STATE HIGHWAY 9 WILDLIFE CROSSINGS MONITORING – YEAR 2 PROGRESS REPORT

December 2015 through April 2017

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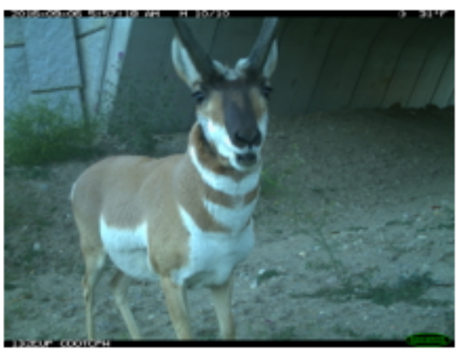
Applied Research and Innovation Branch



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Executive Summary

The State Highway 9 (SH 9) Colorado River South Wildlife and Safety Improvement Project in Grand County was designed by the Colorado Department of Transportation (CDOT) and partners to improve motorist safety by reducing wildlife-vehicle collisions (WVC) while providing opportunities for wildlife to move beneath and above SH 9 through wildlife crossing structures. Prior to the project, WVC were the most common accident type on this segment of highway, accounting for 60% of all accidents reported to law enforcement. In response to these concerns and with partner support, CDOT installed two wildlife overpass structures, five wildlife underpasses, 10.4 miles of eight foot high wildlife exclusion fencing, 61 wildlife escape ramps, and 29 deer guards to help reduce WVC while providing safe passages for wildlife. This research study evaluates the effectiveness of the mitigation infrastructure through the use of motion activated cameras and analyses of WVC crash and carcass data.

The SH 9 project was completed in two phases. Phase 1, the northern portion of the project from milepost (MP) 131-136, was completed in December 2015. Phase 2 construction (MP 126-131) was completed in December 2016. The study maintains a total of 62 motion-triggered cameras at 48 locations to capture animal movements and responses to the mitigation. Cameras were placed at crossing structure entrances and in the nearby habitat, at deer guards, escape ramps, pedestrian gates, and the south fence end.

Overall, the wildlife crossing structures have met or exceeded expectations. In Year 2 of the study (April 2016 – April 2017) monitoring cameras recorded a total of 15,202 mule deer success movements through or over the wildlife crossing structures. The success rate for mule deer passage at the seven structures ranged from 83-99% in Winter 2016-2017. Mule deer movements at the two overpass structures accounted for 48% of all deer movement at crossing structures with a success rate of 95-99% at these locations (Fig. 1). At the underpass structures, the mule deer success rate ranged from 83-98%.

