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MONITORING WILDLIFE-VEHICLE COLLISIONS: ANALYSIS AND COST-BENEFIT OF ESCAPE RAMPS FOR DEER AND ELK ON U.S. HIGHWAY 550

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16. Abstract
Wildlife fencing along highways can lower wildlife-vehicle collision rates by excluding animals from the road right-of-way. Still, animals can breach fencing and end up trapped within the fencing along the highway right-of-way, exposing wildlife and motorists to the risk of collision. Wildlife escape ramps are designed to allow trapped animals safe passage out of the right-of-way. Few recommendations exist on effective design of escape ramps and monitoring data are limited. We investigated the usage levels, escape success, wildlife-vehicle collisions, and design of 11 escape ramps and two escape jumps along an eight-mile stretch of U.S. Highway 550 near Ridgway, Colorado. Our goals were to 1) relate usage levels and escape success to ER structure design and its surrounding environmental characteristics, 2) describe the animal use of ER in the study area, 3) conduct a cost-benefit analysis for escape ramp construction and 4) provide recommendations regarding ER design and WVC based on data collected.

Implementation

A number of Implementation recommendations are made in the report including: installation of additional ramps at specific locations, addition of improved mitigation at the ends of wildlife fencing, and specific improvements to select escape structures.

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Monitoring Wildlife-Vehicle Collisions: Analysis and Cost-Benefit of Escape Ramps for Deer and Elk on U.S. Highway 550

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Executive Summary

Wildlife fencing along highways can lower wildlife-vehicle collision (WVC) rates by excluding animals from the road right-of-way. Still, animals can breach fencing and end up trapped within the fencing along the highway right-of-way, exposing wildlife and motorists to the risk of collision. Wildlife escape ramps are designed to allow trapped animals safe passage out of the right-of-way. Few recommendations exist on effective design of escape ramps (ER) and monitoring data are limited. We investigated the usage levels, escape success, wildlife-vehicle collisions, and design of 11 escape ramps and two escape jumps along an eight-mile stretch of U.S. Highway 550 near Ridgway, Colorado. Our goals were to 1) relate usage levels and escape success to ER structure design and its surrounding environmental characteristics, 2) describe the animal use of ER in the study area, 3) conduct a cost-benefit analysis for escape ramp construction and 4) provide recommendations regarding ER design and WVC based on data collected.

Escape Ramp Usage

1. Escape ramps were used by mule deer, elk, bear, mountain lion, coyote, red fox, bobcat, raccoon, striped skunk, wild turkey, rodents, raptors, and passerines.
2. Mule deer visited escape ramps more than any other species. We documented a total of 1,333 successful mule deer escapes.
3. Elk in the study area used escape ramps far less than mule deer, with a total of 25 successful escapes.
4. Peak escape ramp visits by deer occurred during the early morning and late evening. Seasonally, deer visits to escape ramps peaked in November and May.
5. Most visits to escape ramps by elk occurred during the spring and summer (April-June).
6. Mule deer were able to use escape ramps to enter the highway right-of-way (i.e. reversals). We documented a total of 27 reversals by mule deer, 25 of which occurred at one escape ramp. No elk reversals were documented.
7. Escape success rates for mule deer ranged from 8.2% to 70.3% across the 11 escape ramps. The highest percentage of successes (70.3%) occurred between milepost 108 and 109; the lowest (8.2%) occurred between milepost 110 and 111.

Escape Ramp Monitoring

1. Mule deer were more likely to make a successful escape at ramps with a perpendicular guide fence.
2. Mule deer were less likely to make a successful escape if a horizontal bar was present on the escape ramp.
3. Mule deer were more likely to complete a successful escape if shrubs were located in close proximity to the escape ramp, but not in the landing area.
4. Mule deer were more likely to make a successful escape at escape ramps close to the highway compared to those located farther from highway.

Cost-Benefit Analysis

1. Wildlife-vehicle collision rates were measured as animal collisions per mile per year. Before construction of escape ramps, this rate was 1.94 for mule deer. After construction of three escape ramps in 2005, the rate dropped to 1.53. In 2010, five more escape ramps were constructed in the study area, and the mule deer collision rate dropped to 1.12.
2. Elk collision rate prior to escape ramps construction was 0.58 collisions per mile per year. After construction of three escape ramps in 2005, the rate dropped to 0.32. Finally, after eight more ER were constructed, the rate dropped to 0.03.
3. Prior to construction of ER, wildlife-vehicle collisions in the study area cost society $172,839 per year. Following construction of eight ER, society's cost was reduced to $66,766 ($62,353 for mule deer, $4,413 for elk).
4. The cost recovery timeframe for ER construction was 1.35 to 2.20 years depending upon animal valuation.

Recommendations

1. **Consider installing additional escape ramps between Alkali Creek (milepost 109) and milepost 111.** This is the longest stretch of highway in the study area without an escape measure. This problem area was the site of three wildlife-vehicle collisions from May 2010 – July 2014.
2. **Close openings in wildlife fencing.** We documented 34 openings in the fence between milepost 106 and milepost 112. These openings were large enough for deer to pass through.
3. **Mitigate wildlife-vehicle collisions at ends of wildlife fencing.** Most wildlife-vehicle collisions occurred at the ends of wildlife fencing, both before and after escape ramp construction.
4. **Extend dates of gate closure.** Gates on the bike path are closed from October 1 to April 1. Visits by mule deer to escape ramps indicate closure through May might be more appropriate.
5. **Improve guards.** Install wildlife guards at access road where they do not exist and improve current guards that are filled with gravel or ineffective at deterring wildlife.
6. **Improve select escape structures.** To reduce mule deer reversals at escape structures, add a horizontal bar to the top of the escape ramp near the Dutch Charlie entrance to Ridgway State Park and to the Dry Creek escape jump.

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INTRODUCTION

Wildlife-vehicle collisions (WVC) have substantial negative impacts to human safety and wildlife populations and are of great concern to transportation and wildlife managers (Forman et al. 2003, Mastro et al. 2008). Beyond risks of injury or death, WVC can result in high economic costs from property damage and loss of wildlife recreation opportunities (Huijser et al. 2009). A key mitigation measure includes use of wildlife exclusion fencing (Clevenger et al. 2001, Huijser et al. 2008b), which has been shown to reduce WVC by 79% for deer (Reed et al. 1982), 80% for ungulates (Clevenger et al. 2001), and over 80% for elk (Dodd et al. 2006).

Wildlife fencing, however, is not an absolute exclusion measure as gaps, which allow for unintended wildlife passage through the fencing, exist in most situations (Bissonette and Hammer 2000; Putman 1997). These gaps occur due to driveways, other roads intersecting the highway, erosion of the landscape under the fence in areas with complex topography, animal-created holes, human vandalism, and other factors. Animals of all sizes will find their way through most wildlife fencing and the fencing designed to exclude animals from the dangers of the transportation corridor can create a physical barrier that traps wildlife in right-of-way (ROW) areas near the road and blocks wildlife linkages across the landscape (Huijser and Kociolek 2008). When such situations exist, wildlife fencing has the potential to increase WVC and hinder wildlife movement (Knapp et al. 2004).

Current recommendations on the construction of wildlife fencing consider the fence to be only one part of a multi-part mitigation strategy (Huijser et al. 2008b; Clevenger and Huijser 2011). Wildlife fencing should guide animals to locations along the transportation corridor where they can cross safely. Furthermore, opportunities for escape need to be provided when animals breach the fencing or make runs around the ends of the fencing. Safe crossings can be provided by underpasses, overpasses, or at-grade crosswalks and escapes from the ROW can be facilitated using infrastructure complementary to the fencing such as one-way gates or earthen escape ramps (ER). One-way gates and ER have been implemented as escape measures to alleviate the trapping effects of fencing for large ungulates, however ER are preferred over one-way gates based on their suggested effectiveness (Bissonette and Hammer 2000).

Earthen escape ramps are generally designed from inside of the ROW and consist of a sloping mound of soil with a gradual slope to the wildlife fence. Backing material is used to support the soil at the fence, and the height of the fence is lowered to approximately five feet at the apex of the ramp. This creates a sharp drop off the ramp that allows wildlife to jump to safety outside of the ROW (Huijser et al. 2008b). Such designs permit escape of animals trapped within the fenced ROW area, while discouraging intrusion into the ROW (reversals of the ER). Escape ramp design features such as ramp slope, ramp vegetation, wildlife fence height at ramp, presence horizontal bars, and guide fencing perpendicular to the exclusionary fence can vary. Additionally, nearby fence attributes (e.g., proximity to nearby fence gaps) and landscape features (e.g., proximity to wildlife movement corridors) can influence use of ER.

Studies that have evaluated the effectiveness of ER are limited, especially in any kind of experimental framework. Long-term pre- and post-construction monitoring studies of ER with treatments and controls are lacking. Literature on ER is composed primarily of studies that have documented use of ER by various species and cost-benefit analyses of WVC data before and after ER construction.

Bissonette and Hammer (2000) document use of ER by mule deer (*Odocoileus hemionus*). Species observed using ER in Banff National Park include deer, elk (*Cervus elaphus*), moose (*Alces alces)*, and bighorn sheep (*Ovis canadensis*) (Bruce Leeson, personal communication cited in Huijser et al. 2008b). Clevenger et al. (2002) report successful use of ER by deer, elk, and coyote (*Canis latrans*). They further report success rates of five escapes over 19 visits (26%) for deer, six escapes over nine visits (67%) for elk, and one escape over four visits (25%) for coyote over a two-year and nine-month time period (Clevenger et al. 2002). Desert bighorn sheep used eight ER in Arizona successfully 322 of 337 times (96%), and of 1312 observations of sheep on the safe side of the fence, 44 (3%) made passage to the ROW; however, following the inclusion and adjustment of horizontal bars to approximately 16 inches, no evidence of successful reversals into the ROW by bighorn sheep were documented (Gagnon et al. 2013).

In a study of the effectiveness of ER in comparison to one-way gates along highways U.S. 40 and U.S. 91 in northern Utah, Bissonette and Hammer (2000) found that ER were eight to 11 times more effective than one-way gates in allowing deer to escape the ROW. Along Highway U.S. 91, they observed a decreased amount of deer mortality after the ramps were constructed. In their cost-benefit analysis, they found that the cost of installing ER along highways with wildlife fencing designed to exclude big game is very rapidly offset by the reduction of WVC. In their calculations, if the installation of ER decreased deer mortality by a very conservative two percent, the benefits would offset the costs in one to two years. Additional benefits suggested by Bissonette and Hammer (2000) include: inexpensive cost of maintaining ER, especially compared to one-way gates, ER mimic natural topography which is thought to reduce fright behavior in deer when they are used, and ER are less conspicuous than one-way gates.

Based on data collected using sand tracking beds, Huijser et al. (2010) report successful use of jump-outs by mule deer and white-tailed deer (*Odocoileus virginianus*), domestic cat (*Felis catus*), and coyote. These species used the jump-outs to jump down to the safe side of the wildlife fence as opposed to just visiting the top of the jump-outs and not making an escape. In a subsequent quarterly progress report, Huijser et al. (2013) provide preliminary data, based on track bed surveys, indicating that jump-outs are used by mule deer much more successfully than by white-tailed deer. In an area dominated by white-tailed deer, successful escapes were made less than 2% of the time a deer was detected on top of a jump-out compared with nearly 35% at areas with a larger population of mule deer, and most of these successful escapes (nearly 80%) were at a location made up almost exclusively of mule deer (Huijser et al. 2013). These results are pertinent to the Colorado Department of Transportation (CDOT) as both deer species occur within Colorado, with mule deer occurring throughout the state and white-tailed deer occurring on the eastern plains, Rocky Mountain National Park, Middle Park, the White River drainage, and the San Luis Valley (Armstrong et al. 2011). Information gathered on the use and escape success of mule deer may not be transferable to situations involving white-tailed deer.

Recent literature reviews and comprehensive treatments on highway mitigation that mention ER (Knapp et al. 2004; Huijser et al. 2008b) rely on the work conducted by Bissonette and Hammer

(2000) for their discussion. Clevenger and Huijser (2011) make some recommendations on the design of ER and suggest the use of smooth outside walls to prevent animals, especially bears, from climbing up the ramp. They also discuss ER positioning on the landscape and recommend placing them at set-backs in the fence in areas with dense vegetative cover and preferably at a right-angle jog in the fence (Clevenger and Huijser 2011). Huijser and Kociolek (2008) make similar recommendations regarding design and positioning, and acknowledge the lack of information about the appropriate height for ER, which is dependent upon the terrain and focal wildlife species at any one location. Arizona Department of Transportation provides a useful document that describes various wildlife escape measures including escape ramps (AZDOT 2014).

There is a need for evaluation of ER design and environmental characteristics to maximize the effectiveness for target wildlife. In August 2012 we began the field component of a monitoring effort of ER focused on quantifying use and escape success by ungulates, namely mule deer (hereafter deer) and elk, along U.S. Highway 550 in Ouray County, Colorado. Within our study reach from 2000 to 2014, there were 233 WVC, primarily from mule deer and elk. The number of WVC is an indication of the need for ER along this stretch of highway. We provide additional information on WVC in the cost-benefit section. Our goals were to 1) relate usage levels and escape success to ER structure design and its surrounding environmental characteristics, 2) describe the animal use of ER in the study area, 3) conduct a cost-benefit analysis for ER construction, and 4) provide recommendations regarding ER design and WVC based on data collected.

