main Line (ML) Routes were converted to points using the Environmental Systems Research Institute (ESRI) ArcGIS Linear Referencing Toolbox, Create Route Events tool. Any data with geographic or projected coordinates that did not have a 1/10th mile marker reference were snapped spatially to the nearest WYDOT LRS ML route. Records located more than 152 m (500 ft) from a major road were removed.

Observations across the carcass and crash databases are not independent; it is possible that the same collision could have been recorded in both databases. To remove duplicate records, we flagged records with the same date and within 0.32 km (0.2 mi) of each other. These flagged records were further inspected to see if the sex and age of the animal were identical; if so, these records were combined. We also removed records for which the species was listed as "unknown."

For all District 5 records from 2003 to 2012, we cross-referenced the paper carcass records against the digital records. We discovered more than 800 records in the paper data that were not in the digital data; these were added to the geodatabase.

In comparing the number of collisions before and after reflector installation, we focused on carcass and crash data collected starting in 2004. Carcass records from the 1990s and early 2000s indicate low collision rates with a very large (order of magnitude) increase starting in 2003. It is likely that this reflects improvements in carcass data collection protocols rather than a real ten-fold change in collisions. Total number of collision records (merged carcass and crash records) were compared before and after reflector installation for each of the four stretches of highway for which reflectors were installed.

Experimental Manipulation of Reflectors I

In order to further examine the effects of reflectors on deer-vehicle collision rates and behavior, we set up a cover-uncover experiment in the four reflector treatment areas. This experiment was initiated in February 2013 and terminated in February 2014. In this experiment, we used white canvas sample bags to cover reflectors on alternating one-mile stretches of road for one month at a time, then switched to cover the previously uncovered one-mile stretches of road. Bags were made from 10 oz. cotton duck canvas and measured 34.6 cm (14 in) wide by 60.9 cm (24 in) long. Bags were folded and tied tightly onto reflector posts to prevent them from flapping or blowing off in the wind (figure 4).

The experiment was implemented beginning in February 2013 in North and South Thermopolis (figure 5), where at any one time a total of approximately 1,600 reflectors were covered. Covered stretches of road were switched to uncovered (and vice versa) monthly between February and October 2013, necessitating over 320 miles of roadside hiking during that time. Between October 2013 and February 2014, we extended the experiment to include the Basin-Greybull and Kinnear reflector areas (figure 5; an additional 1,600 reflectors) and switched the treatment configuration twice monthly to ensure adequate representation of both treatments on each one-mile stretch through the peak deer activity and road-crossing season. Throughout this experiment, we worked with Highway Maintenance crews, who helped to replace canvas bags and reflectors when bags were stolen or when reflectors were damaged by collisions.

This experiment created treatments designed to examine both deer collision rates and deer road-crossing behavior in the presence and absence of reflectors. In order to quantify collision rates in these two treatments (reflectors exposed vs. reflectors covered with white bags), we needed to ensure that carcass and deer-vehicle collision (DVC) records were cross-referenced with treatment status of the stretch of road (reflector or white bag) at the time when the collision occurred. In other words, we needed to know whether the collision took place in a treatment area or not, and what the treatment was at that time. To accomplish this, we worked closely with Highway Maintenance supervisors to implement a system where maintenance crews recorded GPS locations of each carcass and recorded on their carcass survey data sheets (a) whether the carcass occurred in a reflector section and (b) whether the reflectors were exposed or covered with white bags at the time of the collision.

Figure 4. Wildlife-warning reflectors covered with white canvas bags in the reflectors-exposed versus covered with white bags experiment.

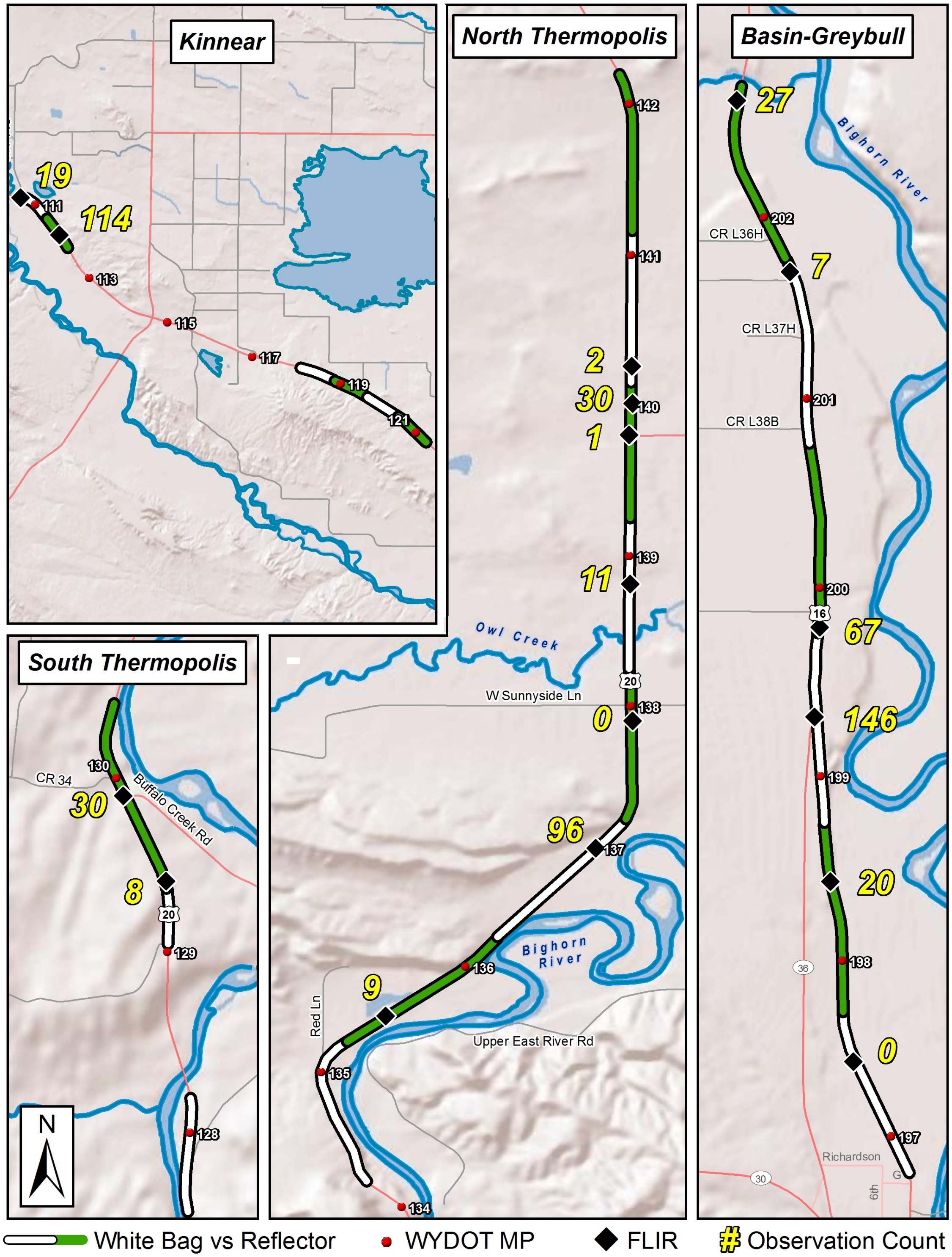


Figure 5. Treatment areas of the reflectors-exposed versus covered with white bags experiment (experiment I) showing alternating 1-mi sections of road with either white canvas bags or reflectors. Infrared camera locations and number of deer observations recorded at each location are also given. (February 2013-February 2014).

Experimental Manipulation of Reflectors II

As a follow-up to the reflectors-exposed vs. covered with white bags experiment, we conducted a second cover-uncover experiment between May and December 2014 using black bags to cover the reflectors. We chose to use black bags because it was clear that white bags were having a strong effect on deer, potentially because they were more reflective than the reflectors themselves (see results below). Unfortunately, covering the reflectors in a semi-permanent way without creating another reflective surface proved challenging. After trying several different methods, we found that spray-painting canvas sample bags black (using Rust-Oleum Painter's Touch Flat Black General Purpose Spray) provided the best durability and coverage (figure 6). Given the large amounts of paint needed to do this, we limited the experiment (reflectors vs. black bags) to a 2-mi (3.2-km) stretch of North Thermopolis with very high deer-vehicle collision rates (figure 7). This experiment was initiated in May 2014, and treatments were swapped monthly between the two miles (one mile of reflectors and one mile of black bags at any time) until October 2014. Between October and December 2014, treatments were swapped every two weeks to ensure adequate representation of both treatments on each 1-mi (1.6-km) stretch through the peak deer activity and road-crossing season. Carcass data were collected during this time by Highway Maintenance crews in the same manner as for the reflector vs. white bag experiment.

Figure 6. Wildlife-warning reflectors covered with black spray-painted canvas bags in the reflectors-exposed versus covered with black bags experiment.

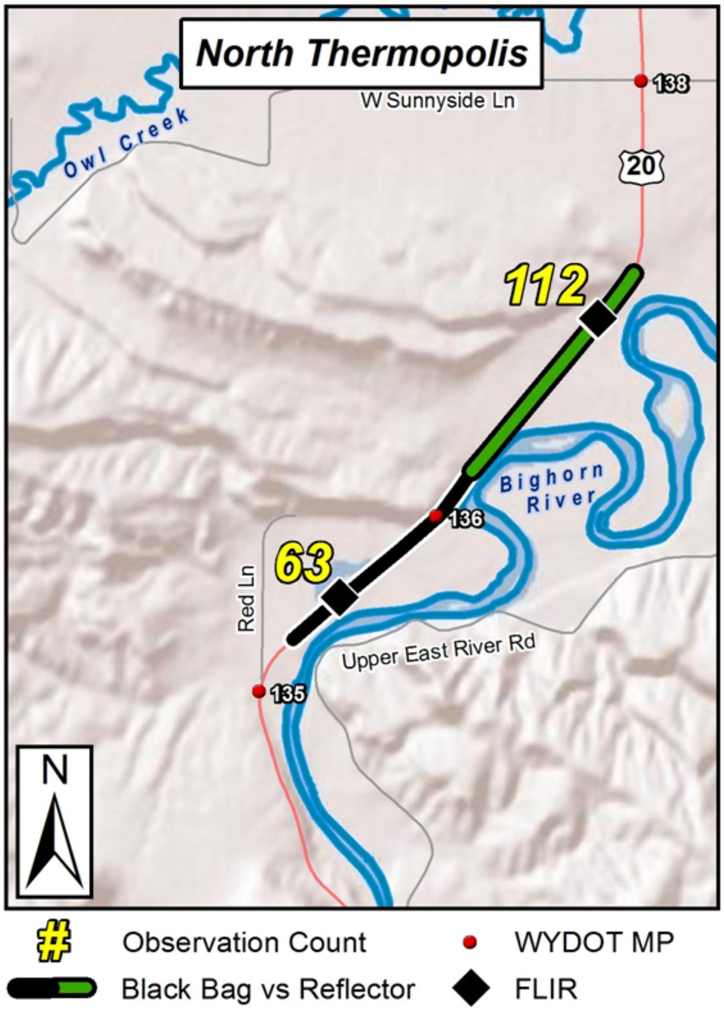


Figure 7. Treatment area of reflectors-exposed versus covered with black bags experiment (experiment II). Two 1-mi long sections alternated between covered with black bags and uncovered (reflectors exposed). Infrared camera locations and number of deer observations recorded at each location are also given. (May-December 2014).

Data Analysis

Collision rates (collisions per mile per year) before and after reflector installation were compared using a *t*-test for each of the four reflector areas. Years were divided into "pre-installation" and "post-installation" years, omitting the year of installation.

To examine the effects of experimental treatments (reflectors exposed vs. reflectors covered with white bags, and reflectors exposed vs. reflectors covered with black bags) on deer-vehicle collisions, we first standardized the carcass data into number of carcasses per mile per day that each treatment was applied. This was done to account for the fact that experimental treatments were applied for an unequal number of days across the study sites. We calculated this rate separately for each mile in each experiment.

For the first experiment (reflectors vs. white bags), we used a paired *t*-test to ask whether treatments differed in carcass rate. Data were paired by mile to control for the fact that deer may cross more frequently (and have more opportunities for collisions) in some 1-mi (1.6-km) experimental highway segments than others. In most experimental segments of the Basin-Greybull and Kinnear sites, carcass counts were zero. This is likely because the experiment was only in place for three months at these sites, potentially compounded by low inherent collision rates, especially in Kinnear, whereas it was in place for 12 months in Thermopolis. Because the Thermopolis data were more robust and complete, we only included these data in our analysis.

For the second experiment (reflectors vs. black bags), there were only two 1-mi (1.6-km) experimental highway segments. While this was insufficient replication to conduct statistical analysis, we nevertheless present mean standardized carcass rates for the seven and a half months that the experiment was in place.

For the first experiment (reflectors-exposed vs. covered with white bags), we conducted two additional analyses designed to determine whether covering the reflectors caused deer to alter their road-crossing frequency or location. If deer changed where or how many times they crossed the highway, this could provide an alternative explanation for differences between treatments in terms of carcass numbers and number of deer vehicle-collisions. We predicted that if deer were averse to crossing in highway segments with white bags covering reflectors, they would (a) show different crossing densities in the same segment when reflectors were exposed versus covered, and/or (b) be more likely to cross and get hit at the edge of the next (adjacent) 1-mi (1.6-km) segment of highway (which would be in a different treatment state).

To test the first prediction, we compared deer crossing densities (from the behavioral observation data, which is detailed in Chapter 3) at each site under the two treatments. We ran a nested generalized linear model (GLM) with treatment (white bag vs. reflector) nested within site (16 sites where behavioral data were collected; see Chapter 3). The number of deer crossing per night was log-transformed to meet assumptions of normality. To test the second prediction, we categorized each carcass as being located at the edge (first and last 25 percent) or middle (center 50 percent) of the road segment in which it was hit. We ran a GLM with a binomial link function with edge vs. middle as the response and treatment as the predictor variable. All analyses were performed using the R statistical software.[45]

RESULTS

Before-After Comparison

A simple comparison of collision rates (number per mile) before and after the reflectors were installed shows inconclusive results. In all four reflector areas, collision rates varied substantially from year to year. The Kinnear reflector area had the lowest collision rates, averaging 2.6 per mile (±0.24 standard error of the mean, SEM) between 2004 and 2013. Basin-Greybull had slightly higher collision rates, averaging 6.4 per mile (±0.59 SEM). Collision rates were highest in North Thermopolis (13.1 ±0.95 SEM and South Thermopolis 15.0 ±1.37 SEM).

Across all four reflector areas, there was no clear pattern of change in collision rates before and after reflectors were installed (figure 8). In Kinnear, collision rates were statistically indistinguishable before and after reflector installation (t=0.54, p=0.60). In Basin-Greybull, carcass rates showed a non-significant increase after the reflectors were installed (t=1.86, p=0.10), whereas in North and South Thermopolis there was a non-significant and significant (respectively) decrease in carcass rates after the reflectors were installed (North Thermopolis: t=-1.66, p=0.14; South Thermopolis: t=-2.85, p=0.02). However, in both sites, the decrease in carcass rate preceded reflector installation by several years and has persisted over the last several years (figure 8). These patterns are likely a product of fluctuations in mule deer populations, perhaps in combination with effects of the reflectors. Without reliable population estimates for local deer populations, it is difficult to assess what effect the reflectors have had on carcass rates using only this before-after comparison. (The Wyoming Game and Fish Department calculates annual herd unit population estimates, but due to the abundance of agricultural land and the wide dispersion of deer during winter, estimates for the study area are not considered reliable at these highly local scales[46]).

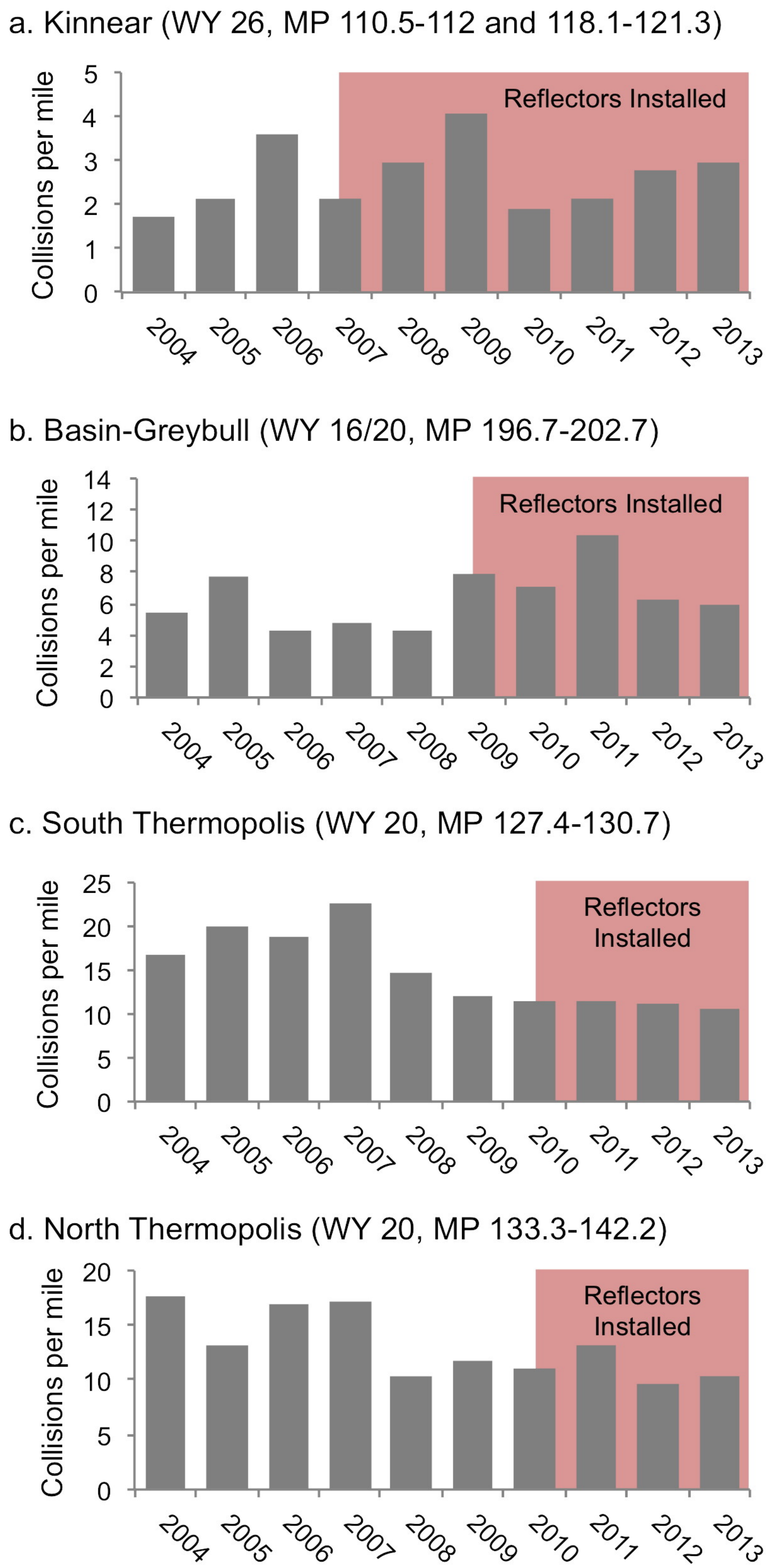


Figure 8. Collisions per mile per year pre and post installation of wildlife warning reflectors for (a) Kinnear (b) Basin- Greybull (c) South Thermopolis and (d) North Thermopolis.

Experimental Manipulation of Reflectors I

Over the course of the reflectors vs. white bags experiment (12 months), 93 carcasses were found in 10 mi (16 km) of highway north and south of Thermopolis. Standardized carcass rates showed that 48 percent more carcasses occurred when reflectors were exposed compared to when they were covered with white bags (figure 9a). Put another way, white bags covering reflectors reduced the number of carcasses by 33 percent compared to where reflectors were visible to deer. Over a year, this difference translates to approximately four fewer carcasses per mile, on average (8.1 versus 12.2 carcasses per mile per year for white bag and reflector treatments, respectively). A paired *t*-test showed that this difference was statistically significant (t=3.38, n=11, p=0.007).

We found no effect of treatment (reflector exposed vs. white bag) on the location within each highway segment at which deer-vehicle collisions occurred ($Z_{1,120} = -0.37$; $p = 0.715$). That is, deer were just as likely to be hit at the edge versus the middle of each 1-mi (1.6-km) highway segment in both treatments. Similarly, deer crossing densities at behavioral observation sites did not depend on whether reflectors were exposed or covered with white bags ($F_{13,13} = 0.86$; $p = 0.60$).

Experimental Manipulation of Reflectors II

Over the course of the reflectors vs. black bags experiment (seven and a half months), 20 carcasses were found in two miles (3.2 km) of highway north of Thermopolis. Standardized carcass rates showed that 48 percent more carcasses occurred when reflectors were covered with black bags compared to when they were exposed (Figure 9b). That is, reflectors reduced the number of carcasses by 32 percent compared to black bags.