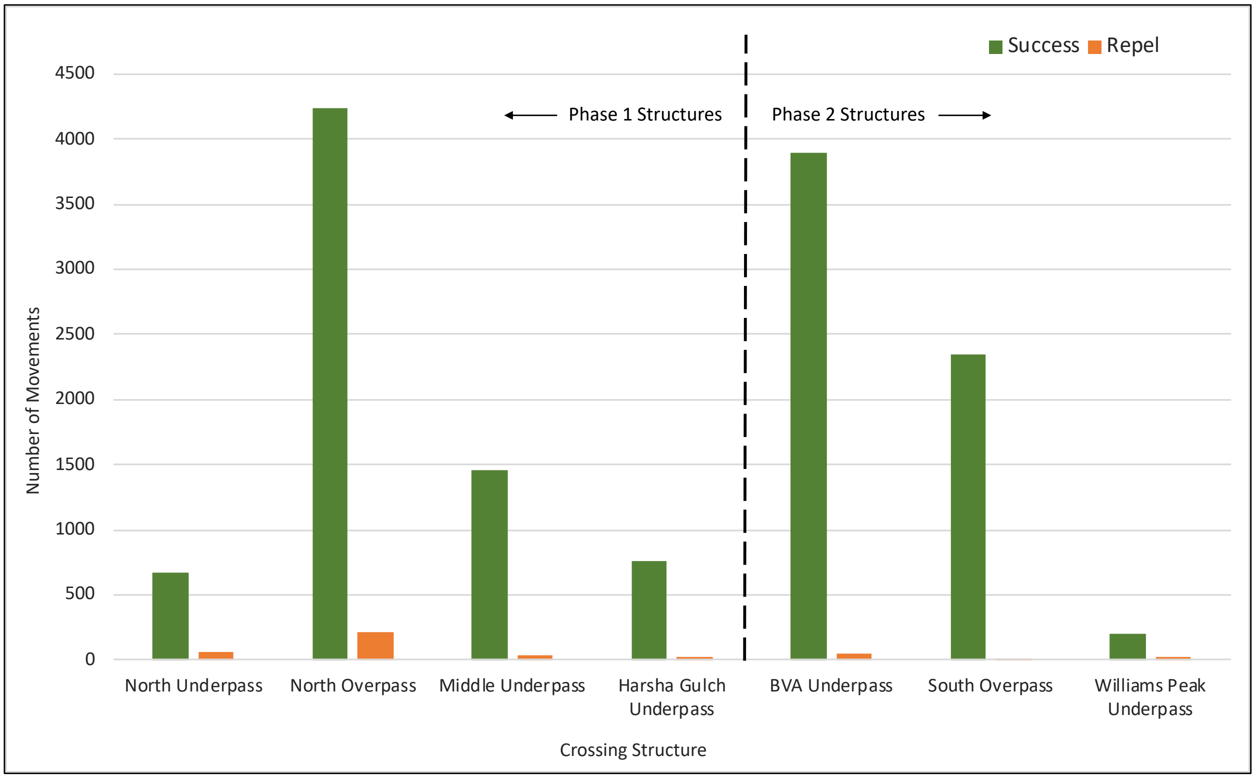

Figure 1. Total number of mule deer success movements and repel movements at each crossing structure location during Winter 2016-17.

Elk activity at Phase 1 locations increased in Winter 2016-17 in comparison to Winter 2015-16, from seven the first winter to 19 the following winter. These results may suggest that elk are slowly adapting to the crossing structures. However, elk movements photographed at crossing structures and at habitat cameras remained low throughout the study area. Species such as black bear, white-tailed deer and pronghorn were most commonly observed using the crossing structures during non-winter months. Others, such as bobcat, coyote, red fox, mountain lion and moose were observed throughout the year. Bighorn sheep were documented making successful crossings on two occasions, one each at an overpass and an underpass. While these other species made fewer movements over and through the structures than mule deer, the success rates for these species were high (83-100%).

Wildlife-vehicle collisions decreased progressively during the first two years of the study. Following the construction of Phase 2, the number of mule deer and elk carcasses dropped by 86% to a total of eight reported carcasses, down from the pre-construction 5-year average of 56.4

carcasses (Fig. 2). Correspondingly, wildlife-vehicle crashes reported to law enforcement personnel decreased by 70%, to just three crashes, during the first winter of monitoring (2015-2016), all of which were in the Phase 2 segment where construction had not yet been completed. Traffic and Safety accident data for Winter 2016-17 were not available at the time of this writing.