METHODS

Study Area

The study area consists of an eight-mile segment of US Highway 550 north of Ridgway, Ouray County, Colorado (Fig. 1). Speed limit on the highway in the study area is 60 mph (CDOT 2011). Average Annual Daily Traffic (AADT) counts range from 6,700 – 7,300 and are projected to increase to approximately 9,500 – 10,500 in the next 20 years. The number of travel lanes and lane width do not change along this segment of highway, but the primary outside shoulder width does (CDOT 2011). Billy Creek State Wildlife Area is located to the northeast and Ridgway State Park, surrounding Ridgway Reservoir, is located to the west. The entire segment has eight-foot wildlife fencing to exclude wildlife, but several subdivisions have driveway access from this segment of the highway that create breaks in the fence and provide entry points for animals to the highway.

The dominant road topography in this area is rolling terrain (CDOT 2011) and elevation ranges from approximately 6,500 to 7,000 feet. Wildlife habitat is primarily pinõn-juniper and mountain shrub vegetation communities with some irrigated agriculture as well as riparian habitats of the Uncompahgre River and its tributaries. The wildlife fence exists on both sides of the highway from mile markers 105.5 – 113.5 (Southern Rockies Ecosystem Project [SREP] 2006). Fencing bisects important habitat for elk and deer, and the area has several resident deer populations. Additionally, road segments between mile markers 105 and 106 and north of mile marker 111.5 have been identified as traditional deer crossings (CPW 2013; Fig. 1). Along this 5-mile segment of highway, three ER were constructed in 2005 and eight were constructed in 2010.

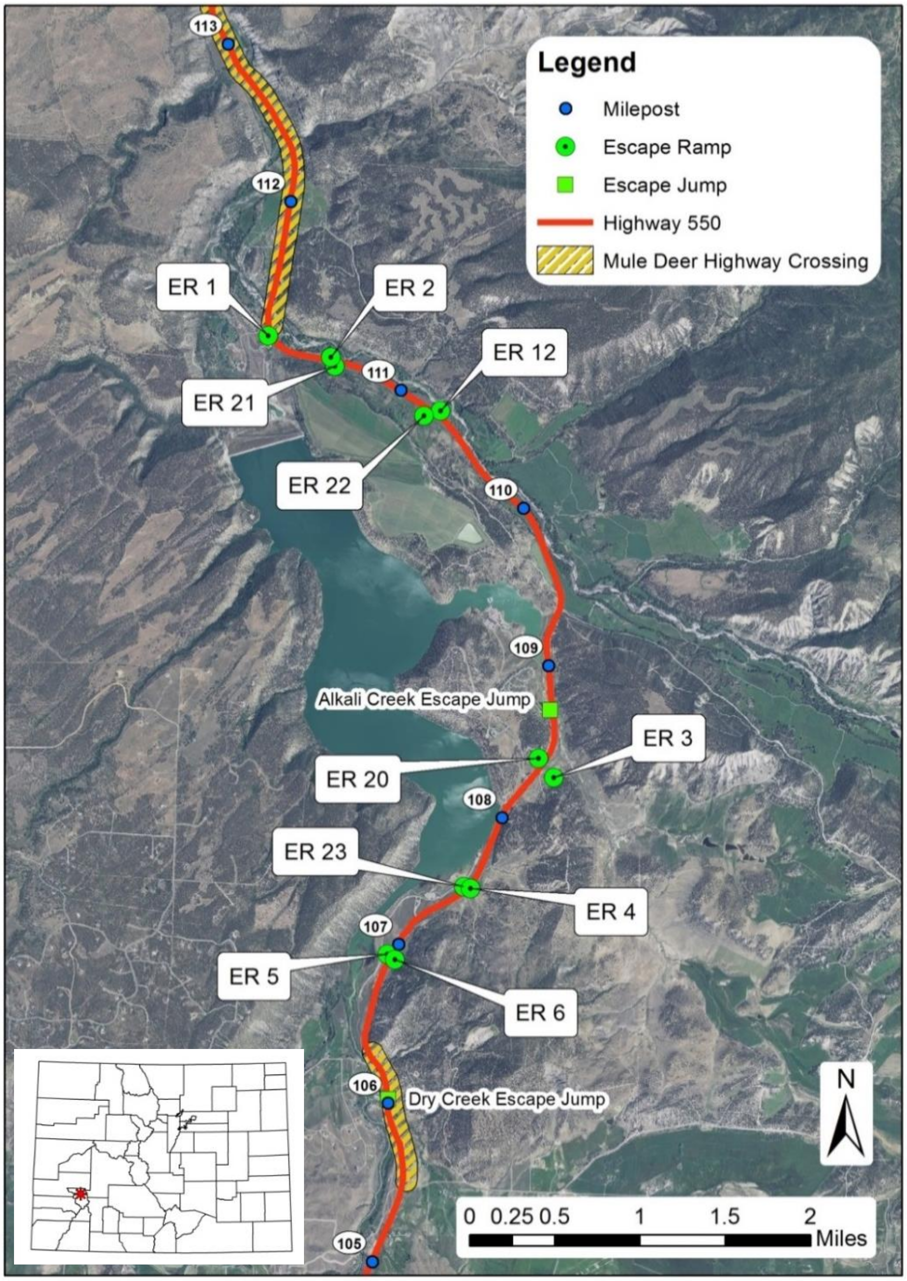

Figure 1. Study area north of Ridgway, along Highway 550, Ouray County, Colorado. Mule deer highway crossings are areas identified as traditional deer crossing by Colorado Parks and Wildlife (CPW 2013). Red star on inset map depicts the location in Colorado.

Earthen Escape Ramp Designs

The 11 ER in the study area vary in overall design and details (Table 1). The three ramps constructed in 2005 do not have perpendicular guide fences and one has a horizontal bar. Photos of each ER are provided in Appendix A.

Table 1. Design characteristics, general location and construction year of 11 escape ramps.

Ramp ID #	Hwy 550 MP[1]	Side of Highway	Perpendicular Guide Fence Present	Horizontal Bar Present	Distance to Highway (m)	Year Built
1	111.5	W	yes	yes	29	2010
2	111+	E	yes	yes	28	2010
3	108+	E	no	no	155	2005
4	107.5	E	yes	yes	25	2010
5	107-	W	no	no	25	2005
6	107-	E	no	yes	52	2005
12	111-	E	yes	no	42	2010
20	108+	W	yes	no	57	2010
21	111+	W	yes	no	45	2010
22	111-	W	yes	no	80	2010
23	107.5	W	yes	yes	25	2010

[1]MP = milepost

Earthen Escape Ramp Monitoring

We monitored 11 ER along Highway 550 using motion-sensitive infra-red cameras (Attack IR™, Cuddeback, De Pere, WI). We monitored ramps continuously for a period of two years (August 2012 – July 2014) and deployed two cameras at each ramp by bolting them within protective cases (CuddeSafe™, Cuddeback, De Pere, WI) to posts of the wildlife fence (Figure 2).

Figure 2. A representative earthen escape ramp along Highway 550 depicting camera placement (cameras circled in red).

We positioned cameras such that animals could be observed on the ER and successful escapes or movements back toward the ROW area could also be observed. Each trigger event resulted in a time-stamped photo followed by a video clip (up to 30 seconds) to record animal activity. We revisited cameras periodically to replace batteries and collect data memory cards.

We viewed photo and video footage to document animal visits to each ER and determine whether or not a successful escape was made. We defined a successful escape as a visit to an ER by an animal with sufficient picture or video evidence to indicate the animal jumped from the ramp (or crawled under a horizontal bar) to the safe side of the wildlife fence. Unsuccessful escapes were defined as a visit to an ER when an animal did not jump to safety, but left the ramp on the ROW side of the fence. We did not consider the amount of time an animal spent at the ramp before making an escape or leaving the ramp in defining successful versus unsuccessful escapes. In addition to escape attempts, our camera placement allowed us to document reversals: occasions where animals were able to jump up from the safe side of the wildlife fencing into the ROW.

Culvert Escape Jump Monitoring

In addition to the camera monitoring of the 11 ER, we also placed one camera at each of two escape jumps at Alkali and Dry creeks, which both pass under Highway 550 through box culverts. Escape jumps have been created by intentional gaps in the fencing above the box culvert headwall at both of these creeks. The Dry Creek escape jump is located on the east side of the highway near milepost (MP) 106. The Alkali Creek escape jump we monitored is on the west side at MP 109-. The fencing gaps are above areas along the vertical headwall that are at heights low enough to provide animals a location where they can jump to safety, but high enough to discourage animals from jumping up into the ROW. A horizontal bar is present on one half of the jump at Dry Creek (Figure 3).

Figure 3. Escape jumps along Dry Creek from the right-of-way above the creek (left) and Alkali Creek from the creek bed (right).

Escape Ramp Data Analysis

To model successful escapes by mule deer at ER, we used several approaches.

We used logistic regression (generalized linear model [glm] function in R, R Core Team 2014) to model successful and unsuccessful escape attempts of mule deer at ER as a function of five independent variables: 1) presence of a horizontal bar at top of ramp, 2) distance of ramp from highway, 3) presence of a guide fence on ramp, 4) distance to nearest shrub on safe side of fence from ramp, and 5) distance to nearest tree on safe side of fence from ramp. Other variables were considered (ER slope, ER jump height, ER opening width, ER length), but there was so little variation among ER with respect to these variables, which was confounded by the small sample size of only 11 ER, that meaningful comparisons could not be made. Additionally, even if some of these variables were statistically significant due to the large sample size of escape attempts, we could find no biological interpretation for deer responses to ER variables such as opening width or ER length, for instance.

We examined all possible models of the five independent variables listed above and compared models using Akaike's information criterion for small sample size (AIC_c) and AIC_c model weights (w_i) (Burnham and Anderson 2002). For each variable, we calculated a cumulative AIC_c weight (w_+) and we report estimates for the regression coefficients (β_i) with 95% confidence intervals (CI) using the highest-ranked model for that variable in the modeling set. Estimates with a 95% CI that did not overlap zero were considered to have a strong effect (Burnham and Anderson 2002).

Additionally, we used Poisson regression in a log-linear model (glm function, offset of deer visits to ER in R, R Core Team 2014) to model counts of successful escapes as a function of the total number of visits by mule deer to ER. We used the same independent variables as the logistic regression analysis above, but the three continuous distance variables were converted to categorical variables with two distance classes each. Thresholds for separating distances into two bins for each category were based upon the data and were defined as 29 meters for distance to highway, 9 meters for distance to nearest shrub, and 43 meters for distance to nearest tree.

To account for overdispersion present in the data, where there is more variability in the data than predicted based on the assumed Poisson distribution, we used a quasi-Poisson approach (glm function, quasipoisson family, in R, R Core Team 2014) to model counts of successful escapes per the total number of visits by mule deer to ER. We used the same independent variables as the logistic and log-linear model, and the same binning thresholds as the Poisson regression.

RESULTS AND DISCUSSION

Earthen Escape Ramp Monitoring

Mule Deer

We recorded 2,965 visits of mule deer to the 11 ER within the study area. Of these visits, we were able to confirm whether or not a deer made a successful escape on 2,588 occasions (confirmed observations), and of these there were 1,333 successful escapes from the ROW (51.5%).

Figure 4. A deer making a successful escape at Ramp 20.

The number of visits and successful escapes also varied by ER (Table 2). Successful escape percentages for deer at each ER ranged from 8.2% to 70.3%. We documented 27 successful mule deer reversals, which are discussed below.

Table 2. Visits, escapes, and reversals of mule deer at each escape ramp.

Ramp ID #	Visits	Confirmed Observations	Successful Escapes	Escape Percentage	Reversals
1	278	252	123	48.8	0
2	104	94	30	31.9	1
3	240	225	89	39. 6	0
4	443	389	251	64.5	1
5	551	523	282	53.9	0
6	305	177	29	16.4	0
12	64	61	5	8.2	0
20	636	553	389	70.3	25
21	85	74	41	55.4	0
22	119	108	30	27.8	0
23	140	132	64	48.5	0
TOTAL	**2965**	**2588**	**1333**	**51.5**	**27**

Over a third of total deer visits to ER that we were not able to confirm as successful or unsuccessful escapes (128) occurred at Ramp 6. Most of these visits were due to a hole in the wildlife fence just behind the ER that we discovered during video analysis. Deer were entering and exiting the ROW through the fence and triggering the camera. For most of these visits, deer did not climb to the top of the ramp to make an escape attempt. These data are still included as they provide information on seasonality, daily timing, and frequency of visits to ER in the ROW.

Most deer visits occurred at the six ER toward the southern half of the study area (Figure 4). The northern five ER had a total of 650 deer visits and the southern six ER had 2,315 deer visits.

Mule deer visits to ER were also quite variable temporally on both hourly (Figure 5) and monthly (Figure 6) scales. Most visits occurred during the early morning and late evening, and seasonally during the fall, peaking in November, and the spring, peaking in May. Visits decreased during the summer and increased again each October.