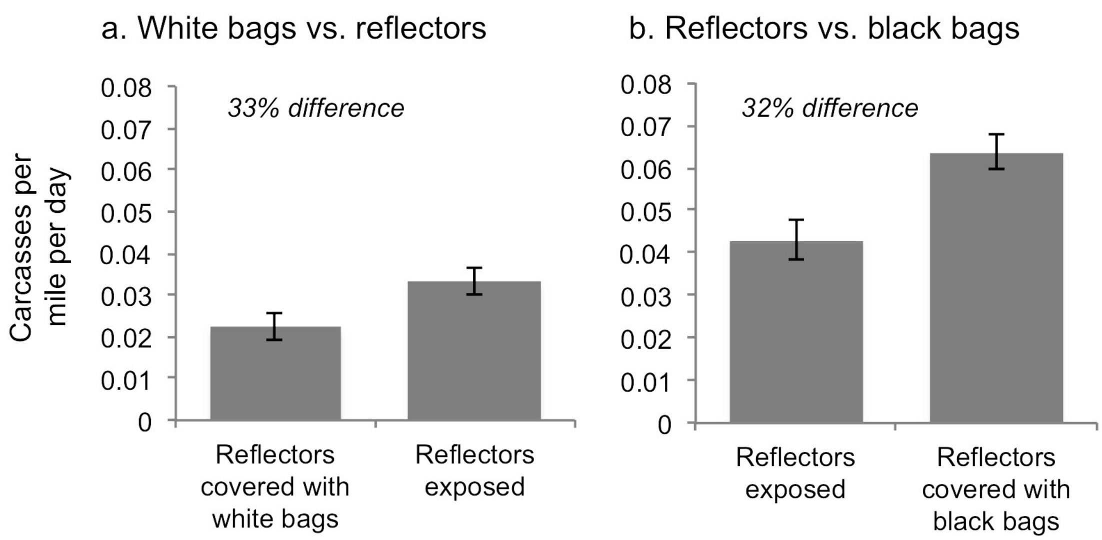


Figure 9. Carcasses per mile per day in experimental treatments (a) white bags vs. reflectors and (b) reflectors vs. black bags.

DISCUSSION

Wildlife-vehicle collision mitigation measures aim to reduce collision rates. Although this desired outcome is very clear, testing the effectiveness of a mitigation measure such as wildlife warning reflectors is surprisingly hard. This is because there are many variables that are difficult to control for, such as fluctuating herd sizes, seasonal differences in deer abundance and behavior patterns, and differences in road conditions and deer-vehicle collision patterns among sites. Additionally, it may take several years for the effects to fully develop (as wildlife learn about and adjust to habitat modifications).

Studies of the effectiveness of wildlife warning reflectors have generally taken one of several approaches. The most common approach is to compare deer-vehicle collision rates before and after reflectors are installed on the same stretch of highway. A second approach is to compare DVC rates in experimental (reflector) and control (non-reflector) stretches of highway. A third approach is to alternately cover reflectors or leave them exposed and compare DVC rates in the same stretches of highway under these two treatments. The fourth approach is to examine deer behavior in relation to reflectors and vehicles. All of these approaches have their own strengths and limitations. In this study we employed three of the four approaches.

A simple before-after comparison of collision rates on the same stretch of highway can yield clear results when a mitigation measure is highly effective. For example, a before-after comparison of the Nugget Canyon project in southwestern Wyoming showed a dramatic 81 percent decrease in deer-vehicle collisions after highway underpasses and extensive fencing were installed.[19] In the present study, however, the effects of wildlife warning reflectors on DVC rates appear to be more subtle or simply reveal the limitations of before-after comparisons. Results from our before-after comparison at four sites were inconclusive, with some sites showing an increase in DVCs after reflectors were installed, some showing a decrease, and some showing no change. At the two Thermopolis sites, where DVCs have decreased in the last several years, the onset of this decrease pre-dates reflector installation by two to three years and was probably driven by a decrease in mule deer herd size. Given these equivocal results, it is difficult to conclude from the before-after comparison that reflector installation has had any effect on collision rates.

Our two experiments were designed with the intent of testing the effects of reflectors on DVC rates more directly, while holding constant year-to-year variability in deer herd size, seasonal behavior, or road conditions. The first experiment (reflectors exposed vs. covered with white bags) was conducted over an extended period of time (one year) and space (10 mi, 16 km, in the Thermopolis area). The treatment configuration was changed monthly or twice-monthly so that each stretch of highway received each experimental treatment repeatedly over time. The advantage of this approach is that each mile received each treatment during each season (including the time of peak DVCs, fall and winter). The disadvantage of this approach is that treatments were regularly re-arranged in space, potentially presenting novel conditions or stimuli to deer.

Our original intent was that white canvas bags would simply negate the effects of reflectors by physically covering them – thus serving as a “control” against which to test the effectiveness of reflectors. To our surprise, we instead apparently introduced a novel treatment that had a distinct effect on DVC rates. Over the course of a year, carcass rates were 33 percent lower in the white bag treatment than in the reflectors exposed treatment, suggesting that the white bags covering reflectors actually prevented deer from getting hit by vehicles much more successfully than the reflectors. Unfortunately, there was no way to assess whether the reflectors themselves also prevented deer from getting hit by vehicles.

Our second experiment (reflectors exposed vs. covered with black bags) was designed to provide a better control for the reflectors by covering them with non-reflective, light-absorbing black bags. Unfortunately the logistics of applying the black bags treatment meant that the experiment could only be conducted over a two mi (3.2 km) area for seven and a half months. Although limited in scope, this experiment yielded very consistent treatment effects between the two 1-mi (1.6 km) experimental stretches; further, the carcass rate for the reflector treatment was very similar to the carcass rate for the same treatment in the first experiment (figure 9). More interestingly, we found that the carcass rate was 32 percent lower in the reflector treatment than in the black bag treatment, indicating that reflectors did prevent deer from getting hit by vehicles.

Taken together, the results of these two experiments suggest that reflectors are about 32 percent more effective than “nothing” (black bags over reflectors) at reducing deer-vehicle collisions, but that white bags over reflectors are an additional 33 percent more effective than “nothing.” This suggests that white bags can reduce actual deer-vehicle collision rates by a substantial amount – perhaps because they are even more visible and reflective than the reflectors. We discuss this possibility and its implications further in chapter 3.

One possible alternative explanation for the effect of white bags in reducing carcass densities is that deer simply did not cross the highway in white bag treatment areas – either because they did not cross at all or they shifted their crossing locations to the adjacent reflector treatment areas. This alternative explanation, however, was not supported by our results. Carcasses were equally likely to be found in the highway in the middle of a 1 mi (1.6 km) treatment zone as they were on the edge of that treatment zone. Further, there was no evidence from direct observations (see chapter 3) that deer crossed the highway any more or less frequently in either treatment. Although data from the reflector-exposed vs. black bag experiment were insufficient to analyze in the same way, direct behavioral observations in this same experiment indicated that deer crossed the highway frequently regardless of treatment.

We discuss these findings further in relation to behavioral results from the same experiments in chapter 3, below.

CHAPTER 3. EFFICACY OF REFLECTORS: ROAD-CROSSING BEHAVIOR

Wildlife warning reflectors are designed to increase the chances of deer crossing highways safely and decrease the chances of deer making unsafe crossings. An unsafe crossing is one in which the deer runs into the highway directly in front of a vehicle. A safe crossing is one in which the deer crosses behind or far ahead of a passing vehicle; if the deer encounters a vehicle on the road as it approaches the road, it should stop and wait or turn around and move away from the road until the vehicle has passed.

Although wildlife reflectors are designed to modify deer behavior, very few studies have examined their effects on deer behavior itself – almost all studies have used carcass counts as their measure of reflector effectiveness. The most comprehensive prior study on deer behavior in relation to reflectors was conducted on a college campus with slow-moving traffic[31]; how reflectors influence deer road crossing behavior in the more dangerous setting of fast-moving rural traffic remains unknown. We used our two experimental manipulations of reflectors to test the effects of reflectors on deer road-crossing behavior. To our knowledge, this is the first experimental test of reflectors on deer behavior in the real-life situation of fast-moving rural traffic.

METHODS

Experimental Manipulation of Reflectors I

Using the reflector-exposed versus covered with white bags experiment (see Chapter 2 for experimental design), we evaluated deer road-crossing behavior with reflectors exposed and with reflectors covered by white bags, both in the presence and absence of a vehicle (2 x 2 factorial design). Between November 2013 and January 2014, we collected 407 independent observations (131 with vehicles) of deer crossing roadways at 16 locations (figure 5). These sites were chosen to represent all of the reflector areas and to maximize the number of deer road crossings captured on camera.

Deer road crossing behavior data were collected between dusk and dawn – the time window when most deer-vehicle collisions occur – using two automated, infrared recording systems. Each system consisted of a FLIR® Scout PS32 Thermal Handheld Camera (FLIR Systems, Wilsonville, Oregon, USA) wired to a laptop and 12-volt deep-cycle marine battery. In the field, we placed the battery and electronics in a padlocked JOBOX (Apex Tool Group, Sparks, Maryland, USA). We mounted the FLIR itself in a custom-welded box bolted to the end of a 3 m (9.8 ft) ranch pole. At each site, we attached the automated recording system to a pre-existing sign post or to a metal post installed by WYDOT specifically for use during the study.

Deer behavioral observations were collected in five "work cycles", each eight nights long (with approximately two weeks between the start of each work cycle) between 19 November 2013 and 21 January 2014. Each night, one camera was set up in a reflector-exposed section and the other camera was set up in a white bag (reflector-covered) section. Cameras were relocated after each night so that all 16 sites were sampled once per work cycle. In addition, we measured the ambient temperature, wind speed, and cloud cover at the start and end of each observation period. We also recorded the moon phase and time of dawn and dusk for each site.

We recorded 832 hours of video footage over the course of the five work cycles. Every time a deer approached the roadway, we considered this to be a "deer-road interaction" event. For each deer-road interaction, we collected data on the number of deer crossing and whether a vehicle was present or not. In cases where deer were crossing in a group, we only collected behavioral data on the leader, since the rest of the deer in the group usually exhibited the same crossing behavior as the leader. (Note, if the group got split, resulting in two sub-groups that had different crossing behavior or deer-vehicle interactions, we treated this as two discrete crossing events).

For each road crossing event, deer behavior was scored using the following yes-no categories: whether the deer crossed successfully (completed crossing or retreated in the direction from which it had come); whether the deer looked before crossing; stopped before crossing; lingered in the road before crossing; stopped in the road while crossing; whether the deer fled from the road; rushed (ran) into or across the road; or walked across the road.

We also calculated an overall risk index based on a composite of five variables: whether the deer looked before crossing (N=1), stopped before crossing (N=1), lingered in the road before crossing (Y=1), stopped in the road during crossing (Y=1), or rushed (ran) across the road during crossing (Y=1). This composite risk index was divided by five to get a continuous risk response variable ranging from 0-1 in value. Other variables (e.g. whether the deer fled from the road) were not included because they were generally mutually exclusive or duplicative of variables already included in the risk index.

Experimental Manipulation of Reflectors II

Between October and December 2014, we observed deer road-crossing behavior in the reflectors-exposed versus covered with black bags experiment (see Chapter 2 for experimental design). Deer road crossing behavior data were collected at two sites over two miles of US 20, just north of Thermopolis (figure 7). One observation site was located in each 1 mi (1.6 km) stretch. Over the course of five nine-night work cycles, an automated recording FLIR was positioned in one or another of these two sites, on alternating nights. A total of 175 road crossings were observed, 47 with vehicles present. Deer behavior was evaluated using the same methods as in the reflector-exposed versus covered with white bags experiment (experiment I; see above).

Experimental Manipulation of Reflectors III

Between October and December 2014, we also set up a new experiment to compare deer road-crossing behavior (in the presence and absence of vehicles) in two paired sets of treatments: reflectors versus no reflectors (removing reflectors from posts) and white bags versus no reflectors. The purpose of this design was to test the effects of reflectors and white bags on deer compared to a true control (an empty post with no reflectors and no bags).

Due to the logistical challenges of removing and replacing reflectors, this experiment was confined to smaller treatment areas. We removed reflectors or covered reflectors with white bags only in the “viewshed” (the extent of roadway visible in the daytime) from the position where each automated recording FLIR was mounted plus a buffer of approximately 300 feet in either direction to avoid edge effects. Treatments were implemented at six sites, one in North Thermopolis, one in South Thermopolis, and four in Basin-Greybull (figure 10). At any one time, each site was configured in one of two possible treatments (figure 10), and treatments were changed every two weeks.

Using the same five work cycles as in the reflectors-exposed versus covered with black bags experiment (experiment 2), we rotated two automated recording FLIR systems among these six sites nightly, so that each site was sampled three times within a nine-night work cycle. This design was employed to provide a balanced representation of each site under different treatment and time of year conditions. Over the data collection period we observed a total of 135 road crossings (50 with vehicle present) in the reflector vs. empty post treatment pair and 153 road crossings (84 with vehicle present) in the white-bag vs. empty post treatment pair. Deer behavior was evaluated using the same methods as in the reflector-exposed versus covered with white bags experiment (Experimental Manipulation of Reflectors I; see above).

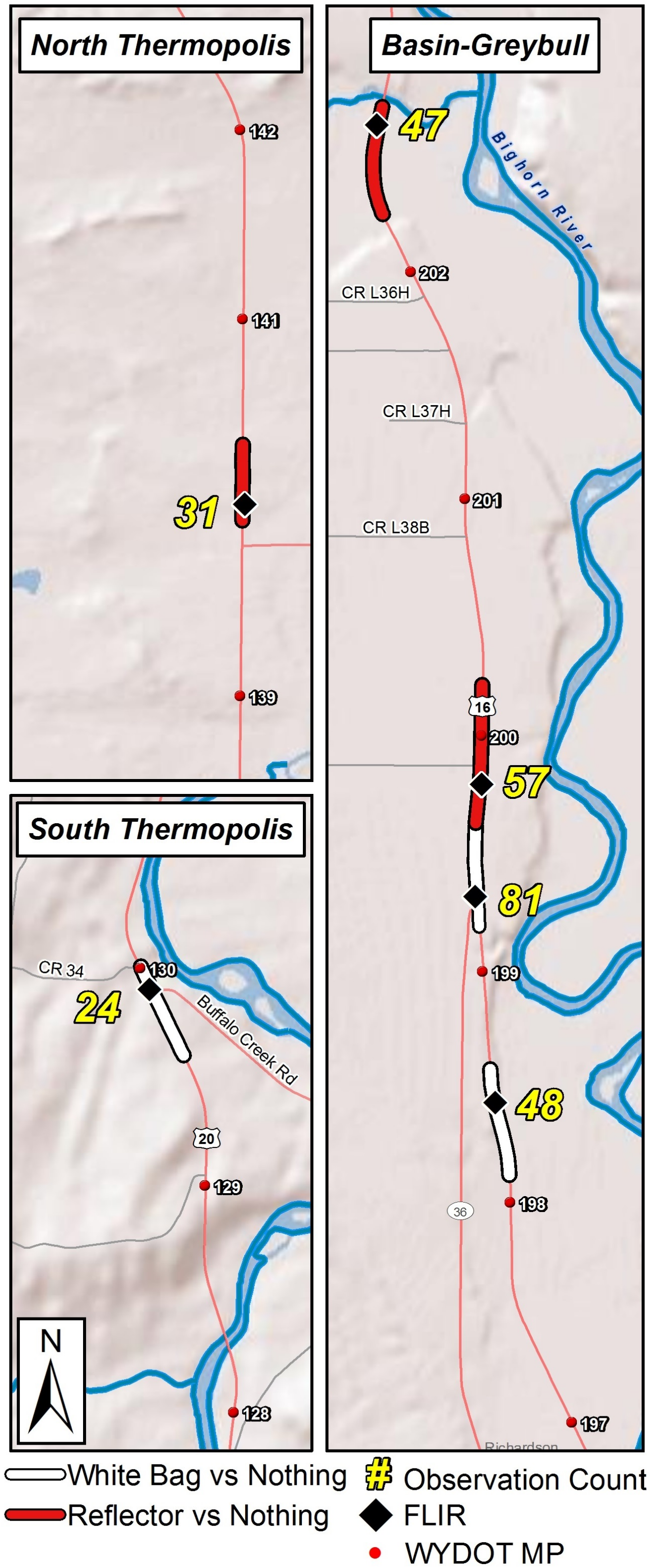


Figure 10. Treatment area of the reflectors-exposed versus white bags versus empty posts experiment (experiment III). Infrared camera locations and number of deer observations recorded at each location are also given. (October 2014 - December 2014).

Traffic Volume Data

In addition to collecting behavior data from the FLIR automated recording system, we also collected traffic count data from this video footage. For each hour that the recording system was deployed, we counted the number of vehicles that passed in the first 10 minutes of the hour. This number was multiplied by six to get an estimated total hourly traffic count. Data were averaged across all sampled nights and all FLIR sites, within each reflector area (Basin-Greybull, South Thermopolis, and North Thermopolis), to get an average hourly traffic count for each reflector area.

Data Analysis

Behavioral data from all three experiments were analyzed using the same general approach, with specific modifications for each experiment. For all experiments, categorical response variables (individual behaviors, such as did the deer stop before crossing the road) were analyzed as a logistic regression, using a GLM with a binomial link function. For the overall risk index (which we treated as a continuous variable), data were analyzed using a GLM with the identity link function. In all cases, we ran analyses for several candidate models and compared the fit of these models using AIC.

For the first experiment (reflectors-exposed vs. covered with white bags), we considered eight predictor variables in our candidate models: reflectors exposed vs. covered with white bags, car present vs. absent, work cycle (1-5), treatment area (Basin, Thermopolis, Kinnear), cloud cover (clear, partly cloudy, overcast, snowing), temperature, moon phase (full= full ±3/4, new=new ±1/4, waxing=1/4 to 3/4, waning=3/4 to 1/4), and time of day (dusk=17:00-19:59, late night=19:59-23:59, early morning=00:00-4:59, dawn=05:00-08:59).

For the second and third experiments (reflectors-exposed vs. covered with black bags; and reflectors vs. white bags vs. empty posts), we considered six predictor variables in our candidate models: treatment, vehicle present vs. absent, work cycle, observation site, moon phase, and time of day. Moon phase and time of day were defined as for the first experiment. Cloud cover and temperature data were not collected for these experiments since we had found them unimportant in explaining variation in the behavioral data in the first experiment.

All analyses were performed in R.[45]

RESULTS

Traffic Volume

In all three reflector zones, traffic volume was highest in the early evening (17:00-19:00) and declined through the night, picking up again between 05:00 and 07:00 (figure 11). Traffic volume was highest in the Basin-Greybull area and comparable between South and North Thermopolis. At peak traffic times, 150 to 300 vehicles passed per hour; that is 2.5 to 5 vehicles per minute.

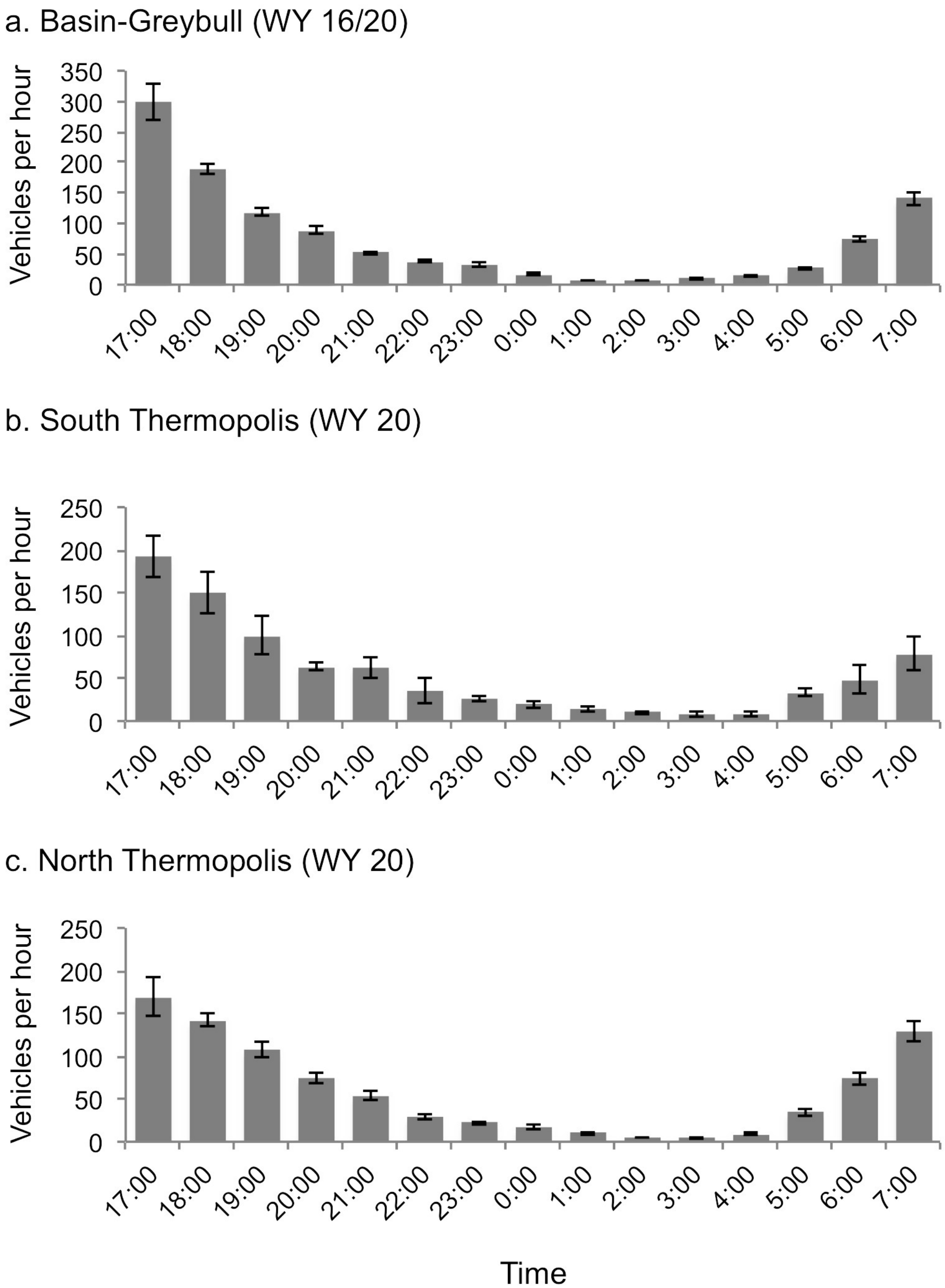


Figure 11. Average vehicles per hour during dusk and dawn in (a) Basin-Greybull (b) South Thermopolis and (c) North Thermopolis.