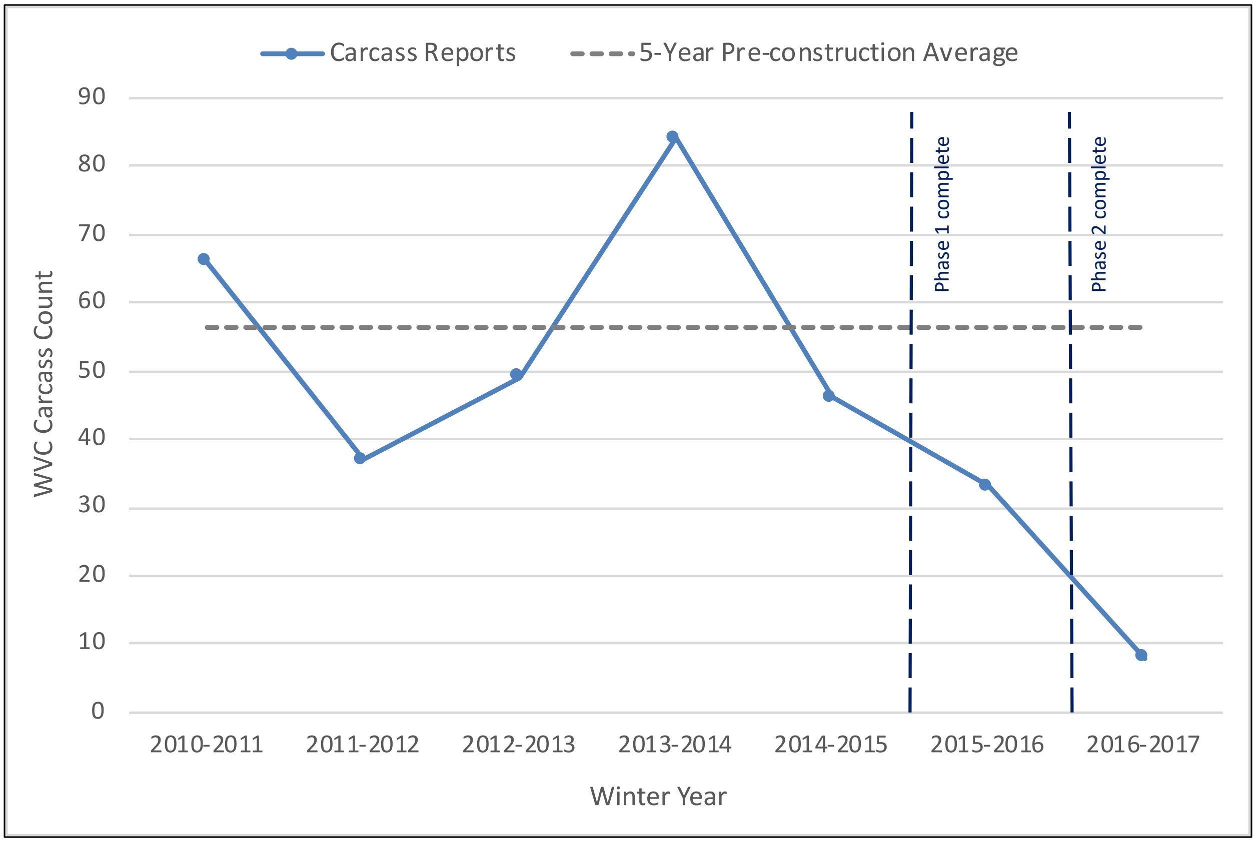

Figure 2. Mule deer and elk carcass counts recorded by Blue Valley Ranch and Colorado Parks and Wildlife pre-construction to post-construction compared to the 5-year pre-construction average of 56.4 carcasses per year.

In addition to the crossing structures, researchers monitored the effectiveness of deer guards in preventing wildlife from breaching into the fenced right-of-way, and escape ramps that provide a one-way escape for wildlife that inadvertently become trapped on the highway side of the fence. The researchers evaluated two different deer guard designs (round bar and flat bar), and found that round bar deer guards were, on average, more successful in deterring mule deer from entering the fenced roadway (87% repel rate) than flat bar deer guards (71% repel rate). When deer did attempt to breach a round guard they generally attempted to jump across. At flat bar guards, deer were most commonly documented walking on top of the bars or walking on snow that had become packed between the bars. Elk mostly repelled from the guards (85% repel rate), and the only elk to breach a round guard did so by jumping across it.

Researchers placed monitoring cameras on select escape ramps to evaluate the effect of ramp steepness and the presence of perpendicular rail fencing placed to guide animals up a ramp on deer and elk use of the ramps to escape the fenced right-of-way. In general, mule deer were more than twice as likely to ascend a ramp without rail fence than one with rail fence, regardless of ramp slope. Of those animals that ascended a ramp, the number of successful escapes (jump downs) to the habitat side of the fence were low across all locations. In total, mule deer were documented making successful escapes on 22 occasions (11% escape rate) and elk were documented on eight occasions (9% escape rate). The study will continue to evaluate and report on all of these features through Winter 2019-20, and the researchers will continue to work with CDOT and Colorado Parks and Wildlife to adaptively manage the structures, fencing, deer guards and escape ramps.

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Introduction

The State Highway 9 (SH 9) Colorado River South Wildlife & Safety Improvement Project resulted in the installation of seven large wildlife crossing structures between Kremmling and Green Mountain Reservoir in Grand County, Colorado. The project was designed to improve driver safety while providing permeability for wildlife. State Highway 9 runs north-south through the Lower Blue Valley, a broad sagebrush valley between the Gore Range to the west and the Williams Fork Mountains to the east. The Blue River also runs from south to north through the valley, west of the highway, to its confluence with the Colorado River.