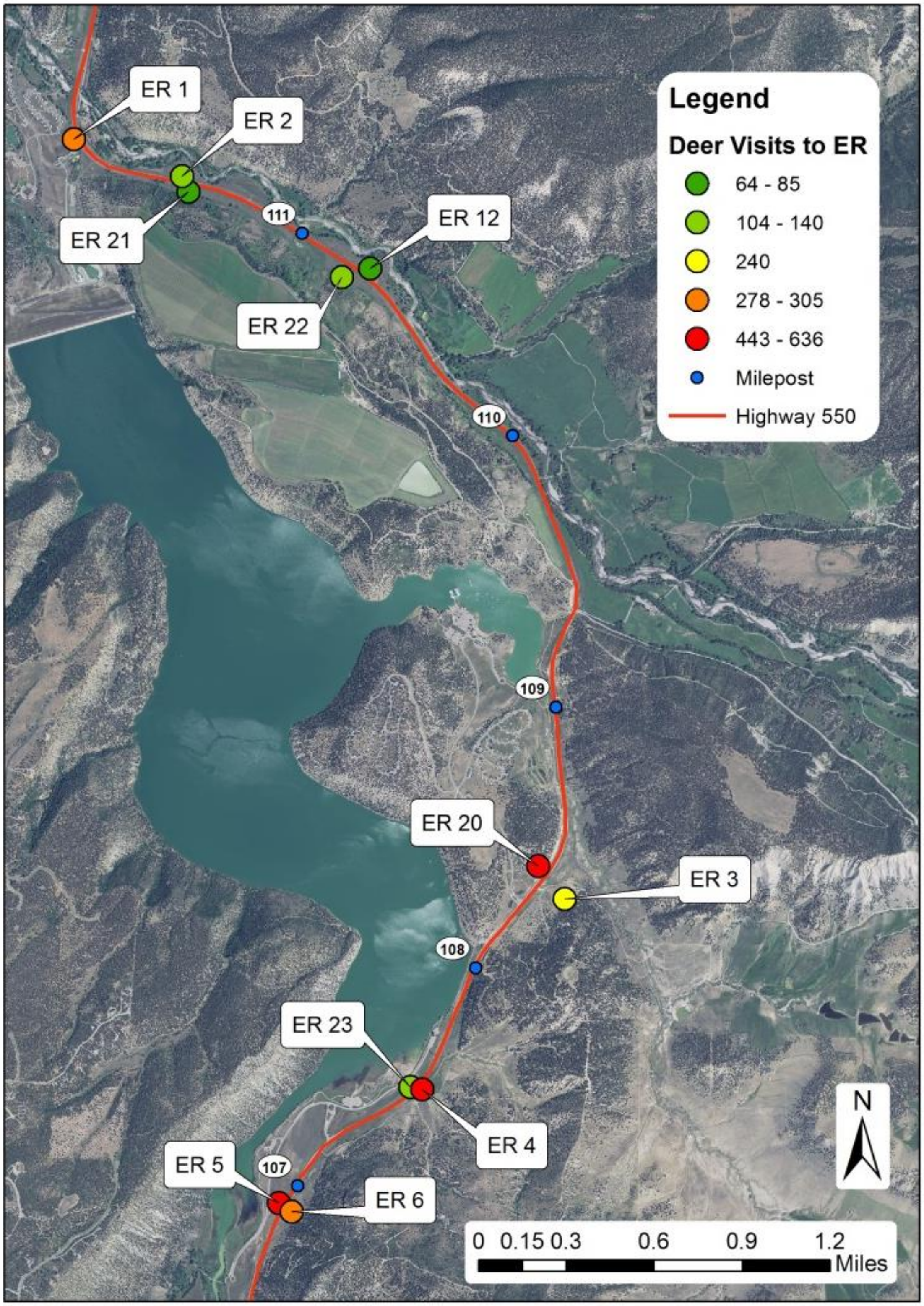

Figure 5. Spatial distribution of mule deer visits recorded at 11 escape ramps along Highway 550 from August 1, 2012 to July 31, 2014.

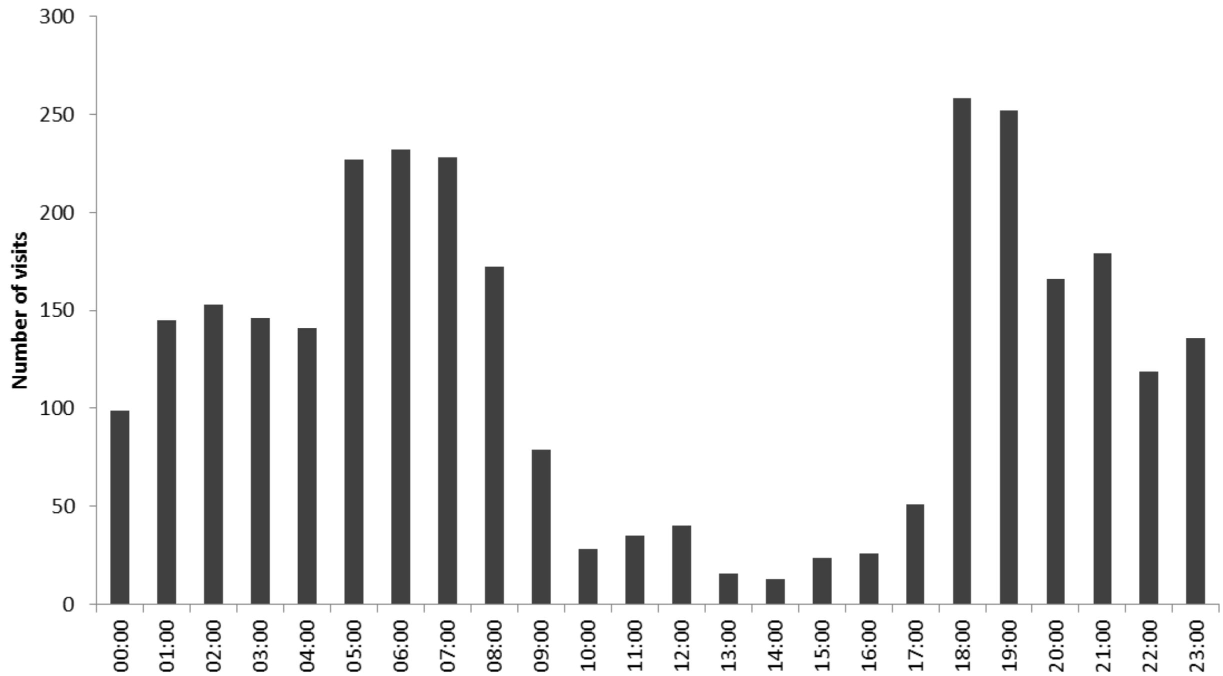

Figure 6. Hourly distribution of visits of mule deer to 11 escape ramps along Highway 550, Ouray County, Colorado USA, from August 2012 – July 2014.

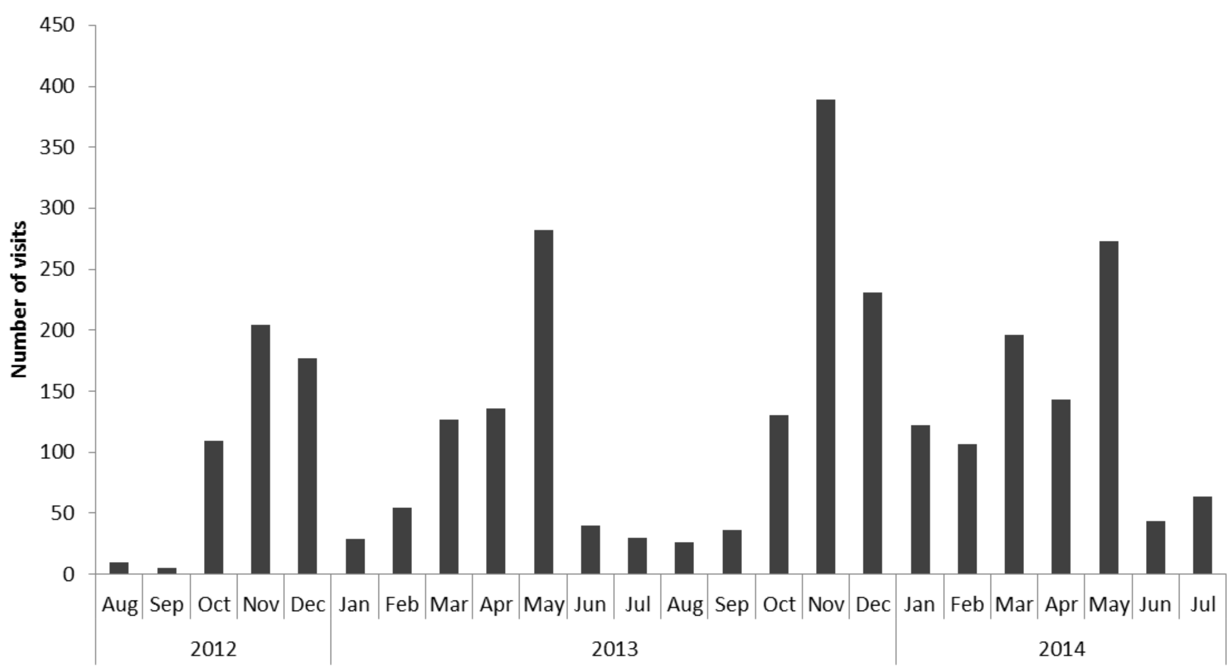

Figure 7. Monthly distribution of mule deer visits to 11 escape ramps along Highway 550 from August 2012 – July 2014.

Mule Deer Reversals

We documented 27 successful deer reversals, i.e., instances where animals used an ER to cross the wildlife fence from the safe side to the ROW. The successful deer reversals occurred at three different ER, two of which (ramps 2 and 4) had a horizontal bar present. One unsuccessful reversal attempt by a deer was observed at Ramp 1 when the animal was able to get its forelegs onto the ramp platform, but then fell back to the safe side of the fence; this ER also had a horizontal bar present (Figure 7).

Figure 8. A deer making an unsuccessful reversal attempt at Ramp 1. Subsequent video data show the deer falling back to the safe side of the wildlife fence and walking away.

All but two successful deer reversals occurred at Ramp 20, which is located approximately 675 feet from the Dutch Charlie Entrance to Ridgway State Park. This ER also had the greatest number of deer visits as well as the highest percentage of successful escapes of any ER in the study area. Reversals at Ramp 20 occurred throughout the study period (Figure 8), with most occurring during the spring and winter and none in the summer (June, July and August).

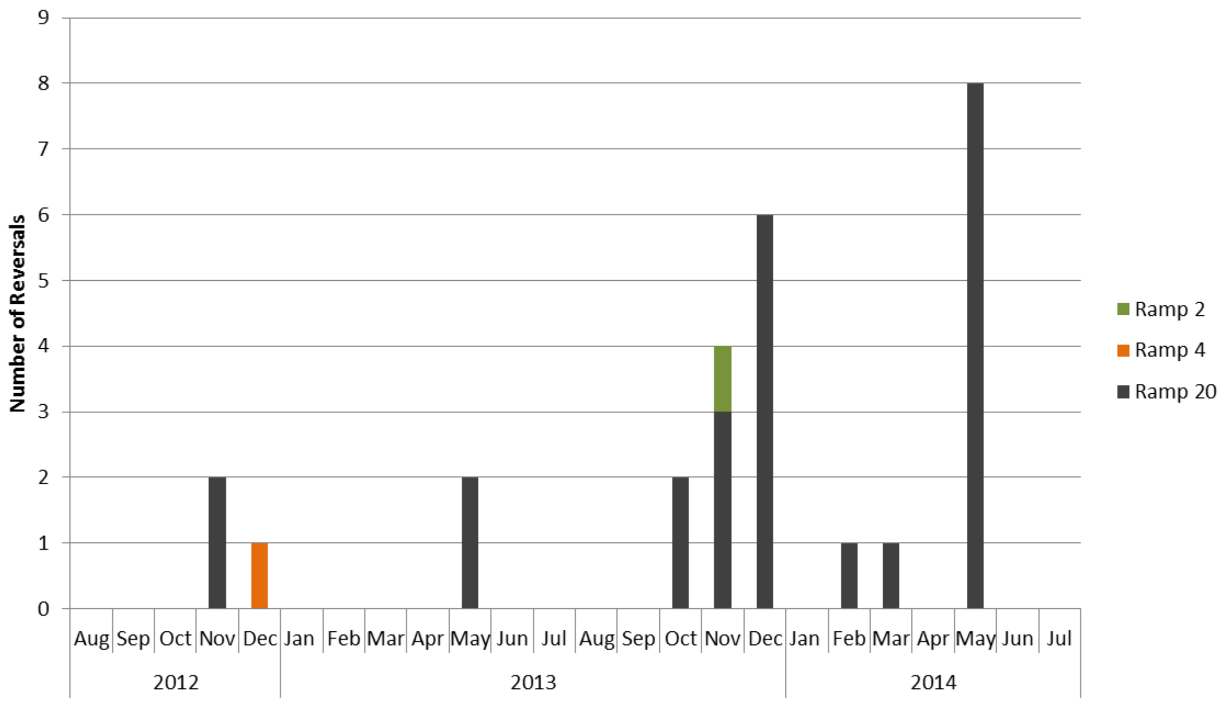

Figure 9. Monthly distribution of mule deer reversals at three escape ramps along Highway 550 from August 2012 – July 2014.

Mule Deer Data Modeling

Logistic Regression. The top model in our model set for the probability of a deer making a successful escape was the global model and included all the variables considered (bar presence, distance to highway, guide fence presence, distance to nearest shrub, distance to nearest tree). The global model had 0.93 of the cumulative model weights (Table 3). Variables with the highest cumulative AIC_c weight included guide fence presence (w_+ = 1.00), and bar presence (w_+ = 1.00).