Experimental Manipulation of Reflectors I

Deer road crossing behavior in the reflector-exposed versus covered with white bags experiment was most strongly influenced by the presence or absence of a vehicle, the treatment (reflector exposed vs. covered with a white bag), the site, and in some cases, the phase of the moon, work cycle, or temperature. Of the individual behaviors, the most informative were whether the deer looked before crossing; whether the deer stopped before crossing; whether the deer fled from the road; and whether the deer rushed (ran) into/across the road. We report the fit of alternative models for each of these four behaviors and the overall risk index in appendix 2 and the best-fit models for each in table 1.

Table 1. Best fit model for each response variable in the reflectors-exposed versus covered with white bags experiment. The set of models considered is given in appendix 2.

Response Variable	Best Model
Deer stopped before crossing (Y/N)	Treatment + vehicle presence + moon phase + site + temperature
Deer looked before crossing (Y/N)	Treatment + moon phase + site
Deer rushed into the roadway (Y/N)	Treatment + vehicle presence + site + temperature
Deer fled from the roadway (Y/N)	Treatment + vehicle presence + weather
Overall risk index	Treatment + vehicle presence + treatment x vehicle presence[1] + moon phase + site + temperature

[1] "Treatment x vehicle presence" indicates an interaction term, which represents non-additive effects of both treatment and vehicle, or that the effect of treatment depends on vehicle presence

Overall, deer were 32 percent more likely to stop before crossing when reflectors were covered with white bags (proportions: reflector covered = 0.84, reflector exposed = 0.63; $Z_{1,504} = 5.39$; $p < 0.001$), and 12 percent more likely to stop if a vehicle was coming (proportions: vehicle absent = 0.70, vehicle present = 0.79; $Z_{1,504} = 2.94$; $p = 0.003$). The effects of vehicle presence and reflector state were additive, such that deer stopped most frequently when a vehicle was present and reflectors were covered with white bags (figure 12a). Deer were also less likely to stop before crossing during the new moon phase (relative to full moon; $Z_{3,504} = 2.79$; $p = 0.005$) and slightly more likely to stop during the waning moon phase (relative to full moon; $Z_{1,504} = -2.10$; $p = 0.035$). Deer were more likely to stop before crossing at the Kinnear treatment area than in the other treatment areas (proportions: Kinnear = 0.76, Thermopolis = 0.69, Basin = 0.67; $Z_{2,504} = 3.44$; $p < 0.0001$).

Deer were also 29 percent more likely to look before crossing the road when reflectors were covered with white bags (proportions: reflector covered = 0.85, reflector exposed = 0.65; $Z_{1,485} = 5.12$; $p < 0.001$). Deer also looked more when a vehicle was present (proportions: vehicle present = 0.76, vehicle absent = 0.67; $Z_{1,485} = 2.37$; $p = 0.017$). As with stopping behavior, deer looked most frequently when a vehicle was present and reflectors were covered with white bags (figure 12b). Deer also looked before crossing less during the new moon phase and more during the waning moon phase (relative to full moon). Deer looked before crossing 5-25 percent more in the Kinnear treatment area than in the other treatment areas (proportions: Kinnear = 0.77, Thermopolis = 0.60, Basin = 0.73; $Z_{2,585} = 3.31$; $p < 0.001$).

Deer were two and a half times (250 percent) more likely to rush into the roadway when a vehicle was present than when there was no vehicle present (figure 12c; proportions: vehicle absent = 0.12, vehicle present = 0.41; $Z_{1,507} = 6.75$; $p < 0.001$). There was a marginally significant trend for deer to rush into the road more in the reflector treatment than the white bag treatment ($Z_{1,507} = -1.76$; $p = 0.079$), particularly in the presence of a vehicle where deer rushed into the road 25 percent less in the white bag treatment than the reflector treatment. Deer were less likely to rush across the road in the Kinnear treatment area than in other treatment areas (proportions: Kinnear = 0.75, Thermopolis = 0.64, Basin = 0.71; $Z_{2,507} = -3.79$; $p < 0.001$).

Whether a deer fled from the road also depended primarily on vehicle presence; deer hardly ever fled when there was no vehicle present and were 12 times more likely to flee when a vehicle was present (proportions: vehicle absent = 0.03, vehicle present = 0.39; $Z_{1,508} = 8.65$; $p < 0.001$). There was also a significant effect of treatment ($Z_{1,507} = 1.92$; $p = 0.054$). This appears to have been driven by higher fleeing behavior in the white bags treatment in the presence of a vehicle (figure 12d). In the presence of a vehicle, deer were 33 percent more likely to flee from the road in the white bag treatment than in the reflector treatment.

The overall risk index, which was a composite of several individual behaviors, was best predicted by an interactive effect between treatment and vehicle presence. Deer exhibited more risky behavior when reflectors were exposed than when reflectors were covered with white bags, especially in the presence of a vehicle (figure 12e). Although this interaction term was only marginally significant ($F_{1,478} = -1.79$; $p = 0.074$), the pattern was clear; deer risk index was 40 percent less in the white bag treatment relative to the reflector treatment. Deer also exhibited less risky behavior during the new moon and more risky behavior during the waning moon relative to the full moon. The least risky behavior was seen in the Kinnear treatment area (means ± SEM: Kinnear = 0.17 ± 0.019, Thermopolis = 0.23 ± 0.018, Basin = 0.25 ± 0.18; $F_{2,478} = -4.54$; $p < 0.0001$).

There was a general pattern – both in the riskiness index and in the individual behaviors that made up this index – for deer to exhibit "safer" road crossing behavior when reflectors were covered with white bags than when they were exposed. One possible explanation for this is that deer had acclimated to the reflectors but not the white bags. Reflectors had been in place for several years at the time of data collection, whereas white bags had been present on alternating 1 mi (1.6 km) stretches of road for 8-12 months in Thermopolis and 0-3 months in Basin and Kinnear. In order to ask whether there was any evidence that deer were acclimating to the white bag treatment, we asked (a) whether treatment differences were less in Thermopolis than in Basin and Kinnear, and (b) whether deer behaviors in Basin and Kinnear changed over time – which would indicate potential acclimation.

We did not find any conclusive evidence that deer were acclimating to the white bag treatment. When we examined all of the behavioral data from Kinnear and Basin through time, we found some evidence that looking and stopping behavior changed over the five work cycles (look: $\chi^2_4 = 12.6$, $p = 0.013$; stop: $\chi^2_4 = 8.4$, $p = 0.077$; rush: $\chi^2_4 = 2.0$, $p = 0.74$; flee: $\chi^2_4 = 1.1$, $p = 0.89$). The overall risk index was significantly lower in the last work cycle relative to the preceding four work cycles ($F_{4,269} = 2.89$, $p = 0.022$). However, when we ran these analyses examining data from the white bag treatment only, we did not find any significant evidence of acclimation – or decreasing levels of risky behavior over time (Table 2; look: $\chi^2_4 = 2.5$, $p = 0.65$; stop: $\chi^2_4 = 1.9$, $p = 0.75$; rush: $\chi^2_4 = 0.88$, $p = 0.93$; flee: $\chi^2_4 = 3.6$, $p = 0.47$; riskiness: $F_{4,102} = 0.77$, $p = 0.49$).

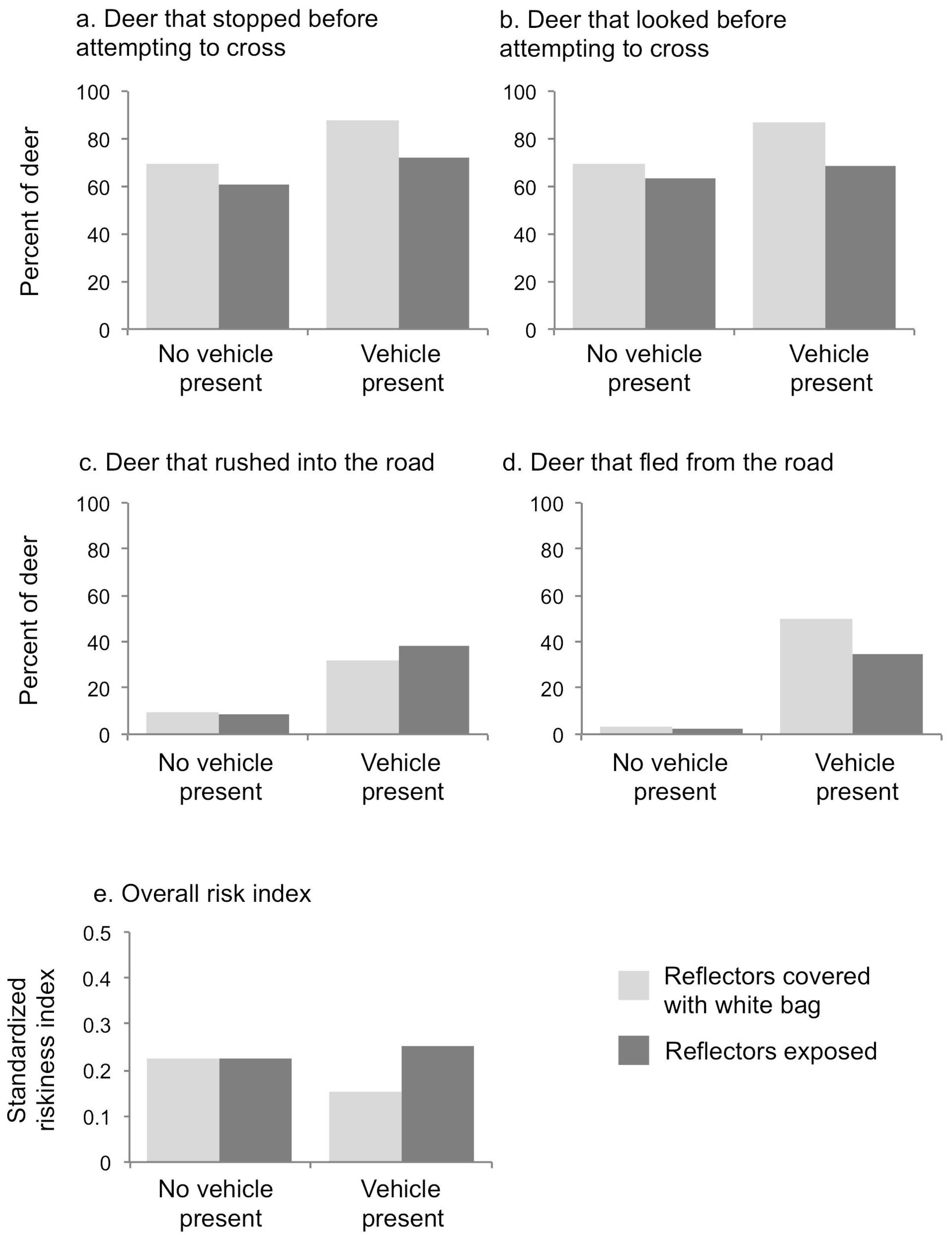


Figure 12. Deer behavior when crossing the road in the presence and absence of a vehicle and with reflectors exposed versus covered with a white bag (experiment I).

Experimental Manipulation of Reflectors II

Deer road crossing behavior in the reflector-exposed versus covered with black bags experiment was, as in the reflector versus white bag experiment, most strongly influenced by the presence or absence of a vehicle and the treatment (figure 13). We report the fit of alternative models for each of the four key behaviors and the overall risk index in appendix 3 and the best-fit models for each in table 2.

Table 2. Best fit model for each response variable in the reflectors-exposed versus covered with black bags experiment. The set of models considered is given in appendix 3.

Response Variable	Best Model
Deer stopped before crossing (Y/N)	Vehicle presence
Deer looked before crossing (Y/N)	Treatment
Deer rushed into the roadway (Y/N)	Treatment + vehicle presence + treatment*vehicle presence1 + time + cycle
Deer fled from the roadway (Y/N)	Treatment + vehicle presence
Overall risk index	Treatment + time

[1] "Treatment x vehicle presence" indicates an interaction term, which represents non-additive effects of both treatment and vehicle, or that the effect of treatment depends on vehicle presence

Vehicle presence was the main predictor of whether deer stopped before crossing the road ($Z_{1,155} = 2.84$; $p = 0.005$). Although there was no significant effect of treatment, there was a strong trend for deer to stop before crossing the road most when reflectors were exposed and a vehicle was present (figure 13a). In the presence of a vehicle, deer stopped 46 percent more in the reflector treatment than in the black bags treatment. Deer were also 20 percent more likely to look before crossing the road in the reflector treatment than the black bags treatment (figure 13b). Treatment was the only (marginally) significant predictor of looking behavior ($Z_{1,155} = 1.68$; $p = 0.093$).

Deer rushed into the road 79 percent more when a vehicle was present than when there was no vehicle present ($Z_{1,172} = 3.99$; $p < 0.0001$). However, there was also a significant interaction between treatment and vehicle presence ($Z_{1,172} = -2.65$; $p = 0.008$); among observations where a vehicle was present, deer rushed into the road 47 percent more of the time in the black bags treatment than in the reflector treatment (figure 13c). The opposite was true of fleeing behavior, where deer fled from the road 137 percent more of the time in the reflector treatment than in the black bags treatment (figure 13d). Both treatment and vehicle presence were individually significant or marginally significant (treatment: $Z_{1,174} = 1.85$; $p = 0.065$; vehicle presence: $Z_{1,174} = 4.81$; $p < 0.0001$).

Consistent with these individual behaviors, overall risk index showed a significant effect of treatment ($t_{1,153} = -2.39$; $p = 0.018$), primarily driven by higher risk in the black bag treatment in the presence of a vehicle (figure 13e).

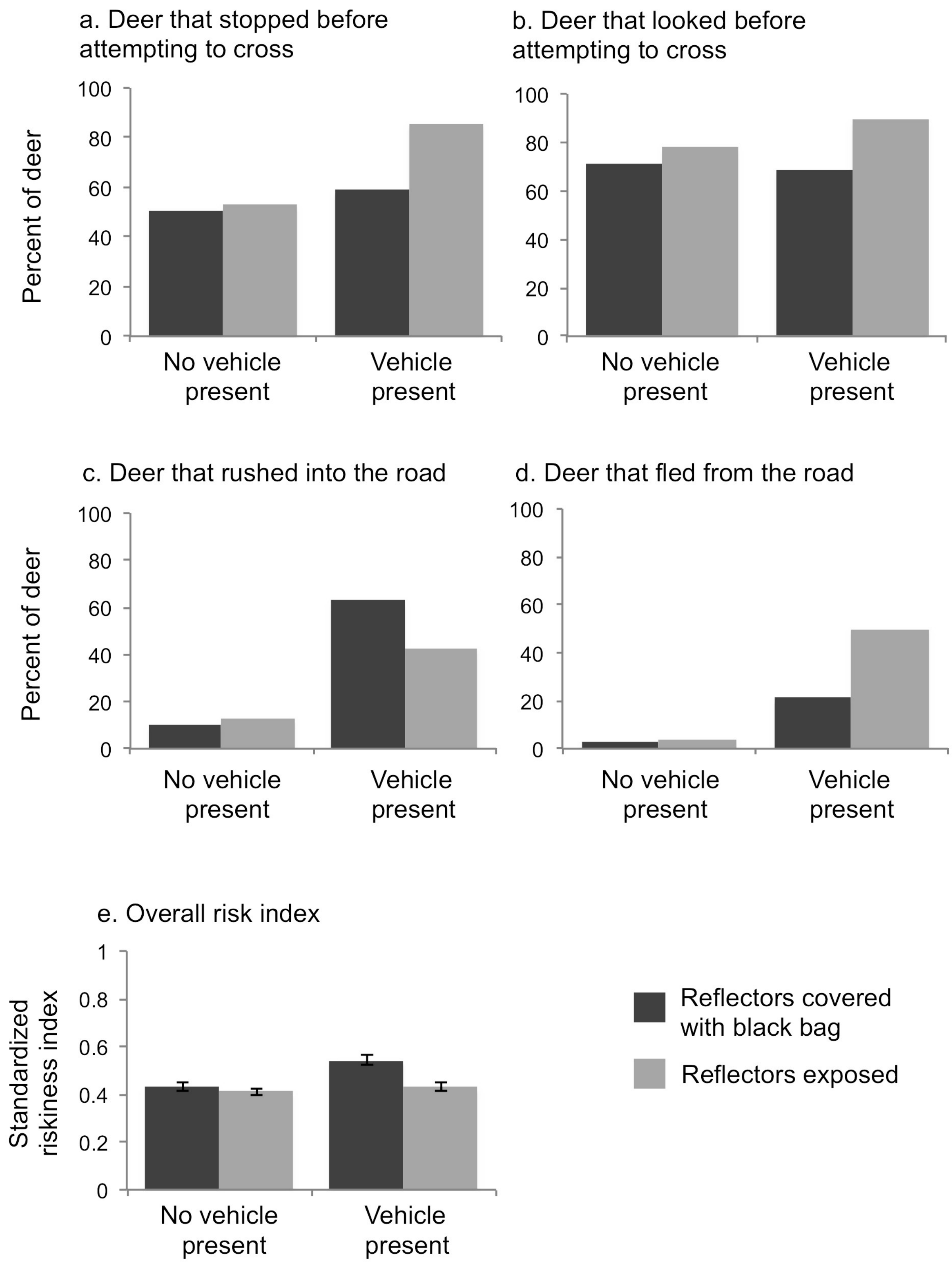


Figure 13. Deer behavior when crossing the road in the presence and absence of a vehicle and with reflectors exposed versus covered with a black bag (experiment II).

Experimental Manipulation of Reflectors III

Deer road crossing behavior in the reflectors vs. white bags vs. empty posts was again most strongly influenced by treatment and the presence or absence of a vehicle. We report the fit of alternative models for each of the four key behaviors and the overall risk index in appendix 4 and the best-fit models for each in table 3.

Table 3. Best fit model for each response variable in the reflectors-exposed versus covered with white bags versus empty posts experiment (experiment III). The set of models considered is given in appendix 4.

Response Variable	Best Model
Deer stopped before crossing (Y/N)	Treatment + time of day
Deer looked before crossing (Y/N)	Treatment + site + time of day
Deer rushed into the roadway (Y/N)	Vehicle presence
Deer fled from the roadway (Y/N)	Vehicle presence + moon phase
Overall riskiness score	Vehicle presence + moon phase + time of day

Deer stopping and looking behavior depended strongly on treatment and time of day. Deer in the white bag treatment stopped 25 percent more than in the reflector treatment and 31 percent more than in the empty posts treatment (figure 14a); however, only the difference between the white bags treatment and the empty posts treatment was statistically significant ($Z_{1,270} = 2.38$; $p = 0.017$). The effect of treatments on deer looking before entering the roadway was more subtle. Deer in the white bag treatment stopped only 5 percent more than in the reflector treatment and 10 percent more than in the empty posts treatment (figure 14b). The difference between the white bags and empty posts treatment, was again significant ($Z_{1,236} = -2.08$; $p = 0.038$). For both stopping and looking behavior, there was a significant trend for more risky behavior (less stopping and looking) in the "late night" time period (19:59-23:59) than in other times (stopping: $Z_{1,270} = -2.54$; $p = 0.011$; looking: $Z_{1,270} = -3.11$; $p = 0.002$).

Consistent with the previous two experiments, deer were much more likely to rush into the road, and much less likely to flee from the road, in the presence of a vehicle than when there was no vehicle present – regardless of experimental treatment (figure 14c,d). Vehicle presence was a significant predictor of behavior for both rushing and fleeing behavior (rushing: $Z_{1,277} = 6.38$; $p < 0.001$; fleeing: $Z_{1,284} = 5.88$; $p < 0.001$). Although treatment was not a significant predictor for either of these behaviors, substantial differences in behavior were seen across treatments in the presence of a vehicle (figure 14c,d). Deer rushed into the road the least and fled from the road the most in the white bags treatment, but the relative effect of reflectors and empty posts differed between rushing and stopping behaviors. Deer rushed into the road 46 percent more in the empty posts treatment relative to the white bags treatment and 76 percent more in the reflector treatment relative to the white bags treatment. Deer fled from the road 69 percent more in the white bags treatment relative to the empty posts treatment and 39 percent more in the reflector treatment relative to the empty posts treatment. Note that the rank order of treatments was different for the "rush" behavior than for any of the other behaviors.