The Lower Blue Valley supports a high concentration of mule deer (*Odocoileus hemionus*) and American elk (*Cervus Canadensis*) during the winter months as wildlife settle onto their winter range. Resident mule deer and elk herds also inhabit the valley throughout the year. Other species include moose (*Alces alces*), pronghorn (*Antilocapra americana*), American black bear (*Ursus americanus*), bobcat (*Lynx rufus*), red fox (*Vulpes vulpes*), coyote(*Canis latrans*), and mountain lion (*Puma concolor*). Some animals make daily movements across SH 9, where the highway bisects an individual's range, while other animals may make more infrequent movements. These concentrations of wildlife have resulted in numerous wildlife-vehicle collisions (WVC), particularly during the winter months.

During the five winters (December through April) prior to the onset of project construction in 2015, reported WVC were the most common accident type on this segment of highway, accounting for 60% of all accidents reported to law enforcement personnel. During this timeframe, 50 WVC accidents with mule deer or elk were reported, 4% of which resulted in injuries to humans. However, accident reports underestimated the full extent of the conflict between traffic and wildlife on SH 9. More comprehensive winter carcass counts conducted by Blue Valley Ranch during this same timespan recorded 282 WVC mule deer and elk carcasses, more than triple the number of reported accidents.

To meet the objectives of reducing WVC and allowing for wildlife movement across the highway, two wildlife overpasses and five arch underpasses were constructed and connected with 10.4 miles of 8-foot high wildlife fencing in two construction phases. Other mitigation features include deer guards installed at all road intersections and private driveways; wildlife escape ramps; and pedestrian walk-through gates to provide a pathway for people through the wildlife fence. The project includes drainage culverts, including several medium-sized (8' box or pipe culverts) that are integrated into the fencing and may provide passage for small or medium-sized fauna. This project is the culmination of a comprehensive and collaborative effort by the Colorado Department of Transportation (CDOT), Colorado Parks and Wildlife (CPW), and the privately-owned Blue Valley Ranch (BVR), as well as many other public and private partners. The goal of this mitigation project was to reduce vehicle collisions with wildlife while providing permeability for these animals to move safely underneath or above the highway. CDOT and CPW are supporting this research study to evaluate how well the wildlife mitigation achieves these goals.

This research study uses motion-triggered cameras to monitor wildlife activity at wildlife crossing structures, wildlife escape ramps, deer guards, pedestrian walk-through gates and the southern terminus of the wildlife exclusion fence. Cameras were deployed to correspond with the two project construction phases. Phase 1 construction was in the northern portion of the project area (milepost [MP] 131-137) and was completed in November 2015. Mitigation features in this phase included one wildlife overpass, three underpasses, six miles of continuous 8-foot high wildlife exclusion fencing on both sides of the highway, 34 escape ramps, 12 deer guards and 2 pedestrian walk-through gates. Phase 2, completed November 2016, was in the southern portion of the project area (MP 126-131), and included a second overpass, two wildlife underpasses, continued wildlife exclusion fencing through the project area, and an additional 27 escape ramps, 17 deer guards and 5 pedestrian walk-through gates.

In addition to camera monitoring, this research study analyzes WVC rates in each phase of the project area, using three long-term datasets. Long-term datasets offer a pre-construction baseline to which post-construction WVC rates may be compared.

This progress report focuses on post-construction monitoring from its onset at the completion of the Phase 1 segment (December 2015) through the second winter post-construction (April 2017).

The results of pre-construction camera monitoring, conducted by CPW (November 2014 – March 2015) and by the research team in the Phase 2 segment prior to construction in this segment (Winter 2015-16) are also included in this progress report.

Research Objectives

The following research objectives were established by the Study Panel for the five-year research study:

1. Determine to what extent the wildlife and safety mitigation measures reduce WVC.
2. Determine the level of effectiveness of wildlife overpasses and underpasses in allowing wildlife, primarily ungulates, to move underneath or above the highway.
3. Determine the ability of animals that breach the fenced right-of-way to use escape ramps to exit the fenced road area.
4. Determine if the fence end, pedestrian walk-through gate and deer guard designs are effective at deterring wildlife (ungulates primarily) from entering the fenced road area.
5. If utilization rates differ among the crossing structures, determine why.
6. Determine if any of the wildlife mitigation features appear to need modification to improve effectiveness.
7. Determine correlation of historic ungulate crossing patterns pre-completion to utilization of post-construction crossing patterns.
8. Compare pre-completion crossing rates to post-construction over/underpass crossing rates.