Table 3. Log-likelihood, number of parameters (*K*), Akaike's information criterion for small sample size (AIC*c*), AIC*c* difference (Δ AIC*c*), and AIC*c* model weight (w_i) for the five most-parsimonious models of escape probability at 11 escape ramps along Highway 550.

Model	Log-likelihood	*K*	AIC_c	ΔAIC_c	w_i
bar presence + distance to highway + guide fence presence + distance to nearest shrub + distance to nearest tree	-1738.66	7	3477.37	0	0.93
bar presence + guide fence presence + distance to nearest shrub + distance to nearest tree	-1742.22	6	3484.48	7.11	0.03
bar presence + distance to highway + guide fence presence + distance to nearest tree	-1742.36	6	3484.75	7.38	0.02
bar presence + distance to highway + guide fence presence + distance to nearest shrub	-1742.75	6	3485.54	8.17	0.02
bar presence + distance to highway + guide fence presence	-1745.66	5	3491.35	13.98	<0.01

The other three variables (distance to highway, distance to nearest shrub, and distance to nearest tree) also had very high weights (w_+ = 0.97 to 0.98). All five variables had 95% CI of β_i that did not overlap 0 (Table 4). Guide fence presence and distance to nearest tree were positively correlated with the probability of a visit by a deer to an ER resulting in a successful escape. Bar presence, distance to nearest shrub, and distance to highway were each negatively correlated with the probability of a visit by a deer to an ER resulting in a successful escape.

Table 4. Cumulative AICc weight (*w*+), regression coefficient estimate (β_i), standard error (SE), and 95% confidence interval (CI) for variables used in the logistic regression.

				95% CI	
Variable	w_+	β_i	SE	Lower	Upper
guide fence presence	1.00	0.692	0.096	0.504	0.880
bar presence	1.00	-0.582	0.105	-0.788	-0.376
distance to nearest tree	0.98	0.003	0.001	0.001	0.005
distance to nearest shrub	0.98	-0.008	0.003	-0.014	-0.002
distance to highway	0.97	-0.004	0.001	-0.006	-0.002

Poisson Log-linear Regression. Based upon the logistic regression results above, we included all five independent variables from the global model (bar presence, distance to highway, guide fence presence, distance to nearest shrub, distance to nearest tree) in the Poisson log-linear regression analysis. The three distance variables (nearest tree, nearest shrub, and highway) were categorized into two bins each (within or beyond specific distances). Thresholds for binning distances were based upon the data and were defined as 29 meters for distance to highway, nine meters for distance to nearest shrub, and 43 meters for distance to nearest tree.

All five variables had 95% CI of β_i that did not overlap 0 (Table 5). Similar to the logistic regression results, guide fence presence was positively correlated with the probability of a visit by a deer to an ER resulting in a successful escape and bar presence, distance to nearest shrub, and distance to highway were each negatively correlated with the probability of a visit by a deer to an ER resulting in a successful escape. However, contrary to the logistic regression, distance to nearest tree was negatively correlated.

Table 5. Regression coefficient estimate (β_i), standard error (SE), and 95% confidence interval (CI) for variables used in the Poisson log-linear regression.

			95% CI	
Variable	β_i	SE	Lower	Upper
guide fence presence	0.459	0.016	0.428	0.491
bar presence	-1.121	0.016	-1.152	-1.091
nearest tree > 43m away	-0.320	0.004	-0.328	-0.311
nearest shrub > 9m away	-0.719	0.020	-0.759	-0.679
highway > 29m away	-1.473	0.009	-1.490	-1.456

Quasi-Poisson Log-linear Regression. Because overdispersion was present in our data, we used a quasi-Poisson adjustment. The resulting regression coefficient estimates were the same, but with decreased precision of estimates.

All five variables had 95% CI of β_i that overlapped 0 (Table 6). Similar to the logistic regression results, guide fence presence was positively correlated with the probability of a visit by a deer to an ER resulting in a successful escape and bar presence, distance to nearest shrub, and distance to highway were each negatively correlated with the probability of a visit by a deer to an ER resulting in a successful escape. Distance to nearest tree was negatively correlated.

Table 6. Regression coefficient estimate (β_i), standard error (SE), and 95% confidence interval (CI) for variables used in the quasi-Poisson log-linear regression.

			95% CI	
Variable	β_i	SE	Lower	Upper
guide fence presence	0.459	2.508	-4.457	5.375
bar presence	-1.121	2.428	-5.880	3.638
nearest tree > 43m away	-0.320	0.677	-1.645	1.006
nearest shrub > 9m away	-0.719	3.170	-6.932	5.493
highway > 29m away	-1.473	1.351	-4.120	1.174

The results of modeling escape success by mule deer at ER are confounded by the small amount of variation among most of the ER variables, the potential lack of independence of crossing attempts due to correlation among animals, and the small sample size of the total number of ER evaluated. Conclusions are based on correlations in some variables with successful escapes from ER, recognizing that when the regression coefficients for a particular variable had a consistent slope among all three regression analyses, the confidence intervals around the regression coefficients for all variables overlapped zero in the log-linear quasi-Poisson regression that accounted for overdispersion in the data.

Elk

We recorded 52 visits of elk to six of the 11 ER within the study area. Of these visits, we were able to confirm whether or not an elk made a successful escape on 49 occasions, and of these there were 25 successful escapes from the ROW (51.0%). The number of visits and successful escapes also varied with each ER (Table 7). We did not observe any reversals by elk.

Table 7. Visits, escapes, and reversals of elk at each escape ramp.

Ramp ID #	Visits	Confirmed Observations	Successful Escapes	Escape Percentage	Reversals
1	0	-	-	-	0
2	0	-	-	-	0
3	37	36	19	52.8	0
4	4	2	1	50.0	0
5	0	-	-	-	0
6	0	-	-	-	0
12	2	2	0	0	0
20	4	4	3	75.0	0
21	2	2	2	100	0
22	3	3	0	0	0
23	0	-	-	-	0
TOTAL	**52**	**49**	**25**	**51.0**	**0**

There were no reports of elk-vehicle collisions during the study period, but elk were observed at ER in the ROW side of the wildlife fence during this time. The study area falls within the overall range for elk in Colorado and within the winter concentration range and severe winter range (CPW 2013). While elk were observed during the fall and winter, most visits to ER occurred during the spring and summer (April – July) (Figure 9).

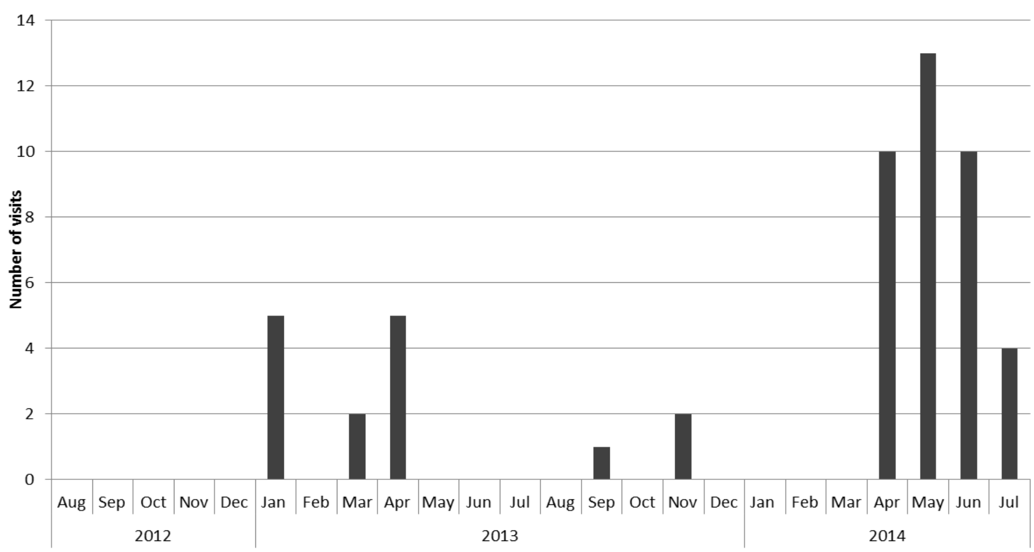

Figure 10. Monthly distribution of elk visits to 11 escape ramps along Highway 550 from August 2012–July 2014.

The majority of elk visits occurred at Ramp 3, which is the ER located furthest from the highway of any ER in this study (over 500 feet). Elk visits were distributed widely across the study area and were centrally located, with no visits occurring at the northernmost or southernmost ramps (Figure 10).

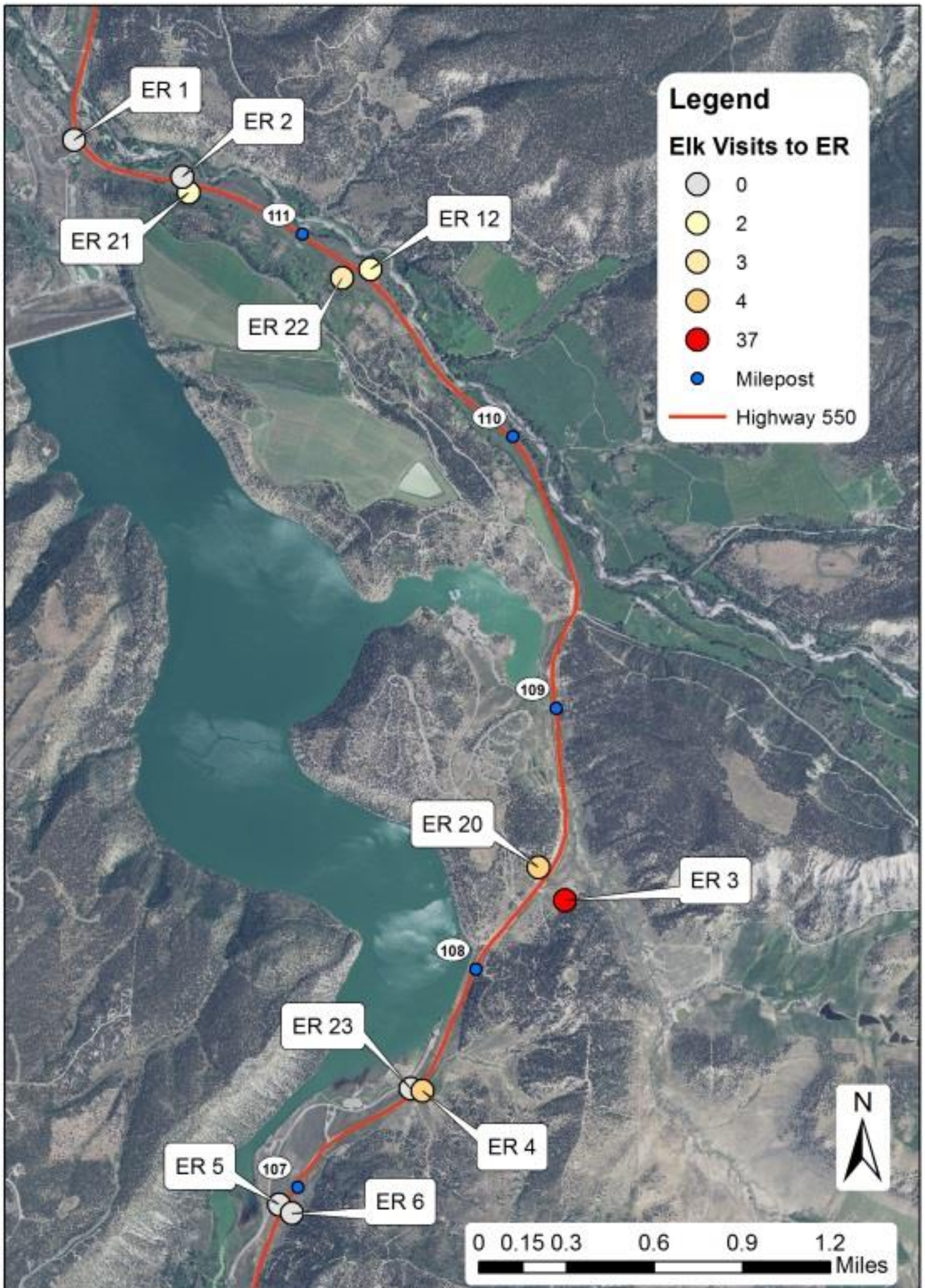

Figure 11. Spatial distribution and frequency of elk visits recorded at 11 escape ramps along Highway 550 from August 1, 2012 to July 31, 2014.

Other Species

In addition to deer and elk, we observed other wildlife species using ER including black bear (*Ursus americanus*), mountain lion (*Puma concolor*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), wild turkey (*Meleagris gallopavo*), numerous rodents, raptors, and passerines. We provide detailed results for black bears and mountain lions which are large enough to be of concern for WVC and that have had occasional documented collisions along this stretch of Highway 550.

The study area falls within the summer concentration area and overall range for black bears in Colorado, and an area of bear-human conflict occurs to the west (CPW 2013). Most black bear visits to ER occurred from late spring to early fall (Figure 11), which concur with the summer concentration area designation (CPW 2013).