In terms of overall risk index, vehicle presence ($Z_{1,284} = 2.25$; $p = 0.025$), moon phase, and time of day were all significant predictors. Although treatment was not a significant predictor of overall risk index, it again led to substantial differences in the magnitude of the response variable. In the presence of a vehicle, deer showed a higher degree of risky behavior in the empty posts treatment than the white bags treatment, with the reflector treatment intermediate (figure 14e).

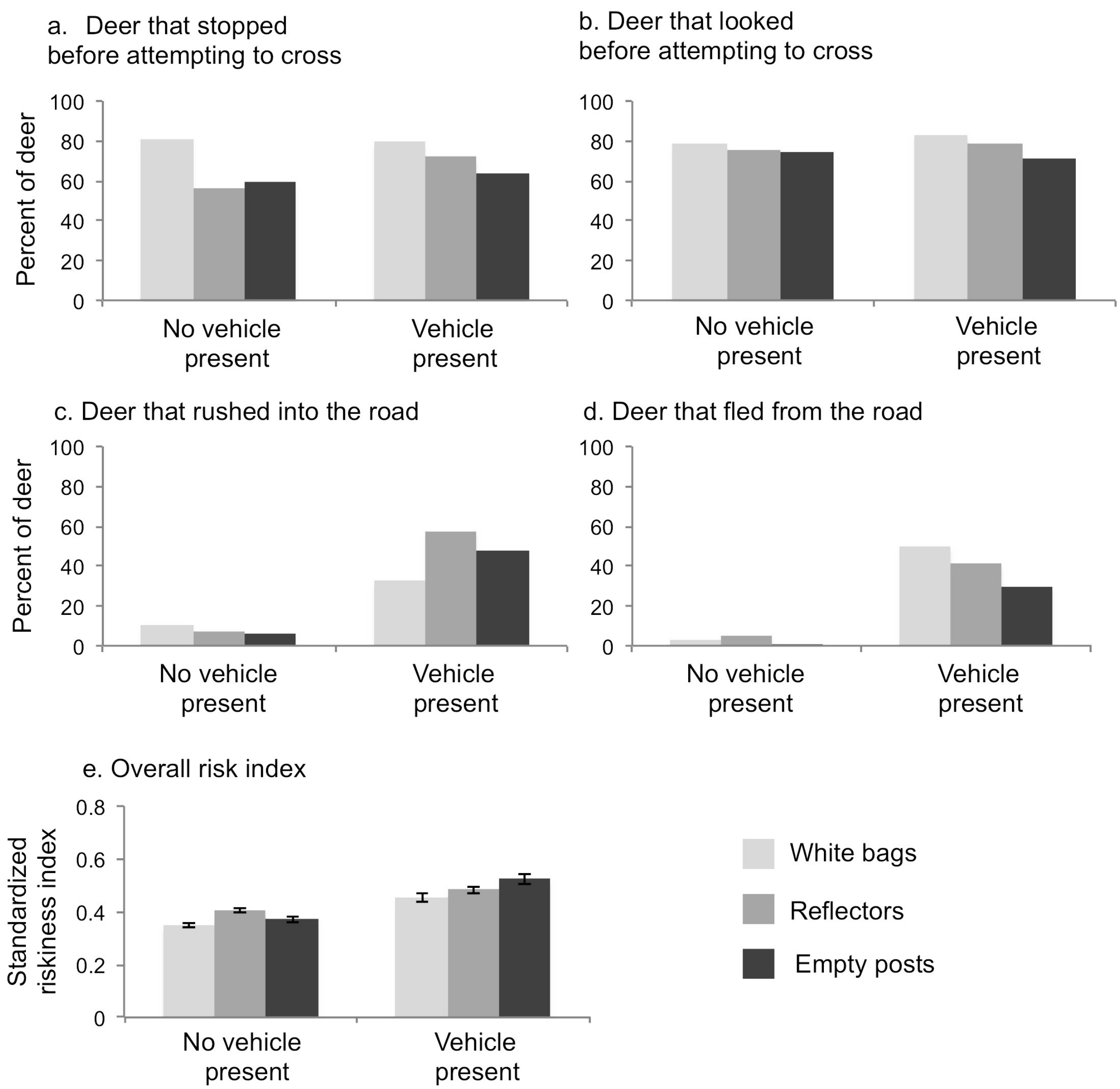


Figure 14. Deer behavior when crossing the road in the presence and absence of a vehicle and with reflectors exposed versus covered with a white bag versus empty posts (experiment III).

DISCUSSION

Across three experiments and two different years, the general pattern of deer road-crossing behavior was for deer to exhibit the least risky behavior when reflectors were covered with white bags, intermediate behavior when reflectors were exposed, and the most risky behavior when reflectors were covered with black bags or removed from posts. This general pattern matches the relative effects of these treatments on deer-vehicle collisions (measured by carcass counts; see chapter 2). By examining deer road-crossing behaviors, we not only provide additional support for the collision results but also provide insights into how DVC mitigations work to alter deer behavior.

In general, deer stopped and looked before entering the roadway at relatively high rates (50-80 percent of the time) regardless of whether a vehicle was present or not. White bags and reflectors however, both caused deer to stop and look more than black bags or empty posts, especially when a vehicle was present (figures 12-14a,b). In contrast, the presence of absence of a vehicle was the primary determinant of deer rushing and fleeing behavior. Deer very rarely rushed (ran) across the road or fled from the road when there was no vehicle present but frequently (about 30-60 percent of the time) engaged in both behaviors when a vehicle was present (figures 12-14c,d). Although neither reflectors nor white bags completely prevented deer from running into the road (the most risky behavior in terms of causing DVC) or caused them all to turn away from the road (the most effective behavior in terms of avoiding DVC), both of these treatments substantially reduced rushing behavior and increased fleeing behavior relative to the two “controls” (black bags and empty posts) by 30-60 percent.

Our understanding of the relative effectiveness of reflectors versus white bags in affecting deer road crossing behavior is somewhat complicated by the fact of having conducted three separate experiments. However, in both the two-way comparison of white bags and reflectors, and in the three-way comparison of white bags vs. reflectors vs. empty posts, the white bags treatment consistently led to less risky deer road crossing behavior. Carcass rates were also significantly lower in the white bags treatment compared to the reflector treatment. In the reflectors vs. black bags experiment, reflectors were highly effective at reducing risky deer road crossing behavior. They also led to a much-reduced carcass rate. Together, these results both indicate that reflectors are a somewhat effective mitigation tool, but that white bags covering reflectors was an even more effective tool.

A study commissioned by the manufacturer of the Strieter-Lite reflector systems reports that these reflectors reduce deer-vehicle collisions by 78-90 percent.[20] Numerous other studies have shown anything from no effect to 90 percent effectiveness of reflector systems (table 4). Here, we found that reflectors reduced deer-vehicle collisions by about 33 percent and reduced risky road crossing behavior by a similar degree, at best. (Note: the reflector vs. black bags experiment was conducted on only two miles, in one of the biggest hotspots of deer crossing activity and collisions in the region, and may not represent all conditions; the smaller magnitude of behavioral effect of the reflectors in the white bags vs. reflectors vs. empty posts experiment is probably more representative of a wider variety of sites and conditions).

Table 4. Summary of major studies on wildlife warning reflectors, indicating (where applicable) percent decrease in carcasses attributed to reflectors.

Location	Type of Deer	Study Design	Conclusion	Reference
Colorado	Mule	Cover-uncover	No effect	21
Illinois	White-tailed	Before-after	No effect	22
Wyoming	Mule	Cover-uncover and case-control	No effect	26
California	Not specified	Before-after	No effect	24
Ontario	Not specified	Cover-uncover	No effect	23
Virginia	White-tailed	Case-control	Ineffective at most sites, highly effective at two sites	25
Indiana	White-tailed	Case-control	19 percent decrease	30
Iowa	White-tailed	Case-control	41 percent decrease	29
Minnesota	White-tailed	Before-after	50-97 percent reduction in rural areas, no effect in suburban areas	28
Washington	White-tailed and mule	Cover-uncover	88 percent decrease	27

As can be seen in table 4, the results of other studies on the effectiveness of reflectors on deer have been highly variable. As discussed above, before-after comparisons of carcass rates are not very reliable, since they cannot account for fluctuations in deer population size. Case-control study designs sometimes suffer from an inappropriate control site – as in at least one study in which collision rates were substantially lower in the control sites even before the reflectors were installed.[29] These methodological issues limit our ability to draw confident conclusions in the results of many of these prior studies. Assuming that the effects of reflectors are, indeed, as variable as the results in table 4 indicate, there are at least two possible explanations.

First, there is a possible trend, across studies, for places with high DVC rates to show a substantial reduction in DVCs due to reflectors, whereas sites with low DVC rates show little effect of reflectors. This was the case in a study of 10 sites in Virginia – where the two that showed substantial reductions had very high DVC rates and the remaining eight had very low DVC rates. This was also evident in the Grenier meta-analysis,[20] where the sites with more than 20 DVC per mile per year had the greatest proportional reductions in DVCs. (Note, however, that this meta-analysis was commissioned by the reflector manufacturers and reports non-independent results as if they were independent, both of which raise some questions about the validity of its findings). Many of the studies cited in table 4 that showed no effect of reflectors had low initial or non-reflector DVC rates (fewer than five per mile per year), making it hard to say whether reflectors changed anything. Notably, however, the one previous Wyoming study in habitat similar to the present study had high DVC rates in both experimental and control sites and found no effect of the reflectors on DVC.[26]

A second possible explanation is that reflectors may be quite effective in some situations or sites, but not in others. There are many variables that differ among sites that cannot easily be controlled for. These include drivers' ability to see deer, roadside micro-topography that may make it difficult for deer to stop an attempted crossing (e.g. a steep embankment), reflector placement and maintenance, whether vehicles are using high-beams or low-beams, and many other possible variables. It is entirely possible that reflectors are more effective under some situations than others, but that the variables mediating this effectiveness are not yet understood.

Although our study design was subject to some of the same challenges that others have faced, our study was uniquely robust in several ways. First, we used a robust experimental design, with reflectors manipulated in several ways and, at least in the reflector vs. white bag experiment, over an extensive length of highway. Second, we used two methods of assessing reflector effectiveness – carcass rates and behavioral observations – both of which supported the same conclusions. Third, our behavioral observations were far more numerous than any other study that has undertaken such observations under comparable conditions. Two earlier studies of carcass rates collected deer behavioral observations but only on fewer than 20 deer.[22,23] In contrast, we were able to use new night-time thermal imaging technology to obtain more than 800 observations of deer road crossings. D'Angelo et al. observed more than 1,300 deer road crossings,[31] but all were on a road with slow-moving traffic, conditions quite different from those in our study area.

The reductions that we observed in terms of both DVC and accident-causing behaviors, such as running into the road without stopping first, are not trivial. Most WVC mitigation strategies have been found to be minimally effective, with the exception of highway under- and over-passes accompanied by game-proof fencing.[16] Even though we did not find the 78-90 percent effectiveness of reflectors reported by the manufacturer, the 33 percent reduction we found is significant. However, in the process of testing the effectiveness of reflectors, we inadvertently found that white bags on posts were even more effective – an additional 33 percent at reducing DVC than reflectors (suggesting that white bags reduce collisions by 66% relative to nothing – but note that this is across two different experiments; see figure 12).

Why the reflectors covered with white canvas bags substantially reduced the likelihood of deer getting hit by cars is not entirely clear. It is possible that light from the cars' headlights was reflecting off of the two rows of canvas bags along the highway, causing deer to startle or look up before crossing. Additionally or alternatively, it is possible that the white bags resembled a raised deer tail, which is generally viewed as an alarm cue or pursuit deterrent.[47,48] This is not entirely surprising given our understanding of deer visual capabilities; at low light levels deer are best able to detect colors at shorter (blue/green) wavelengths.[49,50] D'Angelo et al. found that deer crossing in sections of road with white wildlife warning reflectors exhibited lower deer-vehicle collision risk than deer crossing with red reflectors (although the study also concluded that reflectors as a whole were an ineffective mitigation strategy).[31] It is possible that white canvas bags had been bleached, causing them to reflect light in the UV spectrum.

It is also possible that deer responded more strongly to the white bags covering reflectors because they were habituated to the reflectors,[32] which were installed more than five years prior to the beginning of the experiment – whereas the white canvas bags were a novel stimulus. However, we found little evidence that deer became habituated to the white canvas bags over the three months of the reflectors vs. white bags experiment. The length of time needed for deer to habituate to a novel environmental feature is unknown, and it is possible that the effectiveness of the white bags might decrease over time.

Further study would help to shed light on the long-term effectiveness of a mitigation technology developed after the model of the white bags covering reflectors. Apart from mirrors, which have generally proven ineffective, the Strieter-Lite / Swareflex reflectors are the only vigilance-increasing mitigation measures that have been tested or marketed on a large scale. The results of this study suggest that vigilance-increasing mitigation measures – some of which may not yet have been developed – may be effective enough to be part of the wildlife-vehicle collisions mitigation toolbox.

CHAPTER 4. STATE-WIDE WILDLIFE-VEHICLE COLLISION PATTERNS

We made use of WYDOT's wildlife-vehicle collision records to analyze patterns of deer-vehicle collisions around the state. We focus on deer because they make up the vast majority (>80 percent) of wildlife-vehicle collisions. Other ungulates, such as elk, pronghorn, and moose, are involved in wildlife-vehicle collisions in localized parts of the state. However, our objective here was to look at broad-scale patterns and correlates of wildlife-vehicle collisions over the whole state in order to guide priorities for further investigation and/or mitigation.

METHODS

Data Acquisition and Preparation

We acquired WYDOT's state-wide carcass location data ("carcass" data) and reported wild animal-vehicle crash data ("crash" data) records for the years 1990-2013. We then merged the digital records into a master "collisions" database and converted this tabular data into a spatially explicit geo-database. As outlined for the District 5 data in chapter 2, this was a multi-step process involving substantial data cleanup and removal of duplicate records. Records were coded as "mule deer", "white-tailed deer", or simply "deer." Because of the ambiguity of the latter designation, we combined all three types of record into a master data set of all deer. Given the distribution of mule deer versus white-tailed deer in Wyoming, however, these data likely represent >90 percent mule deer records. For the purposes of analysis, we further restricted our data to the years 2008-2013. According to WYDOT personnel, carcass data collection protocols were improved and standardized across the state starting in 2008.[39]

Collision records varied substantially in their degree of spatial precision. While many crash records have GPS coordinates associated with them, carcass locations are estimated by highway maintenance crews in reference to the nearest mile or 1/10th of a mile. Our analysis of the data showed that a disproportionate fraction of records were referenced to the nearest mile, indicating that it would be inappropriate to use 1/10th of a mile as the scale of any spatial analysis (doing so would under-represent carcasses at small scales and show clusters of carcasses at the whole-mile markers). For the purpose of analysis, we therefore assigned all carcass or crash records to the nearest whole-mile marker. (More fine-scaled spatial analyses can be conducted using only crash records for which GPS data exist).

Road attribute data were derived from WYDOT's Linear Referencing System (LRS) of Wyoming roads. In order to prepare roads data for analysis, we removed:

- Roads that were not ML Routes.
- Roads with no traffic data.
- Roads with no carcass or crash data.
- Roads that were less than two miles long.

For divided roadways represented by two different lines, one line was removed and road attribute and collision data were assigned to the remaining line. The final road network used in our analyses was made up of 161 different roads and 6,692 mi (10,769 km) of roadway.

In our initial data exploration, we examined patterns of deer-vehicle collisions (DVC) by year and by season. Although there were differences among years, patterns across seasons were similar (varying in the number of collisions, but not the locations). We thus combined all DVC records across seasons (within each year) but kept records separated by year. Based on our analysis of the spatial scale of clustering of collisions, we determined that peak aggregation (clustering) of collisions occurs at the scale of 20-25 km (12.4-15.5 mi) (see Data Analysis and Results: Cluster Analysis, below). Based on this, we selected 5 km (3.1 mi) as a suitable scale at which to analyze collision patterns across the whole state because it was substantially smaller than the scale of each cluster but large enough to make data management and analysis feasible. Because the distance between whole-mile markers is not always precisely 1 mi (1.6 km), we extracted collision data over 3.2 mi (5.15 km) segments of road; segments were centered on every fourth milepost and extended 1.6 mi (2.6 km) in each direction (figure 15). Segment-centers started at milepost 2 of each ML route to avoid sampling road intersections twice. Collision data were extracted for a total of 1,518 unique road segments.

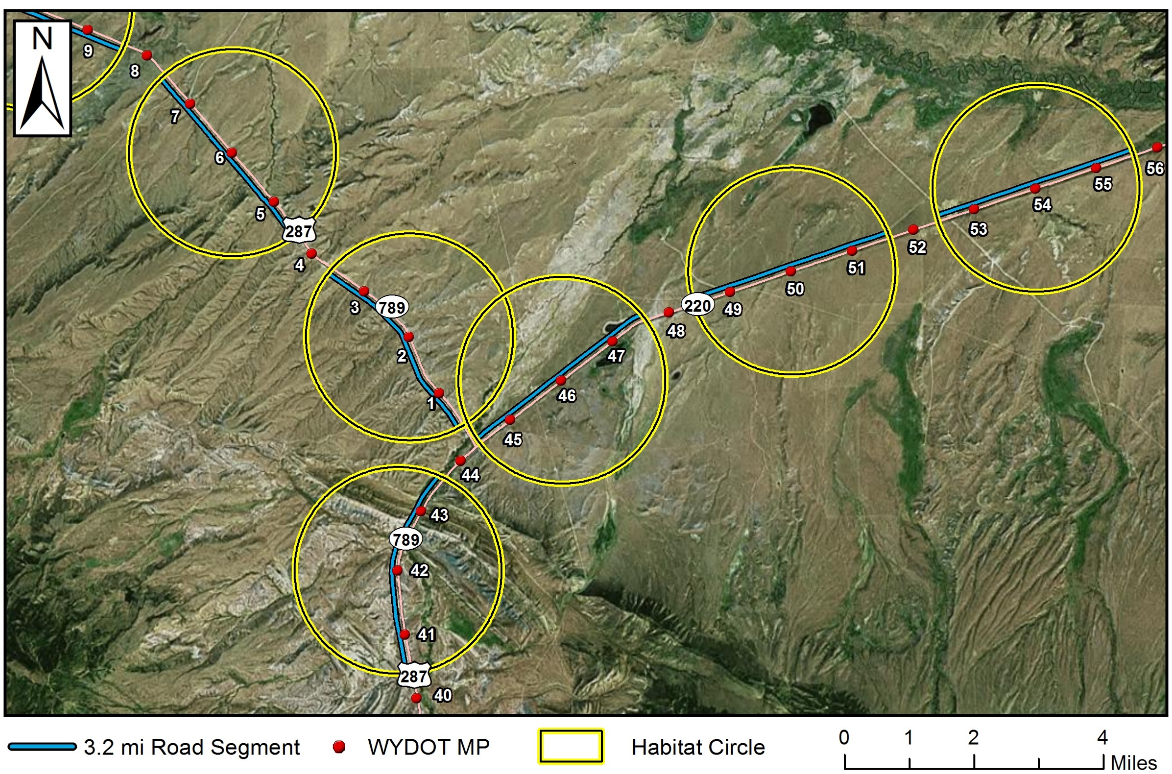


Figure 15. Muddy Gap Junction; 3.2 mi (5.15 km) segments of road centered at every fourth mile marker and surrounded by a 3.2 mi diameter circle from which habitat data were extracted.

For each road segment, we extracted data on a number of road attributes and ecologically important variables as candidate predictors of DVC patterns. Road attributes were:

- Total traffic volume.
- Truck traffic volume.
- Speed limit.

Traffic volume and truck traffic volume were derived from WYDOT's Annual Average Daily Traffic (AADT) estimates, which are maintained for 2,142 road segments across the state.[10] Within each of our 3.2 mi (5.15 km) road segments, total vehicle and truck traffic AADT were averaged for the years spanning 2008-2013. Speed limit data were extracted from WYDOT Traffic Program data.[51] If speed limit or traffic estimates varied within the road segment, we extracted the maximum value within that segment. In order to facilitate analysis, speed limit data were collapsed into three levels: ≤55 mph, 65 mph, and 75 mph.

Potential ecological predictors of DVC patterns fell into two groups: variables related to deer distribution and variables related to deer habitat. Much data and expert knowledge exists about deer distributions in Wyoming, and we set out to assess which of these data could be used to predict DVC patterns. Deer distribution variables we considered were:

- Winter range.
- Crucial winter range.
- Migration routes.

"Winter range" was defined as a composite of several seasonal designations identified and maintained in GIS by the WGFD: winter range (WIN), winter and year-long range (WYL), crucial winter range (CRUWIN), crucial winter and year-long range (CRUWYL), and severe winter range (SWR). These were combined for both mule deer and white-tailed deer, although white-tailed deer range made up a very small (about 1 percent) fraction of our resulting "winter range" composite shapefile. Our "crucial winter range" composite was similarly defined using WGFD's crucial winter (CRUWIN) and crucial winter and year-long (CRUWYL) range designations. Deer migration routes were obtained from WGFD's "mdr08mr" and "wtd06mr" shapefiles,[52] which are linear routes of deer movement patterns developed from expert knowledge and a limited amount of telemetry data. These linear features were buffered by 1 km (0.6 mi) on either side to accommodate for the fact that precise animal movement patterns vary from individual to individual.