Methods

Mitigation effectiveness was measured with two general types of measures: the number of movements made by mule deer, elk and other wildlife through the crossing structures and success vs. repel rates for each species; and the reduction in WVC. The research methods used to evaluate these measures are presented below.

Camera Monitoring

Monitoring locations are listed in Table 1; Figures 1 & 2 depict the locations of all monitoring sites across the project area. Monitoring was conducted in three discrete phases:

Pre-construction: From November 2014 to the onset of mitigation construction in April 2015. Pre-construction camera monitoring was conducted by CPW at all crossing structure locations. At each location, a camera was set up on either side of the highway.

Pre-completion: From the onset of this research study (December 2015) until the completion of Phase 2 construction (November 2016). Pre-completion monitoring involved the deployment of 40 cameras at 24 locations. Pre-completion monitoring was conducted by the ECO-resolutions team with support from CPW.

Post-construction: Following the completion of all construction activities (December 2016) through Winter 2019-20. During Year 2, post-construction monitoring involved the deployment of 62 cameras at 48 locations. Post-construction monitoring is being conducted by the ECO-resolutions team with support from CPW.

Monitoring was conducted using motion-triggered Reconyx Professional Series cameras (PC800 and PC900). Cameras were installed on T-posts using a U-bolt system and Reconyx security boxes. Where cameras were placed in areas with human activity or visible from the roadside, the cameras were mounted inside metal utility boxes to disguise the camera. All cameras were code-locked and secured with master locks and/or cable locks. The cameras were motion-triggered and took photos day and night with a rapid-fire setting and no down time. Cameras were set to take burst of 10 photos per trigger, and continued triggering as long as movement was detected. Exceptions were at deer guards with heavy traffic, where cameras were set to 3 or 5 photos per trigger and were scheduled to trigger only between before dusk to after dawn (from 4:30pm to 8am).

Fourteen pre-construction cameras documented species presence and relative abundance of non-mule deer species at future wildlife crossing locations during Winter 2014-15. At each future structure location, a camera was deployed on either side of SH 9 approximately 50’ (15 m) from the highway. Prior to the construction of the wildlife crossing structures and wildlife exclusion fence, wildlife could cross SH 9 at any point along the highway rather than at discrete crossing locations. Therefore, pre-construction monitoring could only capture a snapshot of this dispersed wildlife activity near the roadway. The objective of pre-construction monitoring was to compare species that were present near the roadway prior to mitigation construction with their relative abundance post-mitigation construction. Accordingly, species presence for all non-mule deer species was tallied without a categorization of animal behavior. Movements across SH 9 or repel movements from the highway right-of-way were not captured in pre-construction monitoring.

Table 1. Monitoring Locations. Highlighted gray rows are wildlife crossing structures and habitat locations adjacent to the structures. Monitoring periods are coded as, 1 = pre-construction; 2 = pre-completion; 3 = post-construction.