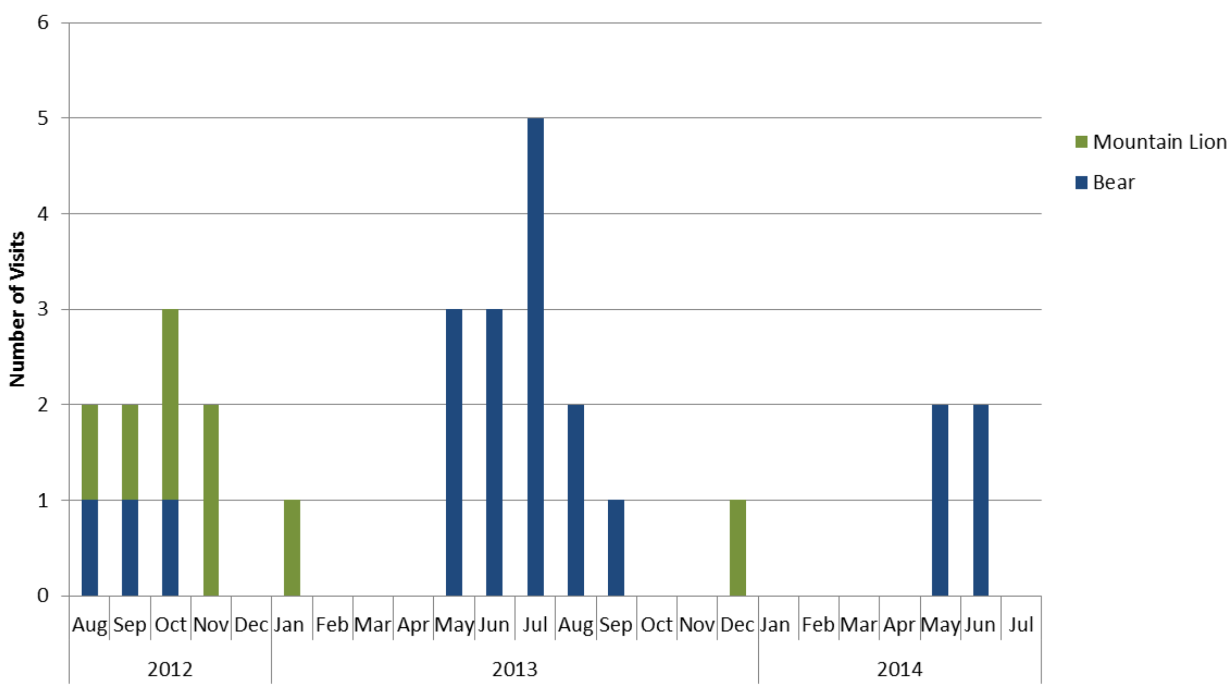

Figure 12. Monthly distribution of mountain lion and black bear visits to 11 escape ramps along Highway 550 from August 2012 – July 2014.

Most visits by black bear occurred at the north end of the study area, especially at ramps 21 and 22, however four visits were observed at Ramp 5 at the southern end (Table 8; Figure 13).

Table 8. Visits, escapes, and reversals of black bear at each escape ramp.

Ramp ID #	Visits	Confirmed Observations	Successful Escapes	Escape Percentage	Reversals
1	1	1	0	0.0	0
2	1	-	-	-	1
3	2	2	1	50.0	0
4	0	-	-	-	0
5	4	4	1	25.0	0
6	0	-	-	-	0
12	3	3	1	33.3	0
20	0	-	-	-	0
21	4	4	4	100	0
22	6	5	4	80.0	1
23	0	-	-	-	0
TOTAL	**21**	**19**	**11**	**57.9**	**2**

Escapes made by bears were often made by the bear climbing down the vertical wall of the ramp to the safe side of the wildlife fence. In a similar fashion, reversals were made by bears climbing up the vertical wall and into the ROW (Figure 12).

Figure 13. A black bear making a successful reversal by climbing up the vertical wall on the safe side of the fence.

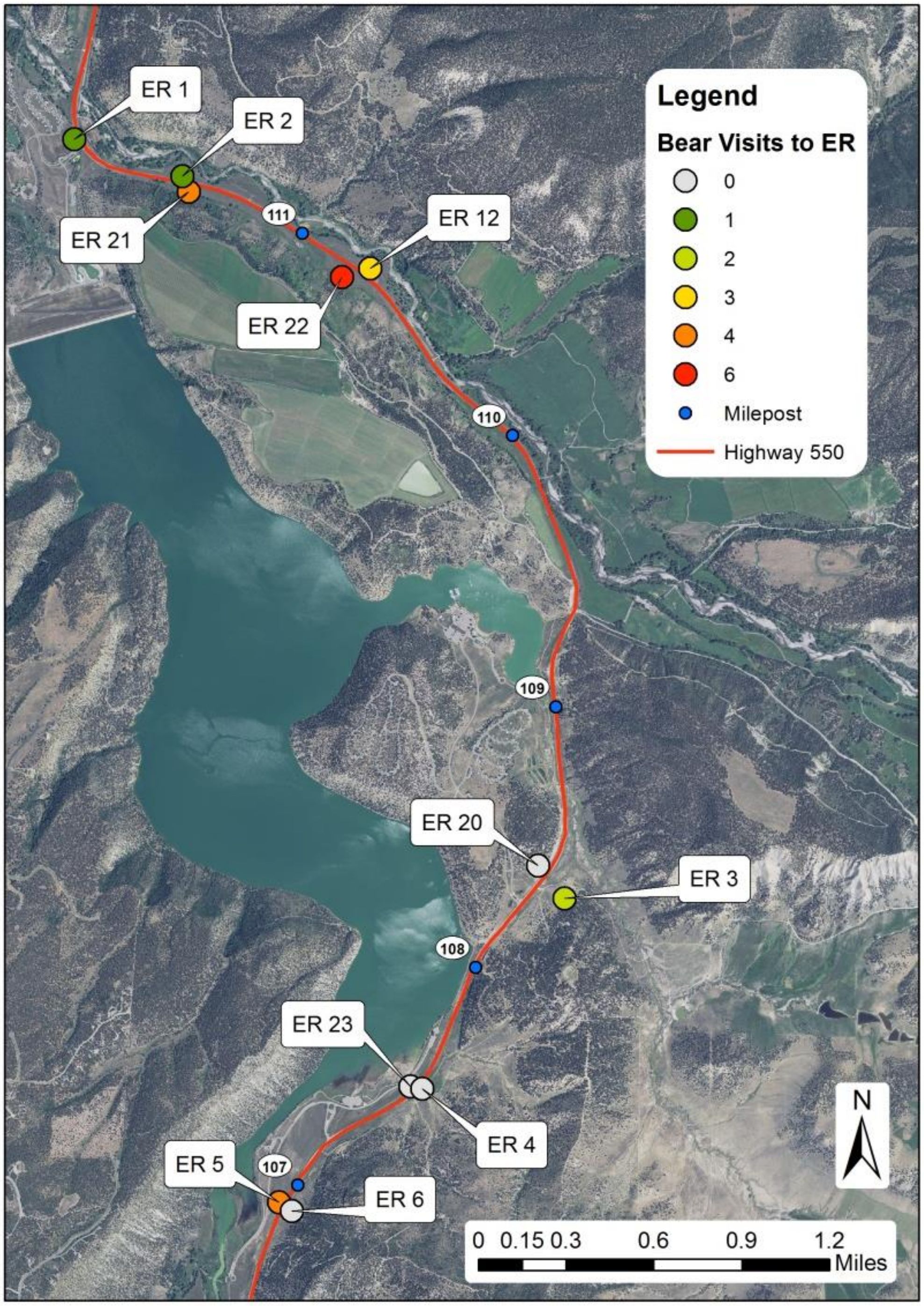

Figure 14. Spatial distribution and frequency of black bear visits recorded at 11 escape ramps along Highway 550 from August 1, 2012 to July 31, 2014.

We observed mountain lion at seven of the 11 ER (Table 9 and Figure 14) and these visits were distributed widely across the study area (Figure 15). The study area falls within the overall range for mountain lion in Colorado, and the areas surrounding the highway north of MP 112 and west of Ridgway Reservoir are designated as mountain lion-human conflict areas (CPW 2013). Mountain lions were observed at ER from late summer (August) to mid-winter (January) (Figure 11).

Table 9. Visits, escapes, and reversals of mountain lion at each escape ramp.

Ramp ID #	Visits	Confirmed Observations	Successful Escapes	Escape Percentage	Reversals
1	0	-	-	-	0
2	1	-	-	-	1
3	1	1	1	100	0
4	0	-	-	-	0
5	1	1	1	100	0
6	0	-	-	-	0
12	1	1	0	0.0	0
20	1	0	-	-	0
21	2	2	1	50.0	0
22	1	-	-	-	1
23	0	-	-	-	0
TOTAL	**8**	**5**	**3**	**0.6**	**2**

Photo and video evidence indicates mountain lions were able to jump up to the ramp from the safe side of the fence to make reversals into the ROW (Figure 14).

Figure 15. A mountain lion making a successful reversal by jumping up the vertical wall on the safe side of the fence.

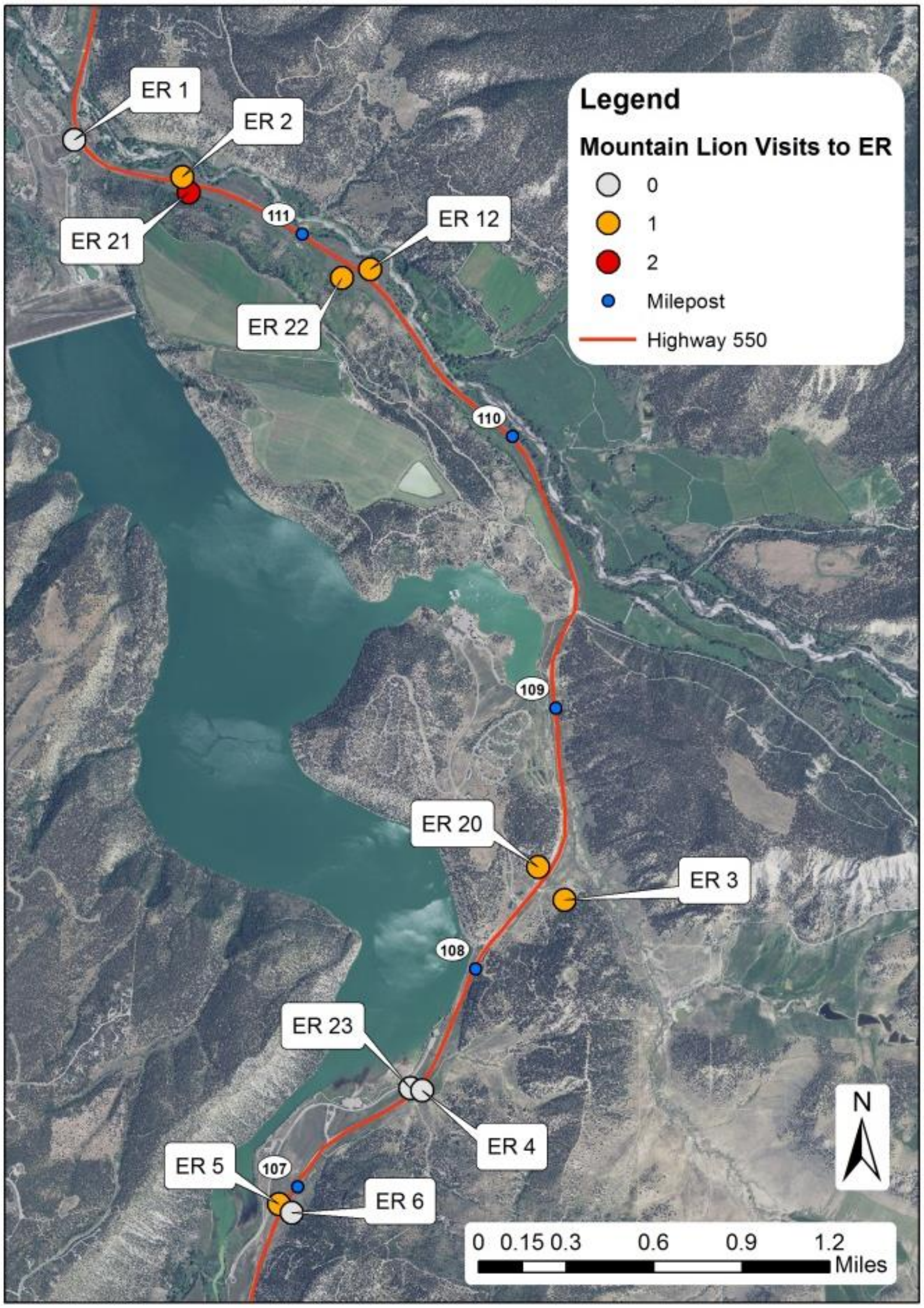

Figure 16. Spatial distribution and frequency of mountain lion visits recorded at 11 escape ramps along Highway 550 from August 1, 2012 to July 31, 2014.

Culvert Escape Jump Monitoring

Alkali Creek

The escape jump at the culvert along Alkali Creek was not used significantly during the two years of monitoring. A total of 22 deer visits were recorded. Of these 22 observations, we documented three successful escapes, 15 non-escapes, and four undetermined observations. One of the deer that made a successful escape skirted the fence and used the ramp created by the slanting headwall (see Figure 3) to walk to safety instead of jumping down to the creek bed. We did not observe any instances of deer jumping up from the creek bed nor using the ramp along the headwall to gain access to the ROW. No species other than deer (and humans) were observed using this escape jump.