Deer habitat variables we considered were:

- Land cover (cropland, sagebrush steppe, forest, wetland, and developed areas).
- Proximity to bridges.
- Anthropogenic disturbance.

Land cover type is widely known to influence deer presence and activity. Land cover classes were derived from the National Land Cover Database 2011[53] (NLCD), with cover classes collapsed into a smaller number of cover classes to facilitate analysis (table 5). Bridges indicate where water bodies intersect roads and, based on our personal observations, appear to be associated with deer road crossings. Bridge presence was determined using data from the WYDOT Planning Section[54]; since we were only interested in bridges that spanned water bodies, we only considered bridges that were within 50 m (164 ft) of a stream or river (using the Environmental Systems Research Institute (ESRI) River_ln_24k layer). Anthropogenic disturbance was derived from a cumulative "anthropogenic footprint" layer that brings together data on residential development, roads, energy development and mines, and agriculture and weights the impacts of these different forms of disturbance to create a continuous index of anthropogenic disturbance in Wyoming.[55]

Table 5. Sixteen cover classes from the National Land Cover Database were collapsed into six cover classes for the purposes of data analysis.

NLCD Cover Class	Cover Class for Analysis
Open Water	Wetland
Perennial Snow/Ice	Other
Developed, Open Space	Developed
Developed, Low Intensity	Developed
Developed, Medium Intensity	Developed
Developed, High Intensity	Developed
Barren Land	Other
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Shrub/Scrub	Sagebrush
Herbaceous	Cropland
Hay/Pasture	Cropland
Cultivated Crops	Cropland
Woody Wetlands	Wetland
Emergent Herbaceous Wetlands	Wetland

For each of our 3.2 mi (5.15 km) road segments, we created a circle 3.2 mi (5.15 km) in diameter and centered on the highway segment. Ecological predictor variables were obtained using these circles to represent the area surrounding the road segments. Road segments were assigned a binary (yes/no) value depending on whether their associated circle overlapped deer winter range, crucial range, a migration route, or a bridge. Land cover data were defined as the percent of the circle that was covered by each land cover type. Anthropogenic disturbance was defined as the average value within each circle.

Data Analysis

In order to facilitate visualization of deer-vehicle collision patterns across Wyoming, we conducted a kernel density analysis of all collisions from 2008-2013. We used the ArcGIS Kernel Density tool from the Spatial Analyst Tools Density toolbox. The cell size was set to 895.5 with a search radius of 3 mi (4.83 km). Initially we conducted separate analyses for each of the six years and each of the four seasons. Since results were generally very similar across years and seasons, we present the results for all years and all seasons together.

We then used Ripley's K function to ask whether deer-vehicle collisions across Wyoming were clustered in space and if so, at what spatial scale. Ripley's K function is a univariate point-pattern analysis that uses progressively larger, concentric circles to detect patterns of aggregation or over-dispersion in point data. We conducted this analysis only on DVC records from the reported wild-animal vehicle-crash database between 2008 and 2013 – limiting the data to points for which there was high resolution (GPS) location data. The analysis was conducted in ArcGIS using the Multi-Distance Spatial Cluster Analysis (Ripley's K Function) Python script in the Spatial Statistics Analyzing Patterns Toolbox. The "reduce analysis area" method of edge correction was employed to remove bias due to edge effects, and the distribution of circles was restricted to the road network. We examined patterns of potential clustering between 0.5 km (0.31 mi) and 100 km (62 mi) using several different distance bands (diameter difference between successively larger concentric circles) that ranged from 1 to 5 km (0.62 to 3.1 mi); because results were almost identical, we present only results for the 5 km (0.62 mi) distance band.

In order to model the effects of habitat and road variables on DVC patterns, we used a two-step hurdle model approach, using the R statistical software.[45] In the first step, we used a logistic regression to model the effects of predictor variables on a binomial response variable: no DVC versus some DVC (any non-zero value). In the second step, we used a generalized linear model (GLM) to model the effects of predictor variables on the count (number) of DVCs including only road segments that had non-zero DVC count values. The number of DVCs response variable was log-transformed to meet assumptions of normality. This two-step approach was chosen because of the very large number of road segments that had zero values, presenting challenges for analysis of count data for the whole data set. In the first step, we effectively ask: "what are the variables that predict occurrence of some level of DVCs versus no DVCs." In the second step, we effectively ask: "what are the variables that predict the magnitude of DVCs in places where DVCs occur?"

For both steps of the modeling process, the same candidate variables were considered (from the suite of possible variables described above). Total traffic, truck traffic, and developed cover were log-transformed to meet assumptions of normality. Several of the candidate variables were correlated with each other; these were not considered in the same model if the correlation coefficient exceeded 0.4. Sage steppe cover was negatively correlated with almost all other cover variables, as well as anthropogenic disturbance. It was also an uninformative variable since almost all of the state had high sage steppe cover; consequently this variable was not considered in any models. Total traffic volume and truck traffic volume were correlated with one another and were not considered in the same models. Anthropogenic disturbance was correlated with crop cover and developed area cover and was not considered in the same models as these two cover variables. Winter range and crucial winter range overlapped substantially (the latter being nested within the former), so these variables were not considered in the same model. Finally, because it was highly non-normal in distribution but apparently an important variable, crop cover was converted to a categorical variable (presence or absence of crop cover).

For both steps of the modeling process, model selection was performed using Akaike's Information Criterion (AIC) and a forward-backward approach in which variables were substituted or dropped and compared to prior models. Model fit was considered "improved" if it reduced the AIC value by ≥ 2. The candidate models and model selection process are summarized in Appendix 4.

RESULTS

Deer-vehicle collisions were clustered in space at all scales between 0.5 km (0.31 mi) and 100 km (62 mi). However, clustering peaked at 20-25 km (12.4-155 mi) and was generally highest between 10 km (6.2 mi) and 40 km (24.8 mi) (figure 16). This can also be seen in the kernel density map of DVCs across Wyoming (figure 17).

The 1,518 road segments that we analyzed in terms of their relationship to habitat and road variables included a total of 22,333 collisions over six years. Total DVC per 3.2 mi (5.15 km) ranged from 0 to 235 – or 0 to 12.2 DVC per mile per year. The vast majority of road segments had 0 (n=234) or between 1 and 5 (n=490) DVC over six years. Ninety-six road segments had more than 50 DVC over six years.

Our analyses of the variables associated with where DVC occur and how many DVC occur yielded results that were broadly similar. In terms of where DVC occur, total traffic volume, followed by the presence of cropland, explained the greatest amount of variation (table 6). Both variables also had large effect sizes – that is, the effect of an increase in traffic volume or the presence of cropland was large in terms of the likelihood of DVC occurrence. Other variables with large effect sizes were whether or not a migration route intersects the road, presence of a bridge, and whether the area falls within winter range or not. The latter two, however, did not explain as much of the variation in DVC occurrence as several of the other variables.

Holding all other variables constant, a 2.7-fold (near tripling) of traffic volume corresponded to a doubling (106 percent increase) in the odds of DVC occurrence. Road segments that intersected migration routes had an odds of DVC occurrence of 3.8; put another way, that means that if a migration route intersects a road segment, there is about a 75-80 percent chance that DVC will occur (compared to no migration route and all else being the same). Where cropland is present in a road segment, odds are 2.59 (about 70-75 percent chance) of DVC occurrence.

Table 6: Parameter estimates, standard error of the mean (SEM), z values, and significance levels for the selected best binomial (DVC presence vs. absence) model.

	Estimate	SEM	z value	*p* value
Intercept	-4.38	0.56	-7.85	<0.0001
Within winter range	0.63	0.16	3.86	0.0001
Intersecting migration route	1.34	0.36	3.69	0.0002
Total traffic volume	0.72	0.08	9.09	<0.0001
Cropland present	0.95	0.17	5.45	<0.0001
Wetland cover	0.04	0.02	2.17	0.03
Developed land cover	-0.03	0.01	-3.49	0.0005
Bridge present	0.81	0.22	3.71	0.0002

Total traffic volume also explained by far the greatest amount of variation in the number of DVC that occurred (table 7; figure 17). Other important predictors of the number of DVC included whether the road segment fell within crucial winter range or not, whether cropland was present or not, speed limit, and whether a migration route intersected the road segment (figure 17). If a road segment fell within crucial winter range, along a migration route, or in an area with cropland present, the number of DVC was about 50 percent higher (figure 18: mean number of DVC by habitat and speed limit). Speed limit had a striking effect on number of DVC, with almost twice as many DVC in 75 mph zones compared to 55 mph or less zones (figure 19: mean number of DVC by habitat and speed limit). According to model results, a 100 percent (doubling) of traffic volume was associated with a 35 percent increase in the number of DVC (assuming all other variables are held constant).

Table 7: Parameter estimates, standard error of the mean (SEM), z values, and significance levels for the selected best count (number of DVC) model.

	Estimate	SEM	z value	*p* value
Intercept	-1.47	0.22	-6.74	<0.0001
Within crucial winter range	0.46	0.06	7.91	<0.0001
Intersecting migration route	0.34	0.08	4.38	<0.0001
Speed limit = 65 mph (compared to ≤55 mph)	0.49	0.09	5.29	<0.0001
Speed limit = 75 mph (compared to ≤55 mph)	0.72	0.11	6.43	<0.0001
Total traffic volume	0.36	0.03	14.26	<0.0001
Cropland present	0.38	0.06	6.79	<0.0001
Forest cover	0.007	0.002	4.10	<0.0001
Wetland cover	0.03	0.004	7.19	<0.0001
Bridge present	0.12	0.05	2.21	0.023

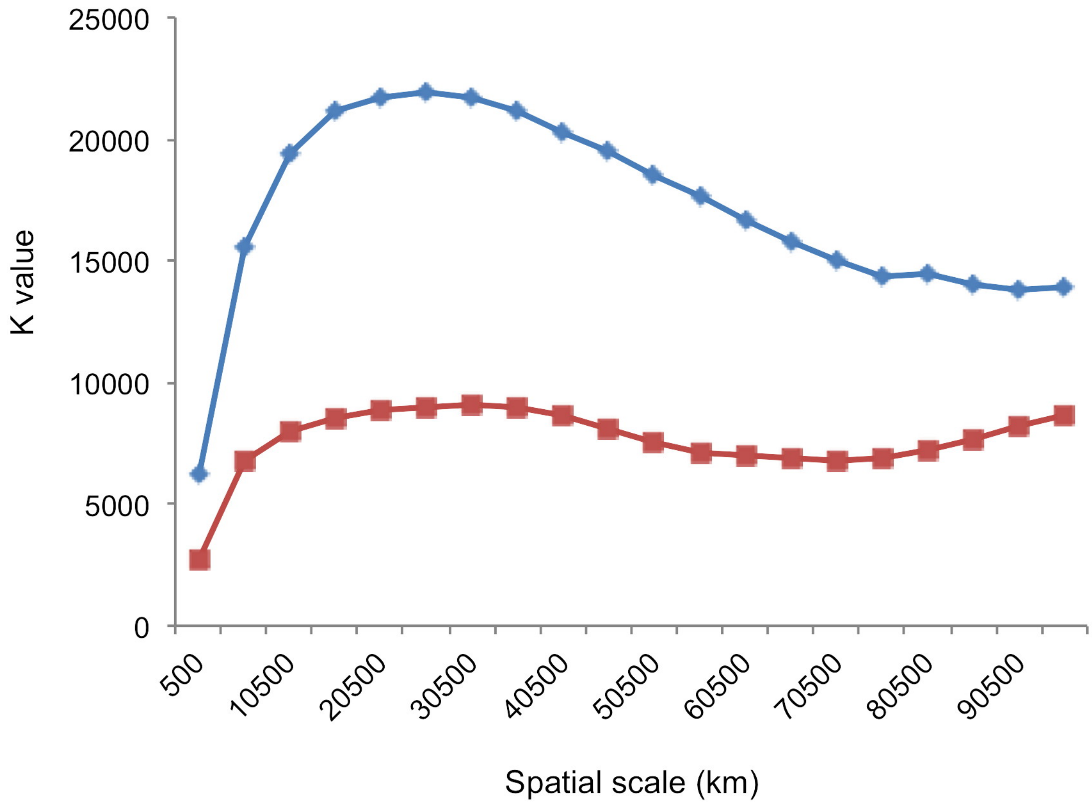


Figure 16. Ripleys-K Function curve with peak clustering between 20 – 25 km (12.4-155 mi) for statewide crash data 2008 - 2013 (blue) compared to the average maximum value over 99 iterations of randomized points (red).

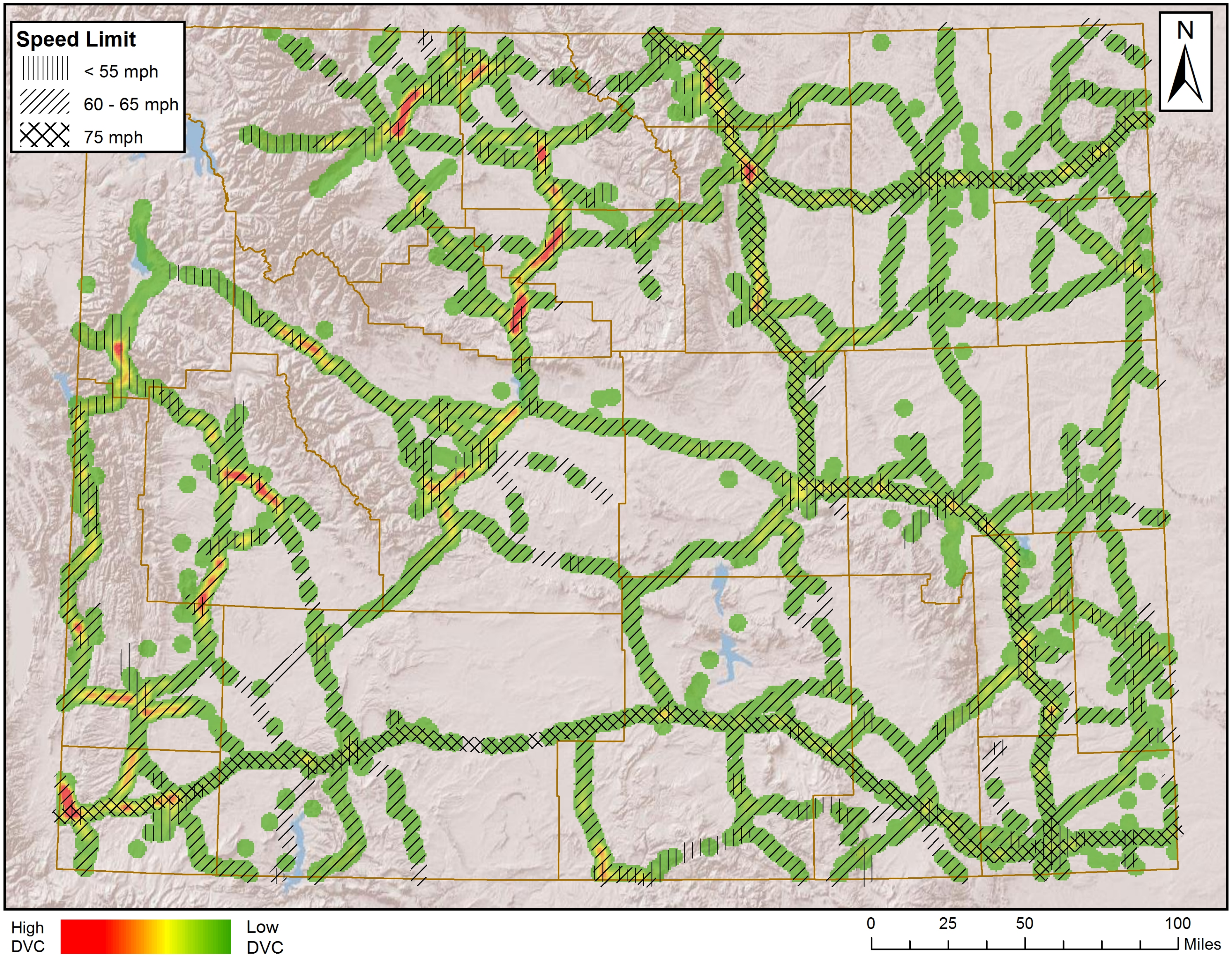


Figure 17a. Deer-vehicle collision distribution statewide overlain with WYDOT speed limits.

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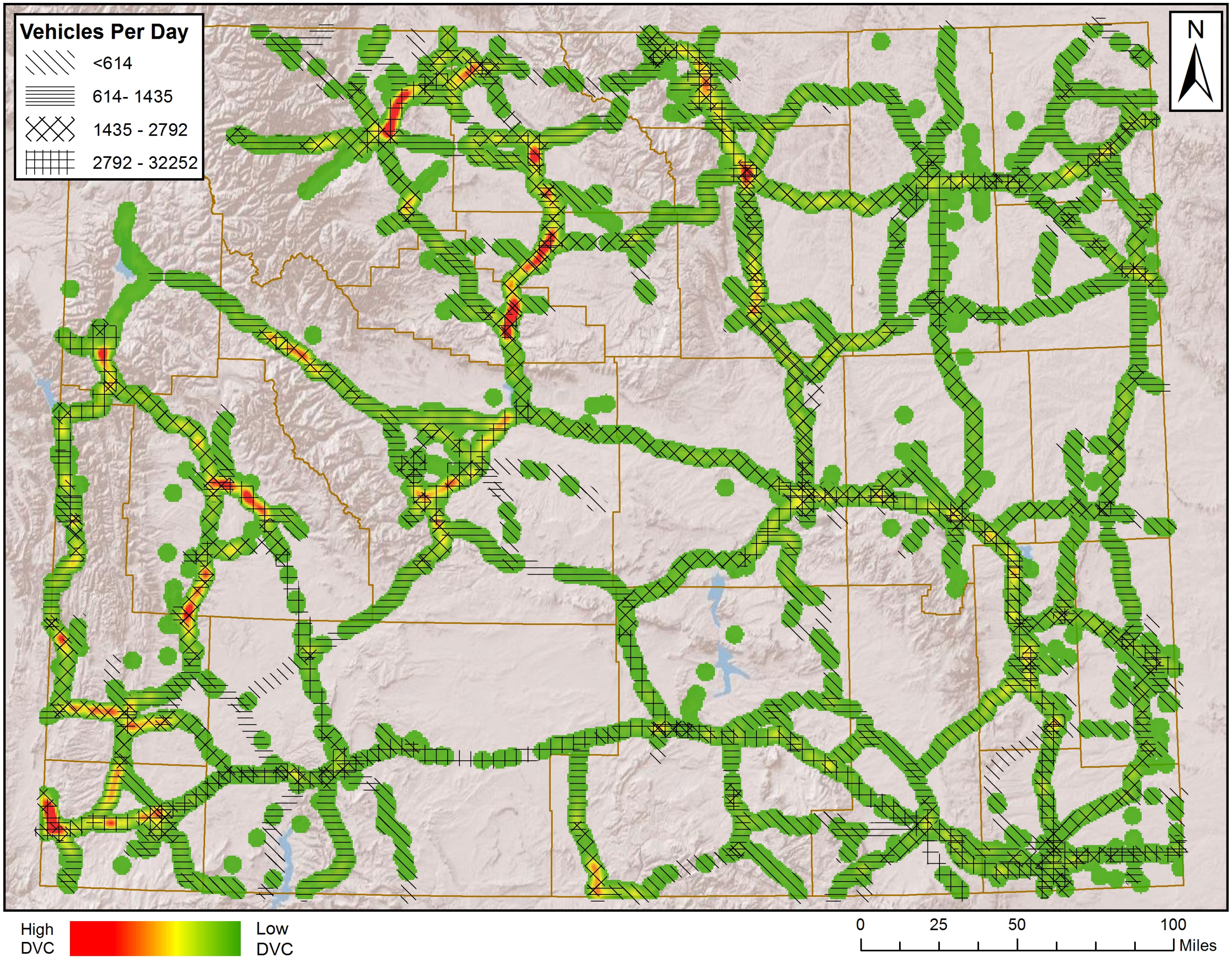

Figure 17b. Deer-vehicle collision distribution statewide overlain with WYDOT average daily traffic counts. Traffic count classes are given as quartiles on log-transformed data (e.g. less than 614 denotes the lower 25th percentile of traffic counts).