MP	LOCATION NAME	MITIGATION TYPE	SPECIFICATIONS	MONITORING PERIODS	NOTES
PHASE 1 SEGMENT – CONSTRUCTED SUMMER 2015					
137.0	Colorado River Bridge	Bridge Underpass	Large existing bridge at north fence end	2 & 3	Existing bridge underpass
136.9	County Road 33 Deer Guard	Deer Guard	Flat bar	2 & 3	-
136.9	Thompson Deer Guard	Deer Guard	Round bar	2 & 3	Replaced flat bar with round bar Summer 2016
136.8	Thompson Escape Ramp	Escape Ramp	2:1 slope with rail fence	2	-
136.6	Trough Road Deer Guard	Deer Guard	Flat bar	2 & 3	-
136.6	Trough Road 3:1 Escape Ramp	Escape Ramp	3:1 slope without rail fence	3	Constructed Summer 2016
136.6	Trough Road 2:1 Escape Ramp	Escape Ramp	2:1 slope with rail fence	3	-
136.0	North Underpass	Arch Underpass	44'W x 14'H x 66'L	1, 2 & 3	-
136.0	North Underpass Habitat	Adjacent Habitat	Habitat camera	2 & 3	-
135.9	SWA Escape Ramp	Escape Ramp	2:1 slope with rail fence	2	-
135.6	SWA Pedestrian Gate	Pedestrian Gate	n/a	2 & 3	Gated Fall 2017
135.1	Culbreath 2:1 Escape Ramp	Escape Ramp	2:1 slope with rail fence	3	-
135.1	Culbreath 3:1 Escape Ramp	Escape Ramp	3:1 slope without rail fence	3	Constructed Summer 2016
135.1	Culbreath Box Culvert	Small Culvert	8'W x 8'H concrete box	3	-
135.1	Culbreath Deer Guard	Deer Guard	Round bar	2 & 3	Replaced flat bar with round bar Summer 2016
134.5	Rusty Spur Deer Guard	Deer Guard	Flat bar	2	-
134.3	Overpass Escape Ramp	Escape Ramp	2:1 slope with rail fence	2 & 3	-
134.3	North Overpass	Overpass	100'W x 66'L	1, 2 & 3	-
134.3	North Overpass Habitat East	Adjacent Habitat	Habitat camera	2 & 3	-
134.3	North Overpass Habitat West	Adjacent Habitat	Habitat camera	2 & 3	-
134.2	BVR Pipe Culvert	Small Culvert	8' diameter concrete pipe	2	-
133.8	BVR Box Culvert	Small Culvert	8'W x 6'H concrete box	3	-

MP	LOCATION NAME	MITIGATION TYPE	SPECIFICATIONS	MONITORING PERIODS	NOTES
132.5	Middle Underpass	Arch Structure	44'W x 14'H x 66'L	1, 2 & 3	-
132.5	Middle Underpass Habitat	Adjacent Habitat	Habitat camera	2 & 3	-
132.4	BLM Pedestrian Gate	Pedestrian Gate	n/a	2	Gated Fall 2017
131.6	Harsha Gulch Deer Guard	Deer Guard	Flat bar	2 & 3	-
131.6	Harsha Gulch Underpass	Arch Underpass	44'W x 14'H x 66'L	1, 2 & 3	-
131.6	Harsha Gulch Habitat	Adjacent Habitat	Habitat camera	2 & 3	-
131.2	Harsha Escape Ramp	Escape Ramp	2:1	2	-
131.0	Pre-Completion South Fence End	Fence End	20' clear zone	2	-
PHASE 2 SEGMENT – CONSTRUCTED SUMMER 2016					
130.8	BVA Underpass	Arch Underpass	44'W x 14'H x 66'L	1, 2 & 3	-
130.8	BVA Habitat	Adjacent Habitat	Habitat camera	3	-
130.8	CR 1002 Deer Guard	Deer Guard	Round bar	3	-
129.7	CR 1000 Deer Guard	Deer Guard	Flat bar	3	-
129.5	South Overpass	Overpass	100'W x 66'L	1, 2 & 3	-
129.5	South Overpass Habitat East	Adjacent Habitat	Habitat camera	3	-
129.5	South Overpass Habitat West	Adjacent Habitat	Habitat camera	3	-
129.1	Badger Road Escape Ramp	Escape Ramp	3:1 slope without rail fence	3	-
128.5	Triangle Road Deer Guard	Deer Guard	Round bar	3	-
128.5	Spring Creek Deer Guard	Deer Guard	Flat bar	3	-
128.5	Spring Creek Escape Ramp	Escape Ramp	3:1 without rail fence	3	-
128.4	South Spring Creek Escape Ramp	Escape Ramp	3:1 without rail fence	3	-
128.0	Summit County Pedestrian Gate	Pedestrian Gate	n/a	3	Gated Fall 2017
127.7	Williams Peak Underpass	Arch Underpass	44'W x 14'H x 66'L	1, 2 & 3	-
127.7	Williams Peak Habitat	Adjacent Habitat	Habitat camera	3	-
126.7	East Fence End Escape Ramp	Escape Ramp	3:1 without rail fence	3	-
126.6	West Fence End Escape Ramp	Escape Ramp	3:1 with rail fence	3	-
126.6	South Fence End	Fence End	30’ clear zone	3	-