Dry Creek

The escape jump at the culvert along Dry Creek was visited to a much greater extent than the jump at Alkali Creek. A total of 147 deer visits were recorded at the Dry Creek escape jump. Of these 147 observations, we documented 42 successful escapes, 90 non-escapes, 11 undetermined observations, and four reversals from the creek bed into the ROW. The deer making the reversals into the ROW used the side of the perpendicular fencing without the horizontal bar and were able to jump up relatively easily, likely using the ramp created by the slanted headwall on the creek side of the jump (Figure 16). Thirty-one of the 42 (73.8%) successful escapes occurred on the side of the escape jump without the horizontal bar. Fox, coyote, American badger (*Taxidea taxus*), raccoon, and skunk were observed in addition to deer at this escape jump. Coyote and fox were observed making successful escapes as well as gaining access to the ROW using this escape jump.

Figure 17. Dry Creek escape jump along Highway 550 from the creek bed.

Cost-benefit Analysis

The effectiveness of any wildlife mitigation strategy must be weighed with the costs of implementing that strategy. We conducted a cost-benefit analysis for the construction of ER in the study area and compared these costs to WVC data to determine how much, if any, WVCs were reduced following the construction of ER. For comparison purposes and future reference, we provided costs for ER construction from previous bids submitted to CDOT. We used the actual project costs for the construction of the eight ER in 2010 for the cost-benefit analysis.

Project Costs

Average unit bid prices for ER construction were obtained from CDOT's annual Engineering Estimates and Market Analysis internet data portal (CDOT 2014). Average unit bid prices per ER for 2006 to 2013 ranged from $4,500.00 to $7,906.90, with an average (for years with data) of $6,434.26 (Table 10). Other reported costs for installation of one ER are approximately $2,000 in 1997-1998 (Bissonette and Hammer 2000), $8,500, which is based on an approximate average of $6,250 and $11,000 (P. Basting, pers. comm. cited in Huijser et al. 2008b), and $9,813 used in a cost-benefit analysis based on 2007 costs (Huijser et al. 2009).

Table 10. Average per unit bid price for wildlife escape ramps (ER, item number 607-60002) from CDOT annual construction cost data books.

year	Average bid price per ER
2006	none
2007	$5,500.00
2008	$4,500.00
2009	$7,906.90
2010	$7,027.78
2011	$7,669.44
2012	$6,001.41
2013	none

Three of the 11 ER within this project were constructed by CDOT Maintenance in 2005 (SREP 2006); the remaining eight were constructed in 2010. We used actual cost figures from the final billing of the eight ER constructed in 2010 for the cost-benefit analysis (Table 11). Specific costs and construction dates for the three ramps installed in 2005 were not available.

Table 11. Actual costs for the installation of eight earthen escape ramps completed in April 2010.

Item	Quantity	Unit Price	Total Cost
Game Ramp (6' high, 2:1)	2	$5,500.00	$11,000.00
Game Ramp (6.5' high, 3:1)	2	$8,500.00	$17,000.00
Game Ramp (4.5' with rail)	4	$5,200.00	$20,800.00
TOTAL			**$48,800.00**

In addition to ER construction, the project in 2010 included repair of the wildlife fence, addition of a jump down, installation of pedestrian gates, and removal of one-way deer gates which were in disrepair and not suitable for elk. Based upon the final billing to the contractor, the total cost for these improvements along with the construction of the eight ER was $143,135.76.

To roughly estimate the costs for construction of the three ramps in 2005, we simply used the rate of $6,100 per ramp from the eight ER constructed in 2010 and multiplied it by three to obtain a total cost of $18,300. This value is in US$ from 2010. We then converted this value to a 2005 value using the average Consumer Price Index adjustment multiplier (U.S. Department of Labor 2014), to obtain a per ramp price of $5,463, which is comparable to bid prices from that time period.

Wildlife-vehicle Collision Data

WVC data for Milepost 105 through MP 113 from May 2000 through July 2014 were analyzed to investigate potential declines in WVC following ER construction (Figure 17). WVC data collection by CDOT maintenance crews began in October 2005 and we assessed data through July 2014. Data collected by the Colorado State Patrol (CSP), which are used by CDOT for official WVC numbers, are complete through June 2012. The data collected by CDOT maintenance crews are useful as a supplement to the CSP data to provide information on unreported wildlife mortality. Animals recorded as "unknown" are large enough to cause a traffic accident and are often deer or elk.

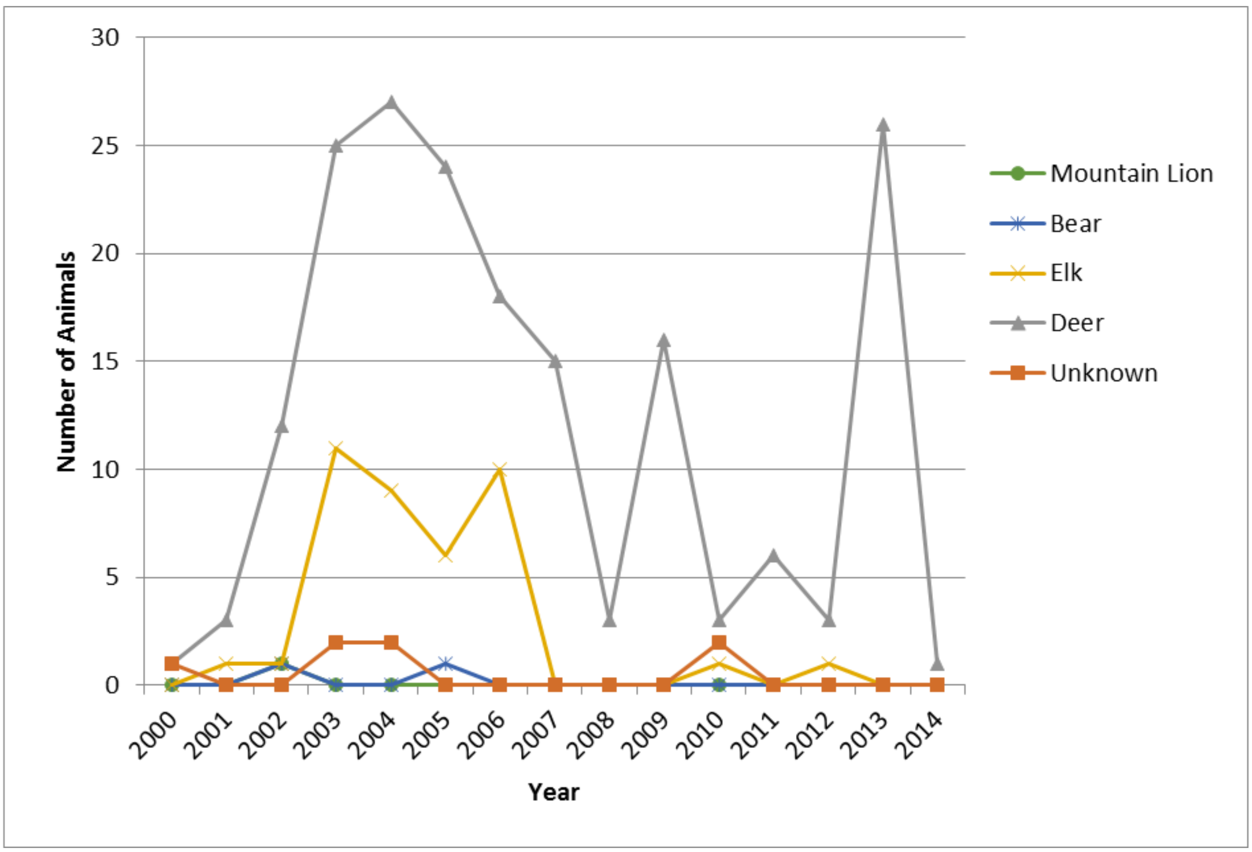

Figure 18. Wildlife-vehicle collision data for May 2000 through July 2014 for Milepost 105 through 113 along Highway 550.

Some of the WVC data collected by CDOT maintenance did not have specific mileposts attributed to each animal, but were reported as number of individuals collected between two mileposts on a particular day. For the most part, the locations provided for these records were completely contained within the study area. When this was not the case and the milepost endpoints partially fell outside of the study area, the percentage of overlap with the study area was multiplied by the total number of animals reported to give an approximation of the number of animals collected within the study area on that date. Three of these records occurred in 2013 and accounted for 25 deer collected in that year within the study area. One additional record occurred in 2007 and accounted for two deer. These records were used in the compilation of data within the study area over a yearly basis (Figure 17) and in the cost-benefit analysis, but were not used in the analysis of animals by milepost (Figures 18 and 19).

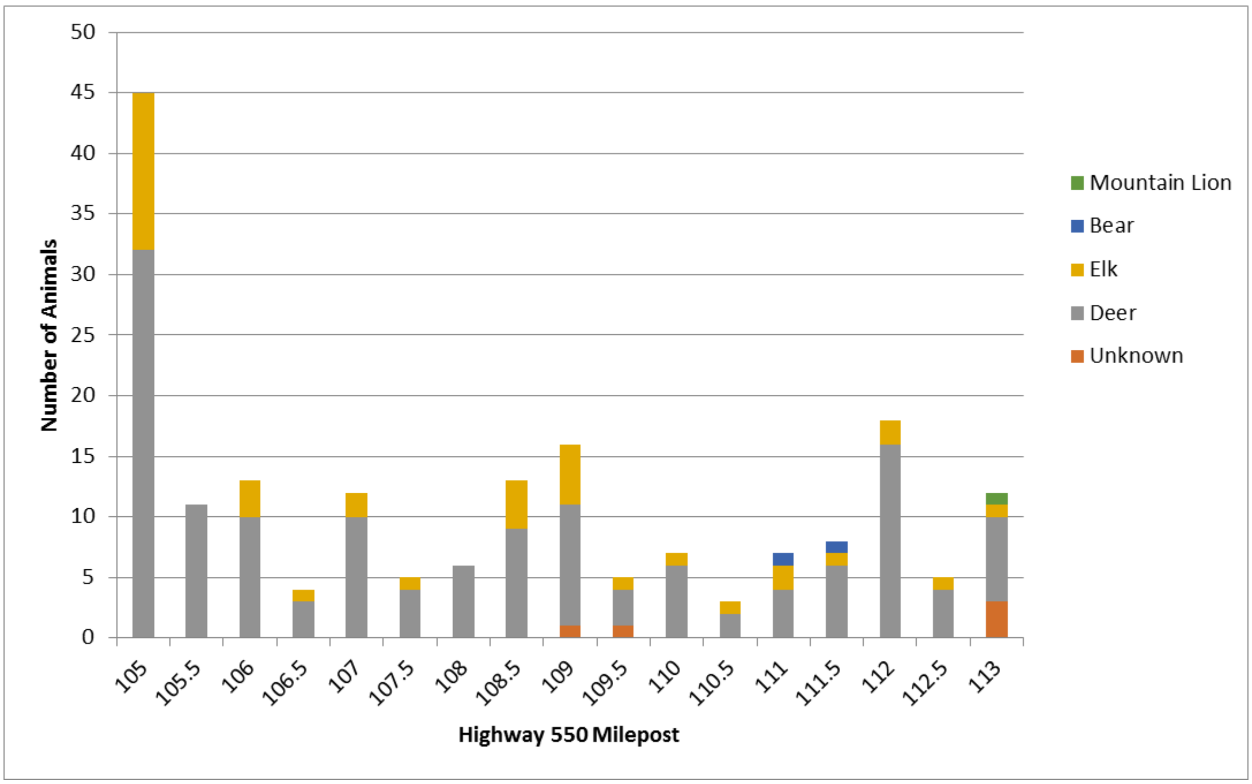

Figure 19. Pre-construction wildlife-vehicle collision data for May 2000 through April 2010 for Milepost 105 through 113 along Highway 550.

Using April 30, 2010 as our date of delineation between pre-construction (Figure 18) and post-construction (Figure 19) for the eight ER, we evaluated data from 10 years prior to construction to the end of the study period (July 31, 2014). We determined rates of WVC for deer and elk by calculating the number of WVC per mile per year for both pre-construction and post-construction time periods.

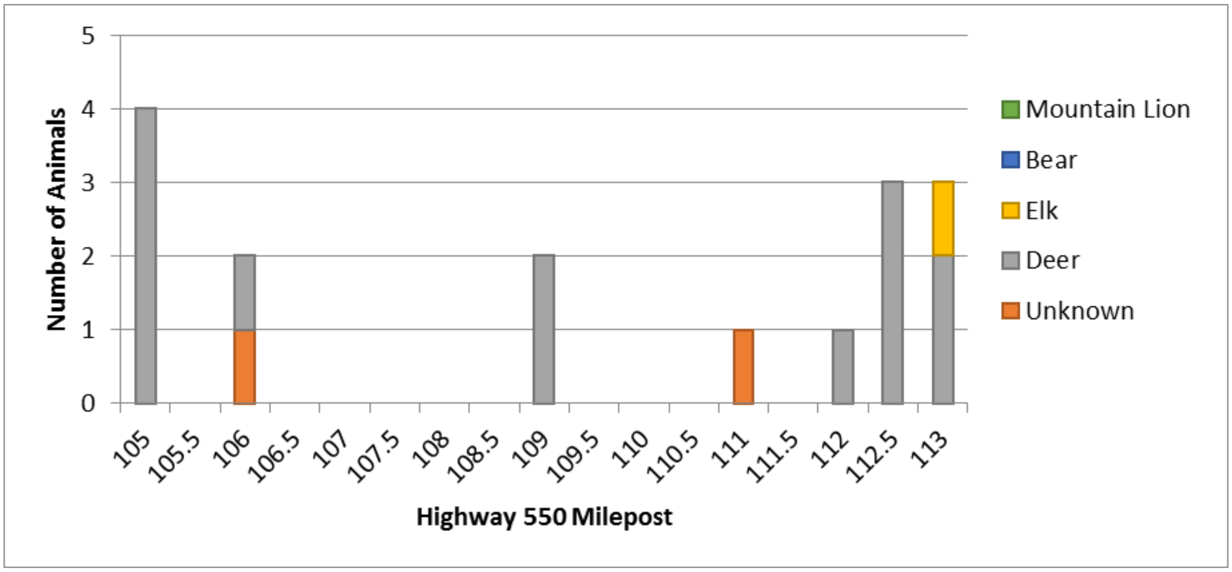

Figure 20. Post-construction wildlife-vehicle collision data for May 2010 through July 2014 for Milepost 105 through 113 along Highway 550.