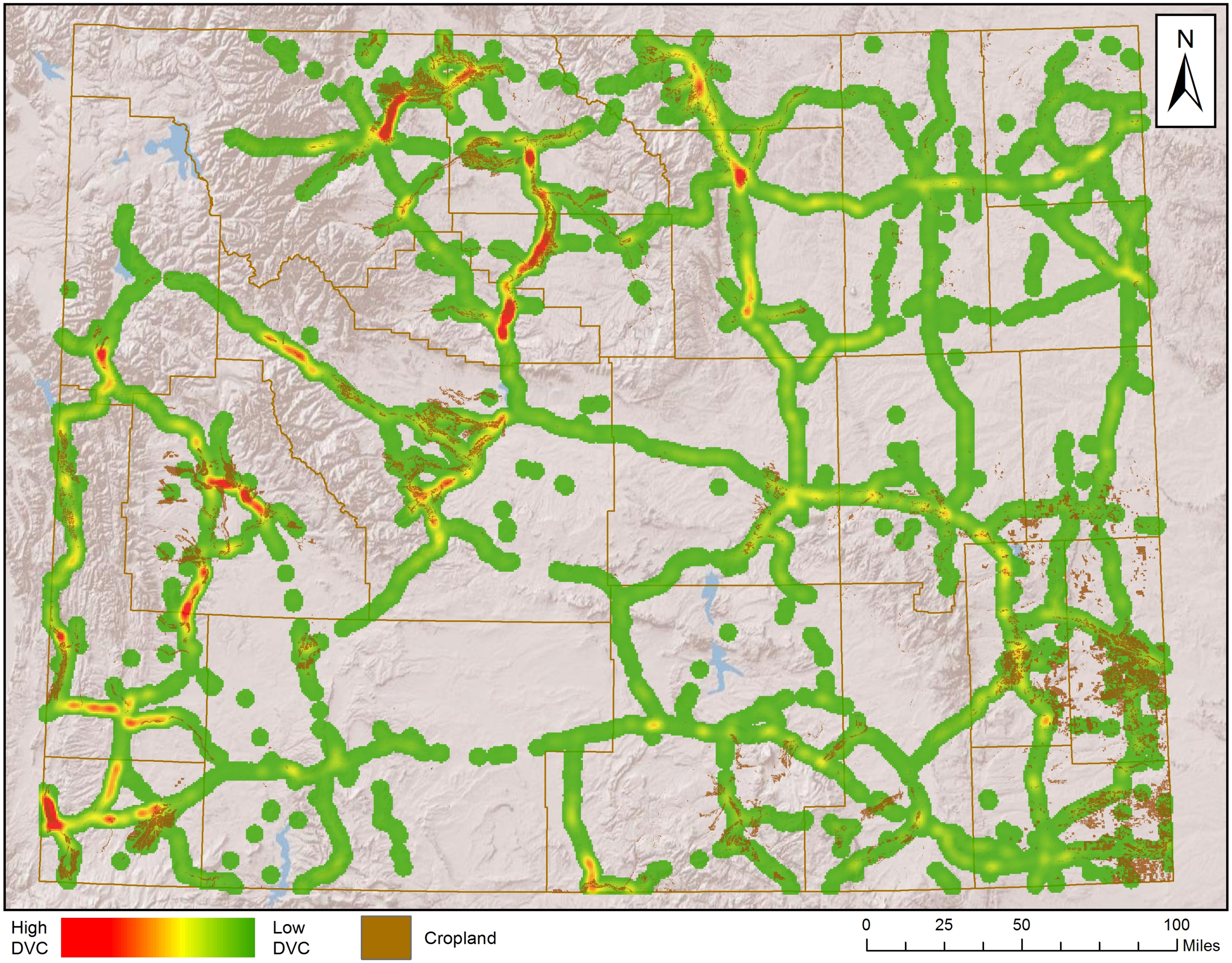

Figure 17c. Deer-vehicle collision distribution statewide overlain with cropland (from the National Land Cover Database).

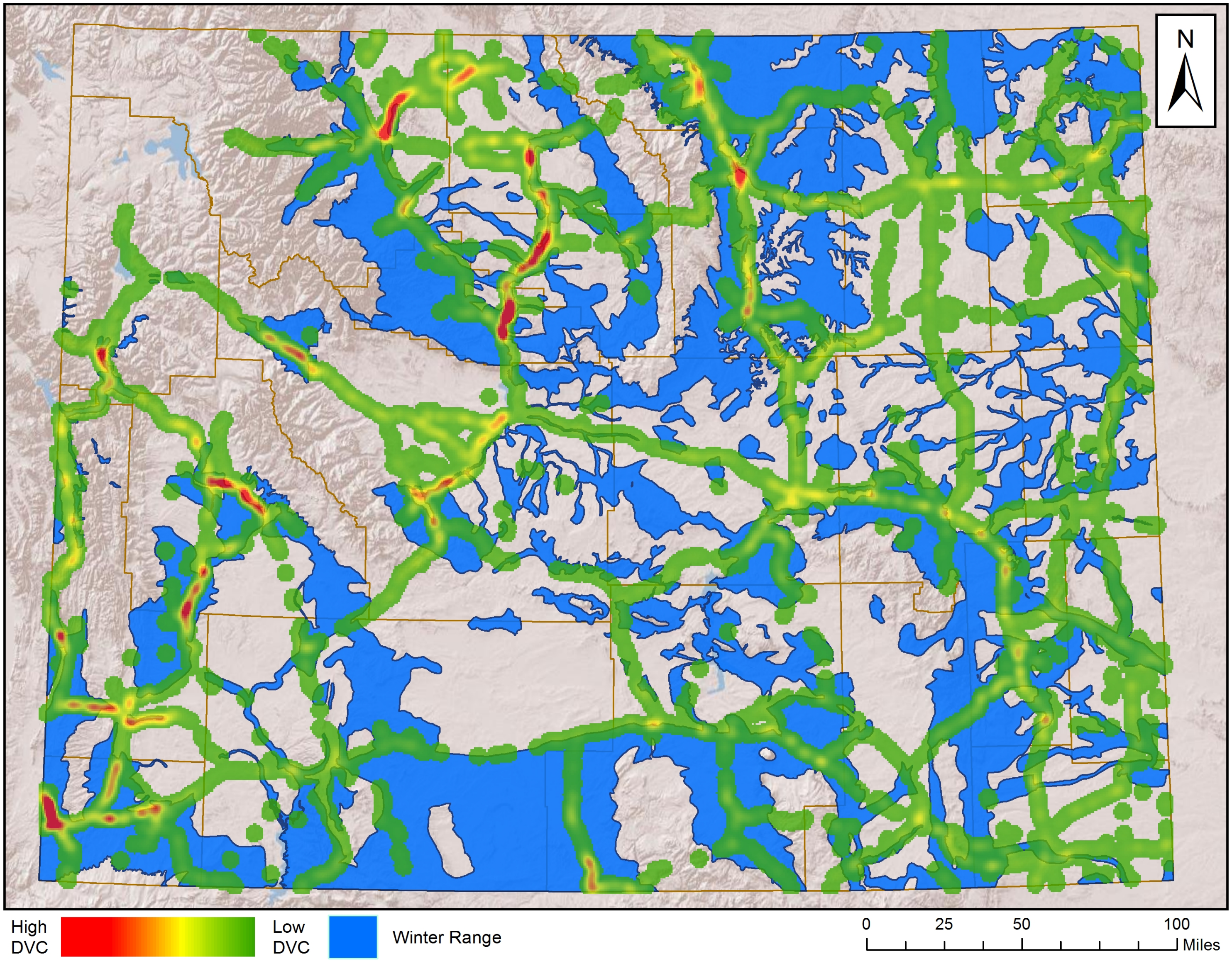

Figure 17d. Deer-vehicle collision distribution statewide overlain with WGFD mule deer and white-tailed deer winter range.

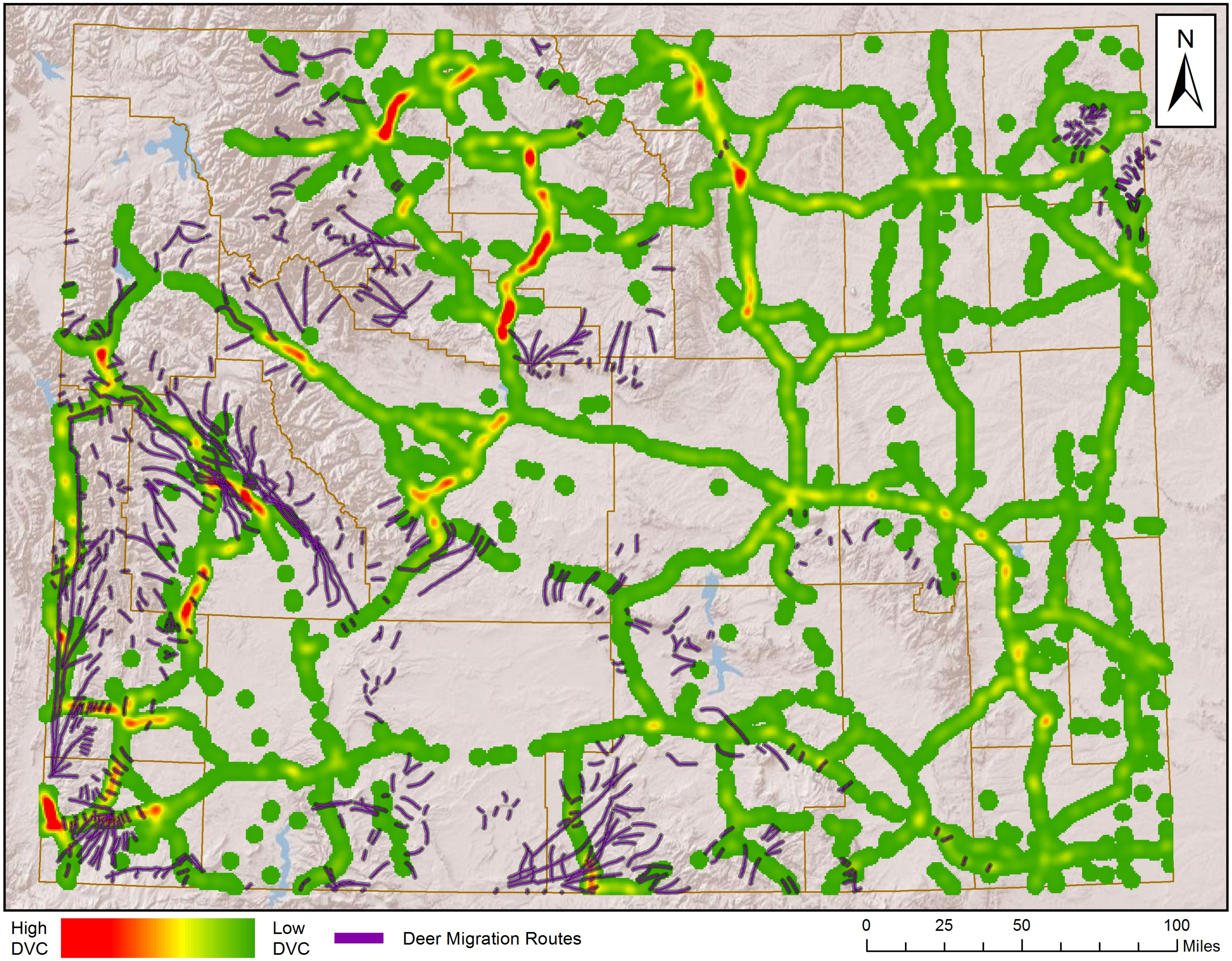

Figure 17e. Deer-vehicle collision distribution statewide overlain with WGFD mule deer and white-tailed deer migration routes.

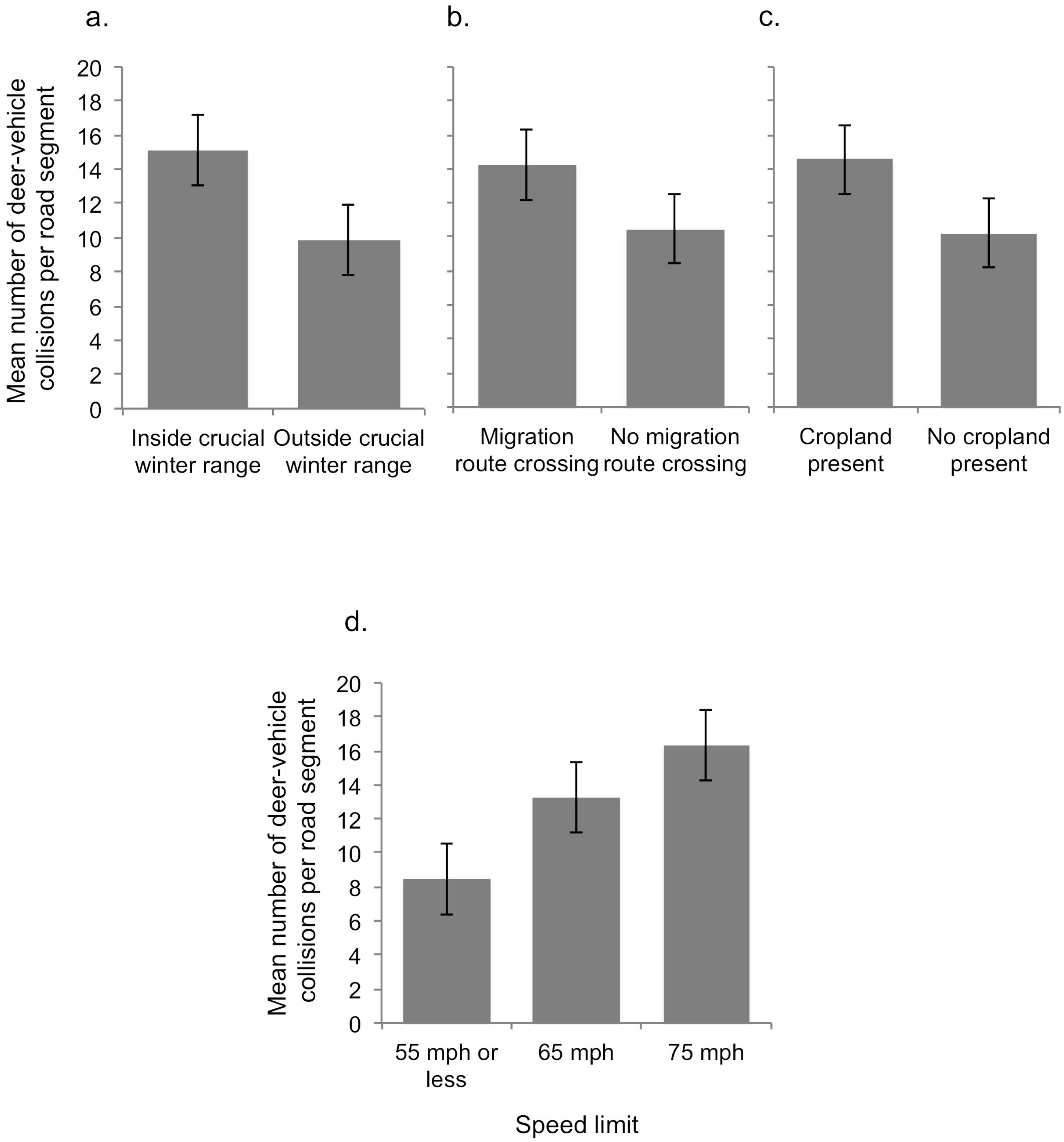

Figure 18. Mean (±SEM) number of deer-vehicle collisions as a function of whether the road segment was located (a) within crucial deer winter range or not; (b) intersecting a deer migration route or not; (c) adjacent to cropland or not; and (d) in a stretch of road with speed limit less than 55 mph, 65 mph, or 75 mph.

DISCUSSION

Deer-vehicle collisions in Wyoming are not randomly located; collisions are clustered in space on a scale of tens of miles / kilometers (figure 17), and these clusters are associated with specific road and habitat features.

We found that DVC clustering peaked at 20-25 km (12.4-15.5 mi) and was generally highest between 10 km (6.2 mi) and 40 km (24.8 mi). For moose, similar clustering patterns have been found at scales of 2-10 km[56] (1.2-6.2 mi) and 22-54 km[38] (13.7-33.5 mi). These clustering patterns likely reflect areas of contiguous, similar habitat or land cover and road conditions (e.g. traffic volume, speed limit). Some of the clustered areas in Wyoming with high levels of DVC between 2008 and 2013 are:

- Evanston area: I80 [ML80B: especially MP 2 – 7], US 150 [ML2100B: especially MP 0 – 8], and WY89 [ML50B: especially MP 0 – 10].
- US30 north of Cokeville [ML12B: especially MP 6 – 7].
- US189 north of LaBarge [ML11B: especially MP 85 – 89].
- Pinedale area: US191 between Daniel Junction and Pinedale [ML13B: especially MP 104 – 108], WY352 north of Trapper's Point [ML352B: especially MP 0 – 2], and US191 south of Pinedale [ML13B: especially MP 94 – 98].
- Jackson area: US26/89/189/191 south of and through Jackson [ML10B: especially MP151 – 154].
- Thermopolis area: US20 through Thermopolis [ML34B: especially 128 – 142].
- Worland area: US20 through Worland [ML34B: especially 158 – 169].
- Greybull area: US20 between Basin and Greybull [ML34B: especially MP 198 – 202].
- Cody area: US Alt14 between Cody and Powell [ML29B: especially MP 2 – 17].
- Buffalo area: I25 through Buffalo [ML25I: especially MP 296 – 300].

Although the area between Daniel Junction and Pinedale had high DVC rates over these years, we expect this to decrease significantly in future years, since an extensive mitigation project was completed in 2012. This project involves two highway overpasses, six underpasses, and 31 miles of fencing. Although its effectiveness in reducing mule deer and pronghorn collisions is still being evaluated, preliminary results suggest that this mitigation will be highly successful.[57] A similar set of underpasses and fencing was completed along US 30 west of Kemmerer (Nugget Canyon Area) in 2008 and reduced DVC rates by 81 percent within the first several years.[19]

Both the occurrence and number of DVC were most strongly related to total traffic volume. The effect of traffic volume was logarithmic. This means that the same absolute increase in traffic volume is associated with a much bigger effect at lower traffic volumes than at high traffic volumes. In general terms, a doubling in traffic volume was associated with a 35 percent increase in DVC. Traffic volume in the study area ranged from a six-year mean average annual daily traffic volume of 37 to 31,673 vehicles per day. Deer-vehicle collisions occurred over the full range of traffic volumes but were generally much less likely to occur in places with low traffic volume. At the high end of the traffic volume spectrum, there was no indication of DVC rates dropping off. In some studies, very high traffic volume has been associated with fewer WVC because traffic volumes are so high that animals do not even attempt to cross the road.[36] However, whether or not a road creates a total movement barrier probably depends on additional factors such as speed limit, number of lanes, and whether there are guard rails, fences, or other barriers along the road or between divided sections of highway. In the network of roads considered here, many of the areas of highest traffic volume were associated with towns and more developed areas and did not necessarily have high speed limits or number of lanes.

Other important variables associated with both the occurrence and number of DVC were the presence of cropland, whether a migration route crossed the road, and whether the road segment fell within deer winter range or crucial winter range (the former being a slightly better fit for DVC occurrence and the latter a slightly better fit for number of DVC). The presence of cropland, a migration route, or crucial winter range were all (each, separately) associated with 50 percent more DVCs than in the absence of these variables. Speed limit was also an important variable associated with number of DVC; areas with a 75 mph speed limit had nearly twice as many DVC as areas with a speed limit of 55 mph or less.

These results include elements that are both similar to and different from findings of similar studies that have been carried out elsewhere. In terms of road conditions, our findings are generally very similar to others. In a review of studies of WVC patterns, Gunson[35] found that increased traffic volume was a strong predictor of WVC rates for many species, including several species of ungulates; this has also been found elsewhere,[38,58] though at least one study found no effect of traffic volume on DVC rates.[59] Gunson's review and several other studies[35,38,58,59] (with one contrary finding[60]) have also shown that increased speed limit is associated with increased ungulate WVC rates.

In terms of the effects of habitat variables on DVC patterns, there appears to be less agreement across studies. Among the studies reviewed by Gunson,[36] most found that ungulate WVC rates were lower in developed (urban) areas and near agricultural land, and higher near forested and open habitat. This is contrary to our findings that DVC rates are highest near cropland and only weakly associated with forest cover. Preference for forested versus open cover is highly species-dependent, and Gunson's review was mostly based on studies of moose and white-tailed deer, which prefer forested habitat. In contrast, mule deer are generally found in open habitat (e.g. sagebrush steppe habitat) in winter, when the majority of DVC in Wyoming occur.

The effects of cropland or agriculture appear to be somewhat context-dependent. Contrary to the studies summarized in Gunson's review, several other studies on white-tailed deer found higher collision rates near agricultural land.[58,61] Whether agricultural land serves as an attractant or deterrent to deer may depend on the types of crops and extent of agriculture involved. Croplands in Wyoming are limited to areas close to water and are often interspersed with more typical mule deer winter habitat (e.g. sagebrush steppe), which may allow deer greater access to this land than in other places where agriculture has displaced ungulate habitat over large areas. Further, in Wyoming, fallow fields in winter offer higher-quality forage than native vegetation and are highly attractive to deer – as they appear to be for white-tailed deer in some other areas.

Development also appears to have a variety of effects on WVC rates, depending on the extent and type of development. While large urban areas are likely a deterrent to ungulates (leading to fewer WVCs in those areas), smaller, low-density developed areas – such as are found in Wyoming – may actually attract deer and other ungulates (for example, to eat high quality forage in lawns and gardens). In rural Sweden, there was a positive effect of development on moose-vehicle collisions,[62] similar to our results. Further, in our analysis, developed cover was correlated with traffic volume, making it difficult to assess whether development itself or traffic volume associated with development is the cause of higher DVC rates in developed areas. Given the strength of the effect of traffic volume in relation to DVC rates, it seems likely that traffic volume, rather than development itself, is the cause of high DVC rates in more developed areas.

Although the specific habitat variables associated with high WVC rates may vary from geographic location to location, a general finding across this and other studies like it is that high quality habitat (whether natural or anthropogenically modified) is a strong predictor of where high WVC rates occur. High quality habitat in combination with high traffic volumes and/or speed limits appears to be the combination of elements that leads to the very highest WVC rates.