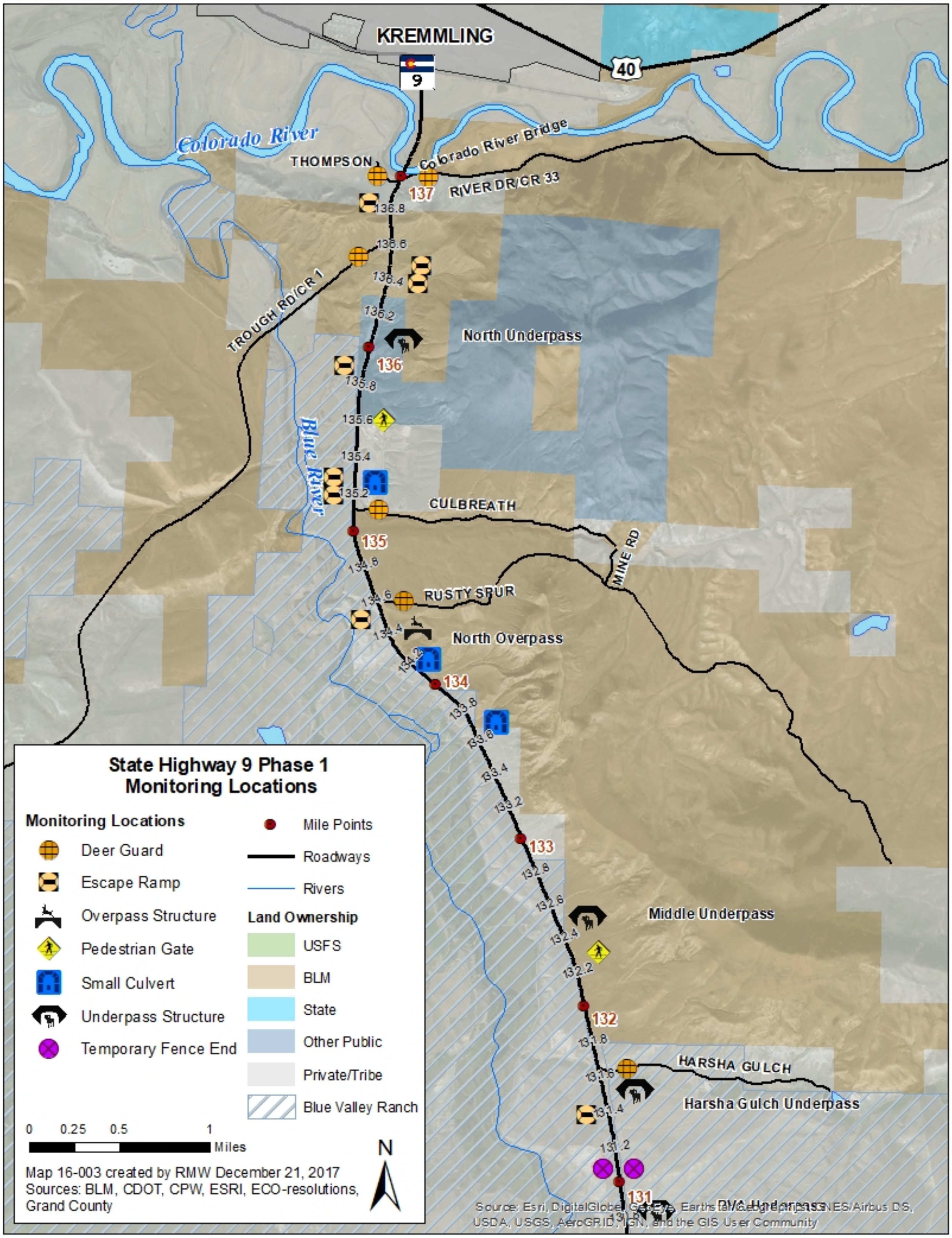

Figure 1. Phase 1 (north segment, MP 131 – 137) monitoring locations.