We calculated collision rates (animal collisions per mile per year) for deer, elk and unknown species for four different time periods (Table 12) for the eight-mile study area. Time periods included six years prior to an estimated completion date of December 31, 2005 for the three initial ER, a period of time between construction of the first three ER and construction of the additional eight, a long-term pre-construction time period for the eight ER built in 2010, and a post-construction time period following construction of the eight ER in 2010.

Table 12. Wildlife collision rates for the eight-mile study area (MP 105 – MP 113) along Highway 550.

Time Period	Dates	Number of Deer Reported	Deer Collision Rate[1]	Number of Elk Reported	Elk Collision Rate[1]	Number of Unknown Reported	Unknown Collision Rate[1]
Prior to construction of 3 original ER	Jan 2000 – Dec 2005	93	1.94	28	0.58	5	0.10
Prior to construction of 8 additional ER	May 2000 – April 2010	145	1.81	39	0.49	5	0.06
After construction of 3 ER; before construction of 8 ER	Jan 2006 – April 2010	53	1.53	11	0.32	0	0
After construction of 8 additional ER	May 2010 – July 2014	38	1.12	1	0.03	2	0.06

[1]Collision rate units are number of animal collisions per mile per year.

Much of the WVC within the study area, both before and after ER construction, occurs at the ends of the wildlife fencing near MP 105 and MP 113 (Figures 18 and 19). The northern terminus of the wildlife fence is at the Uncompahgre River, MP 112.5, and the southern is at MP 105.5 near Ouray County Road 10. The northernmost ER is at MP 111.5 and the southernmost ER is at MP 107-. We conducted a second analysis within a reduced study area to evaluate the continuous stretch of highway that was most influenced by the construction of ER and to eliminate the confounding factor of higher WVC rates at the ends of the wildlife fencing. We added a half-mile buffer beyond the northernmost and southernmost ER to generate a new reduced study area that extended from MP 106.5 to MP 112. Between these two locations along this 5.5-mile stretch of highway, one unknown and three deer mortalities were recorded after construction of the eight ER in 2010 (Figure 19). After including the derived numbers from CDOT Maintenance data collected between mileposts, the number of deer reported increased to 21 and the deer collision rate was 0.90 deer per mile per year (Table 13), which is the lowest rate for deer calculated in this study. There were no elk collisions reported within this reduced study area after construction of the eight ER in 2010, and the most recent report of an elk collision within this area was in 2006 when six were reported.

Table 13. Wildlife collision rates for the reduced study area (MP 106.5 – MP 112) along Highway 550.

Time Period	Dates	Number of Deer Reported	Deer Collision Rate[1]	Number of Elk Reported	Elk Collision Rate[1]	Number of Unknown Reported	Unknown Collision Rate[1]
Prior to construction of 3 original ER	Jan 2000 – Dec 2005	52	1.58	15	0.45	2	0.06
Prior to construction of 8 additional ER	May 2000 – April 2010	80	1.45	21	0.38	2	0.04
After construction of 3 ER; before construction of 8 ER	Jan 2006 – April 2010	29	1.22	6	0.25	0	0.00
After construction of 8 additional ER	May 2010 – July 2014	21	0.90	0	0	1	0.04

[1]Collision rate units are number of animal collisions per mile per year.

Animal Valuation

Huijser et al. (2009) present extensive cost-benefit analyses for WVC mitigation measures. Within their analyses, estimates are made of average costs associated with WVC for deer and elk based on data compiled from the United States and Canada. The costs for a collision that results in human injuries would be higher than these average values, and a collision that results in property damage only would be lower (Huijser et al. 2009). Their values are based upon 2007 values of US$, which we converted to 2010 values using the average Consumer Price Index adjustment multiplier (U.S. Department of Labor 2014) (Table 14).

Table 14. Estimated costs for average vehicle collisions with deer and elk.

Cost Description	Deer (2007 US$)[1]	Elk (2007 US$)[1]	Deer (2010 US$)	Elk (2010 US$)
vehicle repair costs per collision	$2622	$4550	$2757	$4785
human injuries per collision	$2702	$5403	$2842	$5682
human fatalities per collision	$1002	$6683	$1054	$7028
towing, accident attendance, and investigation	$125	$375	$131	$394
Hunting value animal per collision	$116	$397	$122	$418
carcass removal and disposal per collision	$50	$75	$53	$79
TOTAL	**$6617**	**$17,483**	**$6959**	**$18,386**

[1]Values from Huijser et al. (2009).

Bissonette et al. (2008) provide a more conservative value for the average cost of collisions with deer in Utah. By evaluating six years of data for deer collisions and associated costs, they determined an average cost per collision of $3,470. This value accounts for human fatality, vehicle damage, deer loss, and human injury costs. Their values were based on 2001 values of US$, which we converted to 2010 values using the average Consumer Price Index adjustment multiplier (U.S. Department of Labor 2014) to obtain an average cost per deer collision of $4,272. To obtain an approximate conservative value for elk, we divided the adjusted value of $4,272 by $6,959 to obtain a factor of 0.614 which we then multiplied by $18,386 to get $11,289.

Costs vs. Benefits

We compared costs of constructing ER against the benefits gained in terms of reduced WVC. Since ER construction took place over two phases (three in 2005 and eight in 2010), we analyzed the costs and benefits at time periods before and after each construction phase. We evaluated the costs associated with the construction of the eight ER in 2010 at both the full-project level as well as the ER-only level. For the three ER constructed in 2005, we use the estimated costs derived above.

Table 15. Costs, collision rates, and benefits for two phases of escape ramp construction along Highway 550.

Phase	3 ER Constructed in 2005			8 ER Constructed in 2010		
Cost	$18,300			$48,800 (ER only) to $143,136 (total project)		
Time Period Pre	Jan 2000 – Dec 2005			May 2000 – April 2010		
Time Period Post	Jan 2006 – April 2010			May 2010 – July 2014		
Wildlife Species	deer	elk	unknown	deer	elk	unknown
Collision Rate[1] Before	1.94	0.58	0.10	1.81	0.49	0.06
Collision Rate[1] After	1.53	0.32	0.00	1.12	0.03	0.06
Reduction	0.41	0.26	0.10	0.69	0.46	0
% Change	-21.1%	-44.8%	-100%	-38.1%	-93.9%	0%
Cost Per Animal	$6,959	$18,386	$6,959 to $18,386	$6,959	$18,386	$6,959 to $18,386
Annual Benefit	$22,826	$38,243	$5,567 to $14,709	$38,414	$67,660	0
Total Annual Benefit	**$66,636 to $75,778**			**$106,074**		

[1]Collision rate units are number of animal collisions per mile per year.

Another way to look at the benefits gained from the construction of the eight ER in 2010 is that for the 10 years prior to construction, WVC along the eight-mile stretch of highway cost society $172,839 per year ($100,766 for deer and $72,073 for elk). Following construction, that figure was reduced to $66,766 per year ($62,353 for deer and $4,413 for elk), for an annual benefit of $106,073. At this rate, the total project cost of $143,136 was recovered in 1.35 years.

The same calculation using the more conservative values for WVC costs derived above ($4,272 for deer and $11,289 for elk), gives an annual cost to society of $106,112 ($61,859 for deer and $44,253 for elk) before ER construction and $40,986 after ($38,277 for deer and $2,709 for elk). Using this lower cost per animal gives an annual benefit of $65,126 and a cost-recovery timeframe for the entire 2010 project of 2.20 years.

Conclusions and Recommendations

Our results suggest that the presence of a guide fence positively affected whether or not a successful escape resulted when a deer visited an ER. Conversely, horizontal bar presence was negatively correlated with successful escapes and we noted two successful reversals at ER with horizontal bars. Other ER design variables were considered, but there was so little variation among ER with respect to these variables that meaningful comparisons could not be made.

In addition to ramp design details, we noted patterns among landscape characteristics that correlated with successful escapes. The distance of the ER to the nearest shrub on the safe side of the wildlife fence was negatively correlated with escape success. So, the closer the nearest shrub, the more likely a deer was to make a successful escape. The distance to the nearest tree on the safe side of the fence showed a positive correlation on the logistic regression and negative correlations in the log-linear regressions. We also note that the landing areas directly beneath all ER did not have shrubs or trees present, so even when shrubs were close to the ER (less than five meters) they were not directly below the ramp thereby obstructing the landing area. Whether animals view shrubs and trees as safe or unsafe (potentially harboring predators) is unclear, but when possible a prudent approach to ER design is to ensure that the area beneath and within five to ten meters of the landing area is clear.

The distance of ER from Highway 550 was negatively correlated with escape success. The further an ER was from the highway, the less likely a deer was to make a successful escape. Distances from ER to highway ranged from 25 to 155 meters and all but one were less than 80 meters away. The negative correlation of deer escape success to distance from the highway could be due to the urgency with which deer were concerned with escaping the ROW. Deer at ER closer to the highway may be more stressed and sense a greater need to escape. Often when deer were observed on an ER, there was little sense of urgency to escape. Animals were observed casually grazing at some ER and on occasion bedded down on the ramp. Elk visits to ER were greatest at Ramp 3, which is the furthest distance away from the highway of any ER (155 meters), but no patterns of escape success for elk in relation to distance from the highway were noted.

Most deer activity we observed at ER was nocturnal with peaks during the crepuscular time periods (Figures 5 & 6). This pattern is consistent with other studies observing crepuscular and nocturnal ungulate activity (Ager et al. 2003) and indicates that usage levels at ER may be generally reflective of overall activity patterns of deer in the area. We observed a seasonal peak of visits during the fall and spring with decreased activity during the winter and summer months. Based on this activity pattern, warning signs (indicating potential presence of wildlife on the highway), that are triggered by nightfall (reduced light) may help reduce WVC.

There were no reports of elk-vehicle collisions during the study period. However, elk were clearly breaching the wildlife fence and intruding into the ROW during this time. While elk were observed during the fall and winter, most visits to ER occurred during the spring and summer (April – July) (Figure 9).

Based on our analysis, costs of ER installation and associated mitigation measures at both phases were worth the investment. At each phase of ER installation in the study area, collision rates for both deer and elk were reduced. Following construction of the first three ER in 2005, deer collisions were reduced from 1.94 to 1.53 collisions per mile per year. This rate was further reduced following the construction of eight additional ER in 2010 to 1.12 deer collisions per mile per year. Similar WVC rates were observed for elk. Prior to construction of the first three ER, elk collisions were at 0.58 collisions per mile per year. This rate was the reduced to 0.32 following the construction of the three ER and 0.03 following construction of the additional eight. Because WVC involving elk cost society over 2.5 times those involving deer (Table 14), the large reduction of elk collisions in the study area contributed significantly to the benefits of ER construction. Using these WVC rates and depending upon the per-collision costs WVC, construction costs for ER within the eight-mile study area along Highway 550 were recovered within 1.35 to 2.20 years. This is a rapid time frame in which benefits generated by the mitigation measure of ER installation exceed the costs of construction. Because of the large reduction in WVC involving elk in the study area to almost zero, further mitigation actions involving additional construction of ER may not result in as great a cost savings for elk as seen to date.

In the section below, we provide recommendations for reducing WVC within the study area along Highway 550 based upon the results of this study.

Consider additional escape ramps. Based upon guidelines for ER placement and frequency along the highway made by others, we recommend installing additional ER (or other escape measures) along Highway 550 within the study area. In Arizona, AZDOT (2014) recommends installing at least two escape measures every mile on both sides of the highway when large ungulates are the target species, although they recognize there are no clear guidelines on the spacing of escape measures. The standard for Utah is approximately four ER per mile (Cramer et al. 2014). For placement of ER that are not directly adjacent to crossing structures such as an overpass, Huijser et al. (2009) used a between-ramp interval of 1,040 feet (approximately five per mile per roadside). Within this study area, there is a two-mile stretch north of Alkali Creek (MP 109-) and south of Ramp 12 (MP 111-) without an escape measure in place. This is the longest stretch of highway within the study area without an escape measure. We observed three openings passable by deer within this two-mile stretch of highway: an access road (CR 8 and CR 8A) with cattle guard filled with gravel (Appendix B, Opening Number 15), an open gate at an access road (Enchanted Mesa Dr.) without a cattle guard (Appendix B, Opening Number 16), and an access road with an open gate (Appendix B, Opening Number 19). Following ER construction in 2010, WVC in the study area was reduced, however three WVC (two at MP 109 and one at MP 111; Figure 19) occurred near this two-mile stretch of highway without an escape measure.