With these analyses, we took a very coarse-grain, broad-scale look at the patterns and correlates of deer-vehicle collisions across a large geographic area. There are many finer-scale factors that have been found to be strongly associated with high ungulate WVC rates in other studies.[35] These include factors such as road curvature and visibility, roadside fencing, roadside vegetation (e.g. plants that are highly palatable and attractive to ungulates[63-65]), and roadside micro-topography (e.g. ditches or steep embankments). We did not consider these variables because it was impossible to do so at a state-wide scale and because our objective was to identify general patterns. In order to fully understand the causes of high DVC rates in a specific area, it would be valuable to consider both the coarse- and fine-grain variables that are operating in that area.

Understanding the variables that are associated with high DVC rates provides valuable insights into why DVC rates might be high in a particular area and what might be done to manage or mitigate them. Many of the most prominent hotspots of DVC – for example, the areas just north and south of Thermopolis and the area northeast of Cody – appear to be a near "perfect storm" of factors that create high DVC rates: deer winter range with high crop cover, access to water, near a developed area with moderately high traffic volume, and high speed limit (figure 17).

Although land cover is difficult or impossible to manage, speed limits can be managed. Keeping speed limits low (especially at night) may be a particularly important in areas that have high traffic volume, abundant cropland, or where deer seasonal or daily movement routes cross major roadways. Traffic volume is more challenging to manage, but understanding its role is important for long-term planning. If traffic volume is expected to increase substantially, this information can be used to predict the expected magnitude of increase in DVC rates and plan for or justify mitigation measures (for example, future crossing structures). Understanding the scale at which DVCs are clustered is also valuable because any mitigation will have to be applied at the scale of the cluster; if a mitigation is applied at too fine a spatial scale (e.g. one underpass with only a short length of fencing in either direction), it will likely just shift the center of collisions to another, nearby area.

Based on these results, several suggested future analyses of DVC patterns in Wyoming include:

- More thorough examination of the effects of year and season to determine the extent to which our findings are robust to differences across years and seasons. (A preliminary examination suggests that year-to-year variation is minimal).
- Incorporation of additional habitat variables, including topography and plant (forage) production.
- Testing the ability of the models presented here to predict DVC rates – for example, by leaving certain geographic areas left out of the model and testing the model's ability to predict rates for that area, or by back-casting based on past traffic volume data and comparing results to real DVC data from that time period.
- Examination of the roles of both coarse and fine-scale variables for particular smaller geographic areas for which developing mitigation strategies is a high priority.

These are analyses that we are currently exploring along with our partners at WYDOT and the Wyoming Migration Initiative.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Efficacy of Wildlife Warning Reflectors

We found that, over seven and a half months, there were 32 percent fewer carcasses in the same road segments when Streiter-Lite wildlife warning reflectors were exposed than when reflectors were covered with black bags. However, we also found that, over 12 months, there were 33 percent fewer carcasses when reflectors were covered with white bags than when reflectors were exposed. This suggests that reflectors are reducing deer-vehicle collision rates but that white bags on posts (or something similar in appearance) may be even more effective at reducing deer-vehicle collisions.

A detailed examination of deer road-crossing behavior provides further evidence that reflectors are more effective at reducing deer-vehicle collisions than nothing, but that white bags are more effective than reflectors. We observed more than 800 deer attempt to cross the road at multiple sites. A vehicle was present for about a third of these attempts. In general, deer were most likely to stop and look before crossing the road where reflectors were covered with white bags, intermediate where reflector were exposed, and least likely to stop and look where reflectors were covered with black bags or removed from their posts. Deer were also least likely to run into the road where reflectors were covered with white bags and most likely to do this where reflectors were covered with black bags or removed. Conversely, deer were most likely to run away from the road where reflectors were covered with white bags and least likely to do so where reflectors were covered with black bags or removed. Taken together, these results indicate that white bags, and to a lesser extent, reflectors, caused deer to exhibit "safer" road-crossing behavior than they otherwise would. These behavioral findings provide a clear mechanistic explanation for the observed effects of these same experimental treatments on carcass and collision rates.

These results indicate that the reflectors installed over 19 mi (30.6 km) of highway in District 5 of Wyoming may be having some effect in terms of reducing deer-vehicle collision rates. However, DVC rates remain relatively high – about 10 animals per mile per year in the Thermopolis area and 6-8 per mile per year in the Basin area. These are among the highest DVC rates in the state and continue to present a challenge for highway safety. Roadside game-proof fencing and highway under- or over-passes, although highly effective at mitigating DVCs, are logistically challenging in areas like these where there are many different land owners and many driveways or minor roads that would break the continuity of a game fence. Thus there is a significant need to identify new technologies that reduce DVC but do not rely on extensive, continuous game fencing.

Here we unexpectedly found that simple, low-technology white canvas bags were significantly more effective than reflectors in reducing unsafe deer road-crossing behavior and collisions with vehicles. This suggests that there may be a new technology for reducing DVCs that is both cheaper and more effective than reflectors. While putting white canvas bags on poles along the highway might not be aesthetically appealing or durable, there may be similar-looking, more permanent, vigilance-increasing devices that are similarly or more effective. In general, vigilance-increasing mitigation measures have been under-studied. Our findings suggest that there may be scope for new, improved vigilance-based DVC mitigation methods.

State-wide Patterns of Deer-Vehicle Collisions

Around Wyoming, areas with high deer-vehicle collision rates were consistently associated with several road and habitat variables. Traffic volume explained the greatest amount of variation in DVC – with every doubling of traffic volume associated with a 35 percent increase in DVC. Speed limit also has a very strong effect on DVC, with almost twice as many DVC in 75 mph zones compared to 55 mph or less zones. Areas of highway that intersect deer winter range, deer migration routes, or cropland generally have twice as many DVCs compared to areas of highway that lack these features.

Understanding the role of factors like traffic volume may be valuable for predicting future increases in DVC. Understanding the importance of speed limit also suggests that keeping speed limits low in high DVC areas – particularly at dusk and dawn, when most collisions occur – is an important mitigation strategy.

These findings further illuminate why places such as US 20 north and south of Thermopolis – the focus of the reflector portion of this study – are major hotspots of DVC. In the Thermopolis area, for example, multiple predictors of high DVC rates converge: deer winter range intersects habitat with high crop cover (where crop residues provide high quality food for deer) in a place with moderately high traffic volume (lower than in the town but higher than in more rural areas) and a relatively high speed limit (65 mph). Similar associations of multiple DVC-predicting variables occur around Wyoming. Thus our findings and recommendations from the Thermopolis area are likely to apply to many other high DVC areas in the state.

RECOMMENDATIONS

Based on these findings, we recommend that:

- Streiter-Lite wildlife warning reflectors, while somewhat effective at reducing deer-vehicle collisions, are costly relative to their effectiveness. These reflectors cost approximately $23.50 per reflector. The other costs of installation (posts, labor) amount to approximately $80-$130. In total, wildlife warning reflectors cost about $8,000-10,000 per mile to install.
- The benefits of reflectors do appear to outweigh the costs of initial materials and installation. If reflectors are reducing collisions by 33 percent, that means 2-4 fewer DVC per mile per year in the Basin and Thermopolis areas. The restitution value of one deer alone is $4,000, so 2-4 fewer dead deer per mile would equal or exceed the cost of installing the reflectors in just one year. About 1/5th of all collisions are reported, and reported collisions are estimated to incur costs of $11,600 in damage and injury. In order

to offset these costs, reflectors would need to lead to 5-10 fewer DVC per mile over the lifetime of the reflectors. It appears that this is benefit is being met. However, there are additional maintenance costs associated with the reflectors, such as replacing broken ones and the extra maintenance staff time needed to mow around the reflector posts. The net costs after considering these additional costs may outweigh the reflectors' benefits.

- There may be other, less expensive and more effective deer vigilance-enhancing technologies. The simple white canvas sample bags used in this study, for example, cost only about $1.50 per bag, an order of magnitude less than the reflectors (not including the costs of posts and labor, and maintenance costs, which would be similar). Although we recognize that white canvas bags is not a permanent mitigation solution, we highlight this price difference to illustrate that a much cheaper technology may exist that is more effective than the reflectors.
- Such vigilance-enhancing technologies are unlikely to ever be as effective as fencing coupled with highway under- and over-passes, which are 80-90 percent effective. However, even if vigilance-enhancing technologies can reduce DVC by 30-50 percent, this would make them substantially more effective than any other currently-available low- to moderate-cost or fence-less mitigation technology.
- Around Wyoming, the highest rates of deer-vehicle collision are typically found under conditions similar to the Thermopolis and Basin areas in this study: around moderately developed areas and agricultural land outside of major towns. Since it may not be possible to install game fencing in many such areas, it is important to consider and continue testing and developing fence-less DVC mitigation technologies for these areas.
- Deer-vehicle collisions are also strongly associated with moderate to high traffic volumes and high speed limits (65 mph and higher). As traffic volumes continue to rise, DVCs are likely to increase as well. Limiting vehicle speeds, especially at night, may be another way to reduce DVCs. On average, areas with a speed limit of 55 mph have 36 percent fewer DVC than areas with a speed limit of 65 mph. This is comparable to the reductions in DVCs we observed in the reflector treatment areas in Thermopolis. Reducing speed limits to 55 mph at night, dawn, and dusk may be an effective and much less expensive way to reduce collisions.
- Reducing DVCs in District 5 and around Wyoming will likely require a suite of different strategies, some of which may be more or less suitable in different areas. These might include fencing, under- and over-passes, animal detection systems, deer vigilance-enhancing technologies, managing vehicle speed, managing road-side vegetation, and managing driver visibility and awareness. Other less conventional mitigation strategies (see appendix 6) might also be considered. In some cases, more than one of these strategies could be combined to achieve greater effectiveness in reducing deer-vehicle collisions.

APPENDIX 1: OUTREACH ACTIVITIES

Year 1:

- Cody Beers of WYDOT drafted a press release informing the public about deer delineators and outlining our research goals and anticipated activities.
    - Published online by County10 News Desk and The Wildlife Society News.
    - Reported by K2TV (the ABC affiliate of Riverton) and Wyoming Public Media.
- Cody Beers of WYDOT drafted a second press release detailing the cover/uncover study design being implemented in the Thermopolis delineator sections in the off-season. The following reported on the story:
    - The Republic, Columbus, Indiana (February 27th, 2013).
    - Thermopolis Independent Record (March 7th, 2013).
    - L.A. Times, http://articles.latimes.com/2013/mar/11/nation/la-na-nn-wyoming-tries-hightech-to-prevent-deer-crashes-20130311 (March 11th, 2013).
    - Planet Jackson Hole, http://planetjh.com/2013/03/12/them-on-us-riding-for-the-brand/ (March 12th, 2013).
- We discussed study design and potential with Captain Len DeClerq.
- County dispatch was notified of our research activities and was informed each time we performed roadside deer behavior observations.
- We spoke with private citizens regarding our activities whenever behavioral observations were performed along roadways in front of their properties (met with approximately 10 citizens).

Year 2:

- Held seasonal kickoff meeting in Worland, WY on October 4th, 2013.
- Cody Beers of WYDOT issued press releases regarding deer delineators, outlining research goals and anticipated activities within the study area.
    - http://www.whp.dot.state.wy.us/news/study-determining-effects-of-wildlife-warning-reflectors-on-wildlife-v
    - http://www.dailyranger.com/story.php?story_id=9956&headline=Wildlife-warning-reflectors-study-moves-to-Fremont-County
- Presented to 30 Hot Springs County High School Environmental Science juniors and seniors on October 25, 2013.
- Authored outreach flyer describing deer delineators and explained why they are periodically covered with canvas bags. Printed flyer for distribution in mailboxes along the length of the delineator stretches in Thermopolis, Basin/Greybull and Kinnear. Posted the flyer on local billboards (such as the Hot Springs County Library).
- County dispatch was notified of our research activities and is informed each time we perform roadside deer behavior observations.
- Met with Lt. Adams of Fremont County Sheriff's Department to discuss project status in Kinnear, and to obtain access to the Fremont County WVC database.
- Continued speaking with private citizens regarding our activities whenever behavioral observations are performed along roadways in front of their properties or whenever somebody stops to inquire about the project.

Year 3:

- Presented overview of project to 20+ Teton Science Schools (TSS) Americorps Volunteers during orientation weeks.
- Working with Teton Research Institute's Kelli Petrick to create curriculum material that can be used across Teton Science Schools' seven program areas, with activities tailored to the needs and teaching style of each program area (e.g. Field Education, Journey's School). Teton Science Schools (TSS) programming reaches over 12,000 participants per year.
- Developing a flyer and presentation highlighting project findings for use by District Engineer Shelby Carlson. The flyer will be distributed to attendees at the annual State Transportation Improvement Plan meetings.
- Field technicians attended a public meeting hosted by WGFD to listen to public input regarding management of the Owl Creek/Meeteetse mule deer herd.
- Continued to engage private citizens regarding our activities whenever behavioral observations were performed along roadways adjacent to their properties. Fielded inquiries from interested public stopping along the roadside to check on status of project.
- Presented project summary to an audience of ~50 during the Jackson Hole Wildlife Symposium: Large Mammals and Their Interactions with Anthropogenic Disturbances session.
- Participated in conference call hosted by the WYDOT funded Wyoming Migration Initiative at University of Wyoming. Shared impressions on the pros and cons of researchers sharing data with Wyoming Migration Initiative prior to completion of multi-year projects.
- Created interactive activity to engage attendees of the Mix'd Media event at the National Museum of Wildlife Art. Mix'd Media events are designed to entice a younger generation of museum patrons wishing to have a social experience while viewing art.
- Identified two Americorps volunteers to assist TSS Research and Stewardship Coordinator Kelli Petrick with development of educational materials. To date, they have created a two hour program for Wyoming Field Education high school participants.
- Project findings have been integrated into an Introduction to the Greater Yellowstone Ecosystem evening program. This will reach 90 percent of TSS participants, which number greater than 12,000 annually.
- Presented project study design and preliminary results to TSS Field Education Graduate Program Faculty for incorporation into staff training/professional development.
- Curriculum materials will be available for TSS programs: Journey's School, Teton Valley Community School, Teacher Learning Center, Wildlife Expeditions, and Field Education to be used as appropriate.
- Using project as an example to discuss Next Generation Science Standards with TSS Program participants.
- Incorporating project results into TSS Defensive Driver training. Our internal goal is to better inform and influence driver behavior to reduce Wildlife Vehicle Collisions and near misses.

APPENDIX 2: MODEL SELECTION FOR DEER BEHAVIOR ANALYSIS (EXPERIMENT I)

Below are the alternative models considered and ΔAIC for each model for individual deer road-crossing behaviors and overall risk index in the reflector-exposed vs. white bag experiment. Best models are indicated in bold.

Deer Stopped Before Crossing

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	10.43
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle + Weather + Temperature	11.81
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle + Weather + Temperature	12.56
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather + Temperature	5.94
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Weather + Temperature	5.91
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Temperature	9.11
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather	10.12
Treatment + Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	9.84
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Weather + Temperature	16.11
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Weather + Temperature	9.96
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather + Temperature	1.25
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Temperature	4.47
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Weather	5.53
Treatment + Vehicle + Moon + Site + Time + Weather + Temperature	5.3
Treatment + Vehicle + Treatment x Vehicle + Site + Weather + Temperature	10.76
Treatment + Vehicle + Treatment x Vehicle + Moon + Weather + Temperature	5.63
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Temperature	0.54
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather	0.85
Treatment + Vehicle + Moon + Site + Weather + Temperature	0.74
Treatment + Vehicle + Treatment x Vehicle + Site + Temperature	9.83
Treatment + Vehicle + Treatment x Vehicle + Moon + Temperature	3.63
Treatment + Vehicle + Treatment x Vehicle + Moon + Site	0.91
Treatment + Vehicle + Moon + Site + Temperature	**0**
Vehicle + Moon + Site + Temperature	29.94
Treatment + Moon + Site + Temperature	1.52
Treatment + Vehicle + Site + Temperature	8.41
Treatment + Vehicle + Moon + Temperature	2.56
Treatment + Vehicle + Moon + Site	0.21

Deer Looked Before Crossing

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	13.49
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle + Weather + Temperature	14.13
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle + Weather + Temperature	14.94
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather + Temperature	7.9
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Weather + Temperature	8.61
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Temperature	11.41
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather	12.05
Treatment + Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	12.98
Treatment + Vehicle + Treatment x Vehicle + Site + Cycle + Weather + Temperature	8.22
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle + Weather + Temperature	9.47
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather + Temperature	3.18
Treatment + Vehicle + Treatment x Vehicle + Moon + Site+ Cycle + Temperature	6.58
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather	6.51
Treatment + Vehicle + Moon + Site + Cycle + Weather + Temperature	7.4
Treatment + Vehicle + Treatment x Vehicle + Site + Weather + Temperature	16.71
Treatment + Vehicle + Treatment x Vehicle + Moon + Weather + Temperature	7.66
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Temperature	1.48
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather	2.23
Treatment + Vehicle + Moon + Site + Weather + Temperature	3.04
Treatment + Vehicle + Treatment x Vehicle + Site + Temperature	14.62
Treatment + Vehicle + Treatment x Vehicle + Moon+ Temperature	4.72
Treatment + Vehicle + Treatment x Vehicle + Moon + Site	0.79
Treatment + Vehicle + Moon + Site + Temperature	1.3
Treatment + Vehicle + Treatment x Vehicle + Site	12.77
Treatment + Vehicle + Treatment x Vehicle + Moon	6.32
Treatment + Vehicle + Moon + Site	0.47
Vehicle + Moon + Site	29.43
Treatment + Moon + Site	**0**
Treatment + Vehicle + Site	11.52
Treatment + Vehicle + Moon	5.09
Moon + Site	28.42
Treatment + Site	12.19
Treatment + Moon	3.99

Deer Rushed Into the Roadway

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	10.01
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle + Weather + Temperature	7.87
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle + Weather + Temperature	14.44
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather + Temperature	7.18
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Weather + Temperature	10.88
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Temperature	7.49
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather	14.42
Treatment + Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	8.09
Treatment + Vehicle + Treatment x Vehicle + Site + Cycle + Weather + Temperature	5.1
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle + Weather + Temperature	15.53
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather + Temperature	7.73
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Temperature	5.72
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather	12.01
Treatment + Vehicle + Moon + Site + Cycle + Weather + Temperature	5.33
Treatment + Vehicle + Treatment x Vehicle + Cycle + Weather + Temperature	16.04
Treatment + Vehicle + Treatment x Vehicle + Site + Weather + Temperature	2.81
Treatment + Vehicle + Treatment x Vehicle + Site + Cycle + Temperature	5.9
Treatment + Vehicle + Treatment x Vehicle + Site + Cycle + Weather	8.92
Treatment + Vehicle + Site + Cycle + Weather + Temperature	3.2
Treatment + Vehicle + Treatment x Vehicle + Weather + Temperature	13.4
Treatment + Vehicle + Treatment x Vehicle + Site + Temperature	1.85
Treatment + Vehicle + Treatment x Vehicle + Site + Weather	4.78
Treatment + Vehicle + Site + Weather + Temperature	0.96
Vehicle + Site + Weather + Temperature	2.59
Treatment + Site + Weather + Temperature	34.55
Treatment + Vehicle + Weather + Temperature	11.75
Treatment + Vehicle + Site + Temperature	**0**
Treatment + Vehicle + Site + Weather	3.02
Vehicle + Site + Temperature	1.34
Treatment + Vehicle + Temperature	9.7
Treatment + Vehicle + Site	3.1

Deer Fled From the Roadway

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	15.92
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle + Weather + Temperature	14.96
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle + Weather + Temperature	12.61
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather + Temperature	10.36
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Weather + Temperature	13.11
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Temperature	17.46
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather	14.83
Treatment + Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	13.95
Treatment + Vehicle + Treatment x Vehicle + Site + Cycle + Weather + Temperature	10.58
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle + Weather + Temperature	7.12
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather + Temperature	7.84
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Temperature	12.32
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather	9.85
Treatment + Vehicle + Moon + Site + Cycle + Weather + Temperature	8.41
Treatment + Vehicle + Treatment x Vehicle + Cycle + Weather + Temperature	7.51
Treatment + Vehicle + Treatment x Vehicle + Moon + Weather + Temperature	4.2
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle + Temperature	9.05
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle + Weather	6.17
Treatment + Vehicle + Moon + Cycle + Weather + Temperature	5.16
Treatment + Vehicle + Treatment x Vehicle + Weather + Temperature	3.38
Treatment + Vehicle + Treatment x Vehicle + Moon + Temperature	5.52
Treatment + Vehicle + Treatment x Vehicle + Moon + Weather	3.18
Treatment + Vehicle + Moon + Weather + Temperature	2.21
Vehicle + Moon + Weather + Temperature	3.87
Treatment + Moon + Weather + Temperature	87.07
Treatment + Vehicle + Weather + Temperature	1.38
Treatment + Vehicle + Moon + Temperature	3.55
Treatment + Vehicle + Moon + Weather	1.19
Vehicle + Moon + Weather	2.81
Treatment + Vehicle + Weather	**0**
Treatment + Vehicle + Moon	1.56
Vehicle + Weather	1.79
Treatment + Vehicle	1.22

Overall Risk Index

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	10.57
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather + Temperature	4.5
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Weather	9
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle + Temperature	9.4
Treatment + Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	12.6
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Weather + Temperature	7.2
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle + Weather + Temperature	19.4
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle + Weather + Temperature	19.3
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Weather	3
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle + Temperature	3.7
Treatment + Vehicle + Moon + Site + Cycle + Weather + Temperature	6.4
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather + Temperature	1.3
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle + Weather + Temperature	13.8
Treatment + Vehicle + Treatment x Vehicle + Site + Cycle + Weather + Temperature	13.4
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Temperature	**0.3**
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Weather	0.5
Treatment + Vehicle + Moon + Site + Weather + Temperature	3.2
Treatment + Vehicle + Treatment x Vehicle + Moon + Weather + Temperature	12.2
Treatment + Vehicle + Treatment x Vehicle + Site + Weather + Temperature	21.8
Treatment + Vehicle + Treatment x Vehicle + Moon + Site	1
Treatment + Vehicle + Moon + Site + Temperature	1.9
Treatment + Vehicle + Treatment x Vehicle + Moon + Temperature	9.8
Treatment + Vehicle + Treatment x Vehicle + Site + Temperature	19.7
Treatment + Vehicle + Moon + Site + Cycle + Weather + Temperature	6.4
Treatment + Vehicle + Moon + Site + Time + Weather + Temperature	9.2
Treatment + Moon + Site + Time + Cycle + Weather + Temperature	10.6
Treatment + Vehicle + Moon + Site + Time + Cycle + Weather	10.9
Treatment + Vehicle + Moon + Site + Time + Cycle + Temperature	11.3
Treatment + Vehicle + Site + Time + Cycle + Weather + Temperature	19.5
Treatment + Vehicle + Moon + Time + Cycle + Weather + Temperature	20.3
Vehicle + Moon + Site + Time + Cycle + Weather + Temperature	40.5
Treatment + Vehicle + Moon + Site + Weather + Temperature	3.2
Treatment + Moon + Site + Cycle + Weather + Temperature	4.4
Treatment + Vehicle + Moon + Site + Cycle + Weather	4.8
Treatment + Vehicle + Moon + Site + Cycle + Temperature	5.5
Treatment + Vehicle + Site + Cycle + Weather + Temperature	13.4
Treatment + Vehicle + Moon + Cycle + Weather + Temperature	14.5

Treatment + Vehicle + Moon + Site + Cycle + Weather	35.4
Treatment + Moon + Site + Weather + Temperature	1.3
Treatment + Vehicle + Moon + Site + Temperature	1.9
Treatment + Vehicle + Moon + Site + Weather	2.3
Treatment + Vehicle + Moon + Weather + Temperature	13
Treatment + Vehicle + Site + Weather + Temperature	21.7
Vehicle + Moon + Site + Weather + Temperature	29.6
Treatment + Moon + Site + Temperature	0
Treatment + Moon + Site + Weather	0.4
Treatment + Moon + Weather + Temperature	11
Treatment + Site + Weather + Temperature	20.1
Moon + Site + Weather + Temperature	27.6
Treatment + Moon + Site	0.5
Treatment + Moon + Temperature	8.4
Treatment + Site + Temperature	18
Moon + Site + Temperature	24.4

Note: There were three nearly equivalent models as assessed by AIC. Since there was a marginally significant treatment*vehicle interaction term, we selected the model that included this term as the better fit, despite slightly higher AIC.

APPENDIX 3: MODEL SELECTION FOR DEER BEHAVIOR ANALYSIS (EXPERIMENT II)

Below are the alternative models considered and ΔAIC for each model for individual deer road-crossing behaviors and overall risk index in the reflector-exposed vs. black bag experiment. Best models are indicated in bold.

Deer Stopped Before Crossing

Model	ΔAIC
Treatment + Car + Treatment x Car + Moon + Site + Time + Cycle	4.31
Treatment + Car + Treatment x Car + Moon + Site + Time	2.61
Treatment + Car + Treatment x Car +Site + Time + Cycle	2.60
Treatment + Car + Treatment x Car + Moon + Time + Cycle	3.10
Treatment + Car + Treatment x Car + Moon + Site + Cycle	4.87
Treatment + Car + Moon + Site + Time + Cycle	9.03
Treatment + Car + Treatment x Car + Moon + Time	2.85
Treatment + Car + Treatment x Car + Site + Time	3.25
Treatment + Car + Treatment x Car + Moon + Site	1.26
Treatment + Car + Moon + Site + Time	5.30
Treatment + Car + Treatment x Car + Site	1.49
Treatment + Car + Treatment x Car + Moon	2.84
Treatment + Car + Moon + Site	2.21
Treatment + Car + Treatment x Car	0.79
Treatment + Car + Site	1.26
Treatment + Car	0.61
Treatment	6.26
Car	**0.00**

Deer Looked Before Crossing

Model	ΔAIC
Treatment + Car + Treatment x Car + Moon + Site + Time + Cycle	9.19
Treatment + Car + Treatment x Car + Moon + Site + Time	5.66
Treatment + Car + Treatment x Car +Site + Time + Cycle	6.79
Treatment + Car + Treatment x Car + Moon + Time + Cycle	7.19
Treatment + Car + Treatment x Car + Moon + Site + Cycle	10.91
Treatment + Car + Moon + Site + Time + Cycle	11.43
Treatment + Car + Treatment x Car + Moon + Time	3.95
Treatment + Car + Treatment x Car + Site + Time	4.09
Treatment + Car + Treatment x Car + Moon + Site	6.57

Treatment + Car + Moon + Site + Time	6.91
Treatment + Car + Treatment x Car + Time	2.13
Treatment + Car + Moon + Time	5.06
Treatment + Car + Treatment x Car + Moon	5.56
Treatment + Car + Treatment x Car	2.32
Treatment + Car + Time	2.35
Treatment + Time	1.77
Treatment + Car	1.41
Car + Time	4.95
Treatment	**0.00**
Car	1.82
Time	4.78

Deer Rushed Into the Roadway

Model	ΔAIC
Treatment + Car + Treatment x Car + Moon + Site + Time + Cycle	6.72
Treatment + Car + Treatment x Car + Site + Time + Cycle	1.97
Treatment + Car + Treatment x Car + Moon + Time + Cycle	4.86
Treatment + Car + Treatment x Car + Moon + Site + Cycle	18.00
Treatment + Car + Treatment x Car + Moon + Site + Time	8.08
Treatment + Car + Moon + Site + Time + Cycle	12.46
Treatment + Car + Treatment x Car + Time + Cycle	**0.00**
Treatment + Car + Treatment x Car + Site + Cycle	13.08
Treatment + Car + Treatment x Car + Site + Time	4.48
Treatment + Car + Site + Time + Cycle	7.77
Treatment + Car + Treatment x Car + Cycle	11.91
Treatment + Car + Treatment x Car + Time	3.01
Treatment + Car + Time + Cycle	6.25
Treatment + Car + Treatment x Car	8.58
Treatment + Car + Time	5.99
Car + Time	6.08
Treatment + Time	19.96
Treatment + Car	8.50
Time	18.74
Car	6.79

Deer Fled From the Roadway

Model	ΔAIC
Treatment + Car + Treatment x Car + Moon + Site + Time + Cycle	12.61
Treatment + Car + Treatment x Car + Site + Time + Cycle	9.79

Treatment + Car + Treatment x Car + Moon + Time + Cycle	11.30
Treatment + Car + Treatment x Car + Moon + Site + Cycle	7.62
Treatment + Car + Treatment x Car + Moon + Site + Time	10.15
Treatment + Car + Moon + Site + Time + Cycle	11.04
Treatment + Car + Treatment x Car + Site + Cycle	4.16
Treatment + Car + Treatment x Car + Moon + Cycle	6.30
Treatment + Car + Treatment x Car + Moon + Site	5.51
Treatment + Car + Moon + Site + Cycle	6.34
Treatment + Car + Treatment x Car + Cycle	2.55
Treatment + Car + Treatment x Car + Site	2.79
Treatment + Car + Site + Cycle	3.47
Treatment + Car + Treatment x Car	1.34
Treatment + Car + Cycle	1.81
Treatment + Car	**0.00**
Car	1.63
Treatment	28.91

Overall Risk Index

Model	ΔAIC
Treatment + Car + Treatment x Car + Moon + Site + Time + Cycle	7.89
Treatment + Car + Treatment x Car + Moon + Site + Time	5.68
Treatment + Car + Treatment x Car + Moon + Time + Cycle	5.96
Treatment + Car + Treatment x Car + Site + Time + Cycle	6.68
Treatment + Car + Moon + Site + Time + Cycle	10.00
Treatment + Car + Treatment x Car + Moon + Site + Cycle	13.03
Treatment + Car + Treatment x Car + Moon + Time	3.76
Treatment + Car + Treatment x Car + Site + Time	3.96
Treatment + Car + Moon + Site + Time	6.51
Treatment + Car + Treatment x Car + Moon + Site	9.24
Treatment + Car + Treatment x Car + Time	1.99
Treatment + Car + Moon + Time	4.61
Treatment + Car + Treatment x Car + Moon	7.87
Treatment + Car + Time	1.87
Treatment + Car + Treatment x Car	4.08
Treatment + Time	**0.00**
Treatment + Car	2.80
Car + Time	5.72
Time	3.78
Treatment	2.60

APPENDIX 4: MODEL SELECTION FOR DEER BEHAVIOR ANALYSIS (EXPERIMENT III)

Below are the alternative models considered and ΔAIC for each model for individual deer road-crossing behaviors and overall risk index in the reflector-exposed vs. white bag vs. nothing experiment. Best models are indicated in bold.

Deer Stopped Before Crossing

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle	10.24
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle	14.19
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle	8.86
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle	13.08
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time	8.33
Treatment + Vehicle + Moon + Site + Time + Cycle	7.82
Vehicle + Moon + Site + Time + Cycle	4.38
Treatment + Moon + Site + Time + Cycle	6.56
Treatment + Vehicle + Site + Time + Cycle	11.53
Treatment + Vehicle + Moon + Time + Cycle	6.13
Treatment + Vehicle + Moon + Site + Cycle	10.35
Treatment + Vehicle + Moon + Site + Time	5.92
Moon + Site + Time + Cycle	3.20
Vehicle + Site + Time + Cycle	8.57
Vehicle + Moon + Time + Cycle	3.87
Vehicle + Moon + Site + Cycle	6.87
Vehicle + Moon + Site + Time	3.24
Site + Time + Cycle	7.22
Moon + Time + Cycle	2.99
Moon + Site + Cycle	5.72
Moon + Site + Time	3.07
Time + Cycle	4.90
Moon + Cycle	8.23
Moon + Time	5.39
Site + Time	3.84
Moon + Site	5.30
Moon + Time	5.39
Treatment + Moon + Time + Cycle	5.07
Treatment + Vehicle + Time + Cycle	6.47
Treatment + Vehicle + Moon + Cycle	9.34
Treatment + Vehicle + Moon + Time	3.80

Vehicle + Moon + Time	4.24
Treatment + Moon + Time	3.74
Treatment + Vehicle + Time	0.98
Treatment + Vehicle + Moon	7.28
Vehicle + Time	2.36
Treatment + Time	**0.00**
Treatment + Vehicle	3.45
Time	2.31
Treatment	2.19

Deer Looked Before Crossing

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle	13.05
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle	10.62
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle	17.61
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle	19.92
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time	8.25
Treatment + Vehicle + Moon + Site + Time + Cycle	9.75
Treatment + Vehicle + Treatment x Vehicle + Site + Time	5.07
Treatment + Vehicle + Treatment x Vehicle + Moon + Time	14.00
Treatment + Vehicle + Treatment x Vehicle + Moon + Site	15.06
Treatment + Vehicle + Moon + Site + Time	5.20
Treatment + Vehicle + Treatment x Vehicle + Time	8.40
Treatment + Vehicle + Treatment x Vehicle + Site	11.75
Treatment + Vehicle + Site + Time	1.89
Vehicle + Moon + Site + Time	8.14
Treatment + Moon + Site + Time	3.48
Treatment + Vehicle + Moon + Time	10.36
Treatment + Vehicle + Moon + Site	11.54
Vehicle + Site + Time	4.20
Treatment + Site + Time	**0.00**
Treatment + Vehicle + Time	4.71
Treatment + Vehicle + Site	8.16
Site + Time	2.52
Treatment + Time	2.71
Treatment + Site	6.31

Deer Rushed Into the Roadway

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle	19.49
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle	16.05
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle	10.25
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle	19.84
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time	13.56
Treatment + Vehicle + Moon + Site + Time + Cycle	18.45
Treatment + Vehicle + Treatment x Vehicle + Time + Cycle	7.01
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle	10.31
Treatment + Vehicle + Treatment x Vehicle + Moon + Time	4.33
Treatment + Vehicle + Moon + Time + Cycle	9.30
Treatment + Vehicle + Treatment x Vehicle + Time	2.74
Treatment + Vehicle + Treatment x Vehicle + Moon	4.56
Treatment + Vehicle + Moon + Time	3.37
Treatment + Vehicle + Treatment x Vehicle	2.09
Treatment + Vehicle + Time	2.10
Treatment + Vehicle	0.40
Vehicle + Time	2.31
Treatment + Time	34.23
Vehicle	**0.00**
Treatment	54.14
Vehicle + Moon + Time	4.27
Treatment + Moon + Time	27.19
Treatment + Vehicle + Time	2.10
Treatment + Vehicle + Moon	2.51

Deer Fled From the Roadway

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle	15.25
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle	18.79
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle	9.79
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle	14.05
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time	15.33
Treatment + Vehicle +Moon + Site + Time + Cycle	12.58
Treatment + Vehicle + Treatment x Vehicle + Time + Cycle	13.81
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle	8.04
Treatment + Vehicle + Treatment x Vehicle + Moon + Time	6.73

Treatment + Vehicle + Moon + Time + Cycle	6.85
Treatment + Vehicle + Treatment x Vehicle + Time	13.45
Treatment + Vehicle + Treatment x Vehicle + Moon	4.54
Treatment + Vehicle + Moon + Time	3.77
Vehicle + Moon + Time + Cycle	4.00
Treatment + Moon + Time + Cycle	36.48
Treatment + Vehicle + Time + Cycle	10.52
Treatment + Vehicle + Moon + Cycle	5.05
Vehicle + Moon + Time	1.73
Treatment + Moon + Time	35.96
Treatment + Vehicle + Time	9.96
Treatment + Vehicle + Moon	1.51
Vehicle + Moon	**0.00**
Treatment + Moon	55.40
Treatment + Vehicle	6.98
Vehicle	8.13

Overall Risk Index

Model	ΔAIC
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time + Cycle	13.41
Treatment + Vehicle + Treatment x Vehicle + Moon + Time + Cycle	9.48
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Time	10.16
Treatment + Vehicle + Moon + Site + Time + Cycle	10.77
Treatment + Vehicle + Treatment x Vehicle + Moon + Site + Cycle	14.99
Treatment + Vehicle + Treatment x Vehicle + Site + Time + Cycle	18.97
Treatment + Vehicle + Treatment x Vehicle + Moon + Time	5.73
Treatment + Vehicle + Moon + Time + Cycle	6.23
Treatment + Vehicle + Treatment x Vehicle + Moon + Cycle	9.48
Treatment + Vehicle + Treatment x Vehicle + Time + Cycle	14.65
Treatment + Vehicle + Moon + Time	2.71
Treatment + Vehicle + Treatment x Vehicle + Moon	7.46
Treatment + Vehicle + Treatment x Vehicle + Time	8.91
Vehicle + Moon + Time	**0.00**
Treatment + Vehicle + Moon	4.17
Treatment + Vehicle + Time	5.49
Treatment + Moon + Time	6.47
Vehicle + Time	2.67
Vehicle + Moon	3.08
Moon + Time	3.21

APPENDIX 5: MODEL SELECTION FOR STATEWIDE DVC ANALYSES

Model selection process for binomial (DVC presence vs. absence) model. The selected "best model" is shown in bold.

Model	Process Note	AIC	ΔAIC
Winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover + developed cover + bridge	Initial model	1072.7	0
Crucial winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover + developed cover + bridge	Substitute *crucial winter range* for *winter range* => Revert to *winter range*	1081.8	9.1
Winter range + migration route + truck traffic + speed limit + crop cover presence + forest cover + wetland cover + developed cover + bridge	Substitute *truck traffic* for *total traffic* => Revert to *total traffic*	1096.4	23.7
Winter range + migration route + total traffic + speed limit + forest cover + wetland cover + anthropogenic disturbance + bridge	Substitute *anthropogenic disturbance* for *crop cover presence* and *disturbed cover* => revert to *crop cover presence* and *disturbed cover*	1088.7	16.0
Winter range + migration route + total traffic + speed limit + crop cover presence + wetland cover + developed cover + bridge	Drop *forest cover* => keep in	1075.1	2.4
Winter range + migration route + total traffic + crop cover presence + forest cover + wetland cover + developed cover + bridge	Drop *speed limit* => leave out	1073.4	0.7
Winter range + migration route + total traffic + crop cover presence + wetland cover + developed cover + bridge	Drop both *speed limit* and *forest cover* => leave both out	1073.6	0.9
Winter range + migration route + total traffic + crop cover presence + developed cover + bridge	Drop *wetland cover* => keep in	1077.1	4.4
Winter range + migration route + total traffic + crop cover presence + wetland cover + bridge	Drop *developed cover* => keep in	1080.7	8.0
Winter range + migration route + total traffic + crop cover presence + wetland cover	Drop *bridge* => keep in	1090.7	18.0
Winter range + migration route + total traffic + wetland cover + developed cover + bridge	Drop *crop cover presence* => keep in	1102.4	29.7
Winter range + migration route + crop cover presence + wetland cover + developed cover + bridge	Drop *total traffic* => keep in	1160.9	88.2
Winter range + total traffic + crop cover presence + wetland cover + developed cover + bridge	Drop *migration route* => keep in	1090.1	17.4
Migration route + total traffic + crop cover	Drop *crucial winter*	1086.4	13.7

presence + wetland cover + developed cover + bridge	*range* => keep in		

Model selection process for count (number of DVC) model. The selected "best model" is shown in bold.

Model	Process Note	AIC	ΔAIC
Winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover + developed cover + bridge	Initial model	3368.4	9.7
Crucial winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover + developed cover + bridge	Substitute *crucial winter range* for *winter range* => Keep crucial winter range	3358.7	0
Crucial winter range + migration route + truck traffic + speed limit + crop cover presence + forest cover + wetland cover + developed cover + bridge	Substitute *truck traffic* for *total traffic* => Revert to *total traffic*	3432.9	74.2
Crucial winter range + migration route + total traffic + speed limit + forest cover + wetland cover + anthropogenic disturbance + bridge	Substitute *anthropogenic disturbance* for *crop cover presence* and *developed cover* => revert to *crop cover presence* and *developed cover*	3380.0	21.3
Crucial winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover + bridge	Drop *developed cover* => leave out	3359.6	0.9
Crucial winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover	Drop *bridge* => keep in	3362.5	3.8
Crucial winter range + migration route + total traffic + speed limit + crop cover presence + forest cover + bridge	Drop *wetland cover* => keep in	3408.7	50
Crucial winter range + migration route + total traffic + speed limit + crop cover presence + wetland cover + bridge	Drop *forest cover* => keep in	3374.5	15.8
Crucial winter range + migration route + total traffic + speed limit + forest cover + wetland cover + bridge	Drop *crop cover presence* => keep in	3403.2	44.5
Crucial winter range + migration route + total traffic + crop cover presence + forest cover + wetland cover + bridge	Drop *speed limit* => keep in	3397.2	38.5
Crucial winter range + migration route + speed limit + crop cover presence + forest cover +	Drop *total traffic* => keep in	3547.8	189.1

wetland cover + bridge			
Crucial winter range + total traffic + speed limit + crop cover presence + forest cover + wetland cover + bridge	Drop *migration route* => keep in	3376.8	18.1
Migration route + total traffic + speed limit + crop cover presence + forest cover + wetland cover + bridge	Drop *crucial winter range* => keep in	3419.1	60.4

APPENDIX 6: ALTERNATIVE MITIGATION STRATEGIES

The following possible mitigation strategies have not yet been thoroughly tested:

- Animal Detection Systems: The accuracy of Animal Detection Systems has improved drastically over the past 10 years. Animal Detection Systems are designed to warn drivers (e.g. with a flashing sign) when an animal is approaching the roadway at a designated crossing location. There are three major types of Animal Detection Systems: 1) Passive infrared systems detecting animal body heat 2) Microwave radar systems detecting movement 3) Geophone systems detecting vibration. Each of these has limitations, the primary one being lack of driver compliance. As with static Deer Xing signs, once a driver has seen a warning sign or signal enough times without seeing an actual animal, they tend to ignore them. Overall, the microwave radar systems show the most promise and several prototype systems are proving effective.[66]
- Deer silhouettes: Rear-facing silhouette models of deer with raised tails may deter deer from crossing. (Note: This may be effectively similar to white canvas bags, which may resemble raised tails to deer).
- Lighting: Additional lighting along roadways may improve driver vision of the highway right-of-way in high density deer crossing locations.[67]
- Reducing incentive for deer to cross the road: Establishing intercept feeding and watering stations may draw deer away from the highway or prevent them from crossing to access food or water on opposite sides of the highway.[68]

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