Close openings in the wildlife fencing. The greatest factor leading to potential WVC is the sheer number of wildlife, especially deer, observed within the ROW at ER. We observed 2,965 visits of mule deer to ER over the two-year study period. Averaged over the study period, this equates to over four visits to ER within the study area per day. There were undoubtedly many additional wildlife intrusions into the ROW during this time period that did not result in visits to an ER. It is recognized that wildlife fencing is often not an absolute barrier to wildlife (Bissonette and Hammer 2000;

Putman 1997), however fence maintenance and repair of holes are necessary (Feldhamer et al. 1986) as well as functional complementary structures at access roads such as wildlife guards (Allen et al. 2013) or double cattle guards (Cramer et al. 2014). Clevenger et al. (2001) found that WVC were not associated with gaps (access points), however in their study area they noted only 10 access points along 44 km (27.3 mi.) of highway. We recorded 34 openings in the wildlife fence from MP 106 to MP 112+ that had the potential to allow deer or other wildlife access to the ROW (Figure 20; Appendix B). Twenty of these openings were easily passable by deer at the time of the inventory. Many of these openings were noted by SREP (2006) in their inventory of gaps along this stretch of Highway 550.

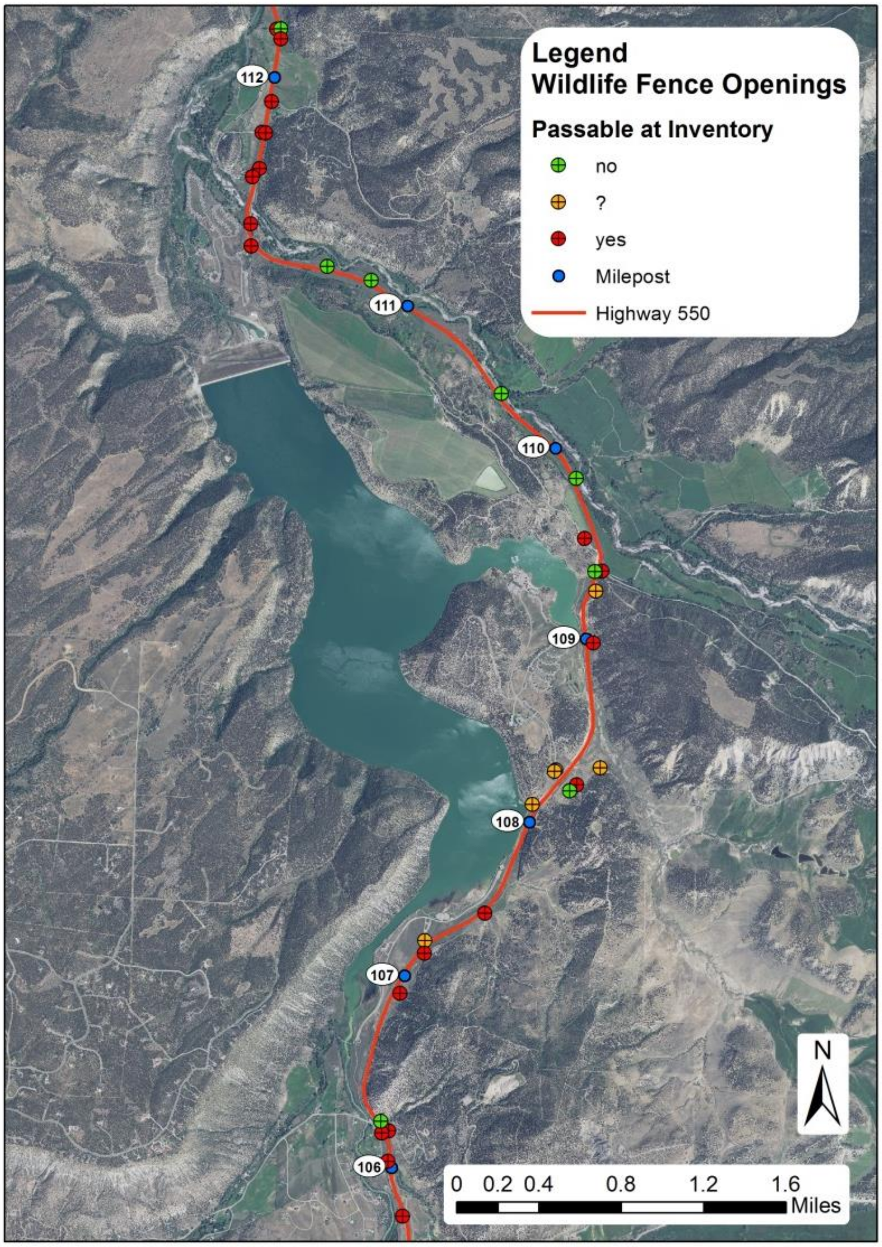

Figure 21. Openings in the wildlife fence along Highway 550. Legend indicates openings deemed passable by deer at the time of inventory.

Mitigate WVC at ends of wildlife fencing. Much of the WVC within the study area, both before and after ER construction, occurred at the ends of the wildlife fencing near MP 105 and MP 113 (Figures 18 and 19). The northern terminus of the wildlife fence is at the Uncompahgre River, MP 112.5, and the southern is at MP 105.5 near Ouray County Road 10. Clevenger et al. (2001) found that WVC were associated with and close to fence ends. In their study, WVC were clustered on average 735 meters from fence ends. Huijser et al. (2008a) provide recommendations on how managers can mitigate the high concentration of WVC at fence ends. These include ending the wildlife fence: near safe crossing opportunities, in areas with steep, rugged terrain, in habitats that may limit movement (such as non-forested areas or open water), and in areas exposed to regular human activity or disturbance (Huijser et al. 2008a). They also provide additional fence-end mitigation strategies like wildlife warning signs, ending the fence near the road, boulder fields between the fence and road, wildlife guards across the road, electric mats embedded in the road surface, and strategies that allow for better driver visibility such as ending fences on straight highway sections or lighting (Huijser et al. 2008a). Specific to this study area, SREP (2006) made recommendations for mitigation to the southern end of the wildlife fence including re-routing the bike path so that it does not intersect the wildlife fence, and removing the section of fence from MP 105.5 to 106.5 along with removing vegetation cover and installing targeted wildlife activity signage. At the northern end of the fence, SREP (2006) suggested the options of extending the wildlife fence ½ mile beyond the Uncompahgre River span bridge and tying the fence ends into terrain features.

Extend dates of gate closure. Wildlife gates on the pedestrian/bike trail at the southern end of the study area are closed from October 1 to April 1. Based upon the activity of mule deer observed at ER in the study area (Figure 6), we recommend considering extending dates of closure for pedestrian gates through May, or investigating the use of gates that automatically close.

Improve guards. To reduce the number of wildlife entering the ROW, double cattle guards, wildlife guards or electric mats should be considered at all access roads. Guards should have rounded surfaces on the top to deter animals from walking across the bars (Cramer et al. 2014) and should be maintained to remove debris from vaults. Single cattle guards and painted lines simulating cattle guards are ineffective for diverting mule deer and elk compared to double cattle guards and wildlife guards (Cramer 2012; Cramer et al. 2014). Allen et al. (2013) found that wildlife guards (6.6 m X 6.8 m steel grates) were 93.8% effective at deterring mule deer movement at access roads in Montana. Reed et al. (1974) evaluated the effectiveness of deer guards (flat mill steel ½-inch wide at the top and spaced 4 inches apart) and found that 16 of 18 mule deer crossed the deer guard after being released from cages. Concern for safety of pedestrians and bicyclists using traditional guards led to the development of a wildlife grate pattern that was 99.5% effective in excluding Key deer (Peterson et al. 2003), but this design would likely need to be modified for use with mule deer and elk as these are larger species. Regardless of the mitigation method chosen, structures must be maintained to be effective. During this study, the vaults of some guards were filled in with gravel, rendering them ineffective. One example of this is at the intersection of County Road 8 where guard vault was completely filled in with gravel (Figure 21). In their inventory of gaps in the deer fencing along this same stretch of highway, SREP (2006) also noted that this guard was filled with stone.

Figure 22. Cattle guard at the intersection of County Road 8, County Road 8A and Highway 550.

Improve select escape structures. Some escape structures we evaluated during this project could be modified to improve effectiveness and eliminate undesired movement of deer into the ROW. Ramp 20 had the greatest number of reversals of any ER. We observed 25 reversals at his ER throughout the two-year monitoring period. The top of the ramp was measured at 180 cm, which was the lowest ER we evaluated of ER without horizontal bars (range 180 - 196 cm). This ER also had the greatest number of deer visits as well as the highest percentage of successful escapes of any ER in the study area. We recommend modifications to this ER to reduce or eliminate the number of reversals that are made at this location. A low horizontal bar, which deters reversals and still provides a jump height low enough for deer and other wildlife to make successful escapes, could be added to this ER, but it would need to be placed very close to the top of the ramp to still allow wildlife to make successful escapes. Alternatively backing material (*e.g.*, a wood plank) could be added to the wall of the ER to increase the effective height of the ramp. Additionally, a horizontal bar could be added to the to Dry Creek escape jump to deter wildlife from making reversals of this structure on the side of the escape jump without the existing horizontal bar.

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APPENDIX A. PHOTOS OF ESCAPE RAMPS WITHIN THE STUDY AREA.

Ramp 1. MP 111.5 on the west side of the highway near the Pa-co-chu-puk Entrance to Ridgway State Park.

Ramp 2. MP 111+ on the east side of the highway.

Ramp 3. MP 108+ on the east side of the highway.

Ramp 4. MP 107.5 on the east side of the highway.

Ramp 5. MP 107- on the west side of the highway.

Ramp 6. MP 107- on the east side of the highway.

Ramp 12. MP 111- on the east side of the highway.

Ramp 20. MP 108+ on the west side of the highway near the Dutch Charlie Entrance to Ridgway State Park.

Ramp 21. MP 111+ on the west side of the highway.

Ramp 22. MP 111- on the west side of the highway.

Ramp 23. MP 107.5 on the west side of the highway.

APPENDIX B. INVENTORY OF OPENINGS IN THE WILDLIFE FENCE ALONG HIGHWAY 550.

Opening Number	Opening Type	Side of Highway	MP	SREP (2006) Location[1]	Comments	Passable by Deer at Time of Inventory
1	driveway	W	112+	41	open on 9/12/2014	yes
2	driveway	E	112+	41	closed on 9/12/2014	no
3	driveway	E	112+	41	open on 9/12/2014	yes
4	county road	E	112-	40	4 RD - cattle guard	yes
5	county road	W	112-	39	no guard, shorter fence adjacent	yes
6	pedestrian trail	E	112-	-	open gate on 9/12/2014	yes
7	driveway	E	111.5+	38	open gate on 9/12/2014	yes
8	driveway	W	111.5+	38	open gate on 9/12/2014	yes
9	driveway	E	111.5+	36		yes
10	State Park entrance	W	111.5	35	Pa-co-chu-puk entrance 2 gates - cattle guard in middle	yes
11	access road	E	111.5-	-	closed gate in good repair on 9/12/2014	no
12	access road	E	111+	-	closed gate in good repair on 9/12/2014	no
13	driveway	E	110.5	31	closed gate with a cattle guard on 9/12/2014	no
14	driveway	E	110-	27	closed gate with a cattle guard on 9/12/2014	no
15	county road	E	109.5	24	CR 8 & CR 8A; 2 cattle guards, S. guard vault filled in	yes
16	road/drive	W	109.5	25	Enchanted Mesa Dr. - open gate, no guard	yes
17	State Park gate	W	109.5	-	closed gate on 9/12/2014	no
18	access road	E	109+	-	gate closed, but with approx. 1 foot gap	?
19	access road	E	109	-	open gate on 9/12/2014	yes
20	road	E	108.5	20	gate with gap potentially wide enough for deer to pass	?
21	road	E	108+	17	drainage ditch has created a gap under gate	yes
22	access road	E	108+	-	closed gate in good repair on 9/12/2014	no
23	State Park entrance	W	108+	16	cattle guard	?
24	State Park entrance	W	108+	16	cattle guard	?

[1]Location number of gaps in fence identified by SREP (2006).

Appendix B (continued). Inventory of Openings in the Wildlife Fence Along Highway 550.

Opening Number	Opening Type	Side of Highway	MP	SREP (2006) Location[1]	Comments	Passable by Deer at Time of Inventory
25	State Park utility entrance	W	108	15	gate closed, but with > 1 foot gap	?
26	gate on path	W	105+	2	near S end of fence - closed Oct. 1 to April 1	yes
27	driveway	E	107.5	12	S of Ramp 4	yes
28	State Park entrance	W	107+	10	2 gates with cattle guard in the middle	?
29	driveway	E	107+	11	open gate on 9/12/2014	yes
30	hole in fence	E	107-	-	Behind Ramp 6. Video data show movement of deer through hole.	yes
31	driveway	E	106+	6	Lowery Ct. cattle guard - broken fence adjacent	yes
32	road	W	106+	6	no guard	yes
33	driveway	E	106+	7	closed gate in good repair on 9/12/14	no
34	gate on pedestrian/ bike path	W	106	5	closed Oct. 1 to April 1	yes

[1]Location number of gaps in fence identified by SREP (2006).