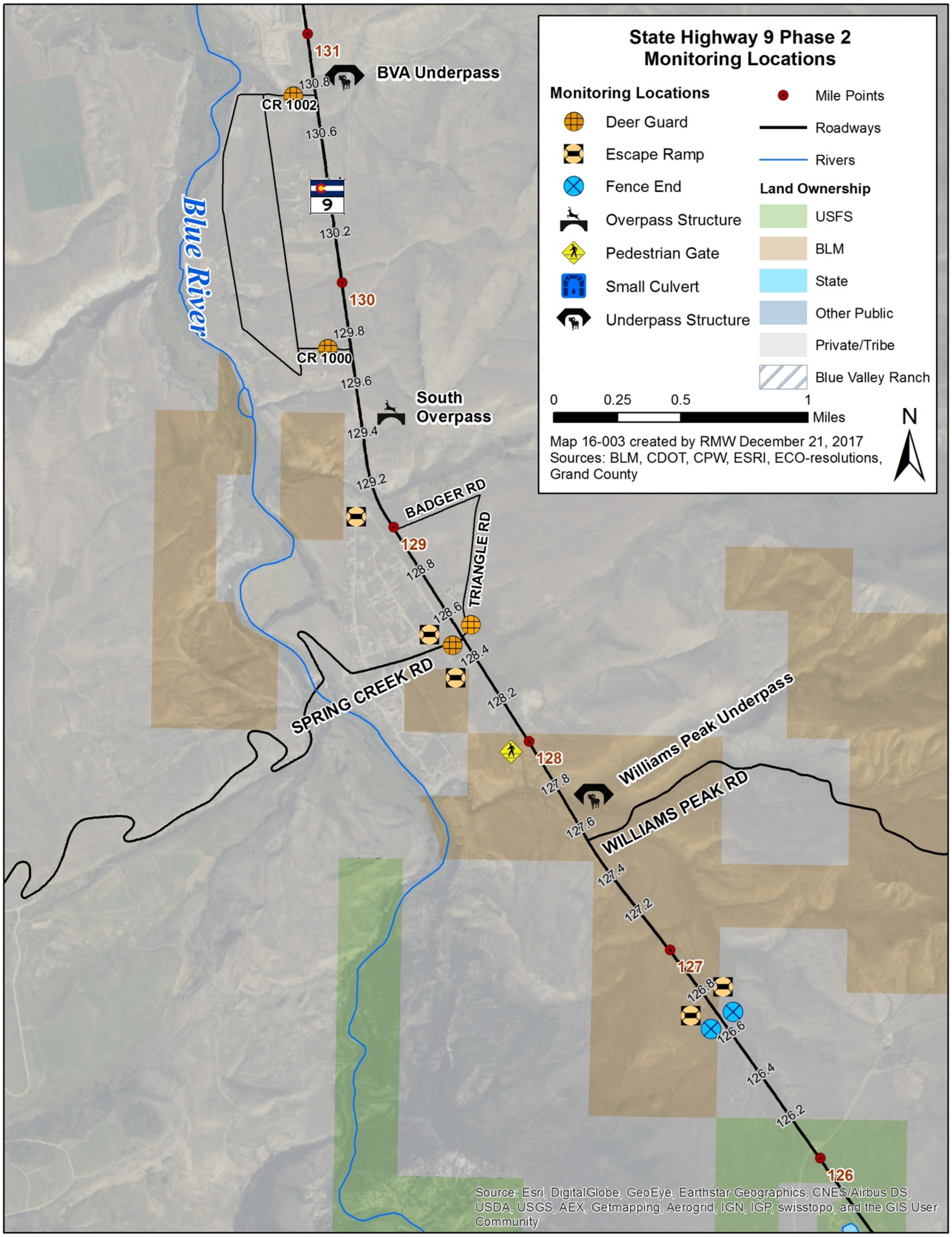

Figure 2. Phase 2 (south segment, MP 126 – 131) monitoring locations.

For post-construction monitoring, cameras were set up at each monitoring location to maximize capture rates and wildlife responses to the mitigation features. At crossing structures, cameras were placed to capture wildlife behavior at the entrance of the structure to distinguish success movements (passage through a crossing structure) from repels and parallel movements. Two cameras were placed at each arch underpass, at opposite corners. In addition, a habitat camera was placed on one side of each underpass, 50-100 feet from the structure entrance, directed toward the habitat facing away from the road (Fig. 3). The two overpass structures have steep entrance slopes leading to the top of the structures, so in addition to the two cameras on top of each structure, additional cameras were placed at the bottom of the slopes on either side of the structure. These ‘entrance’ cameras were more likely to capture repels and parallel movements, while the structure cameras could be used to confirm through-passage. Habitat cameras were placed on each side of the overpass facing outward to capture wildlife movements in the adjacent habitat.

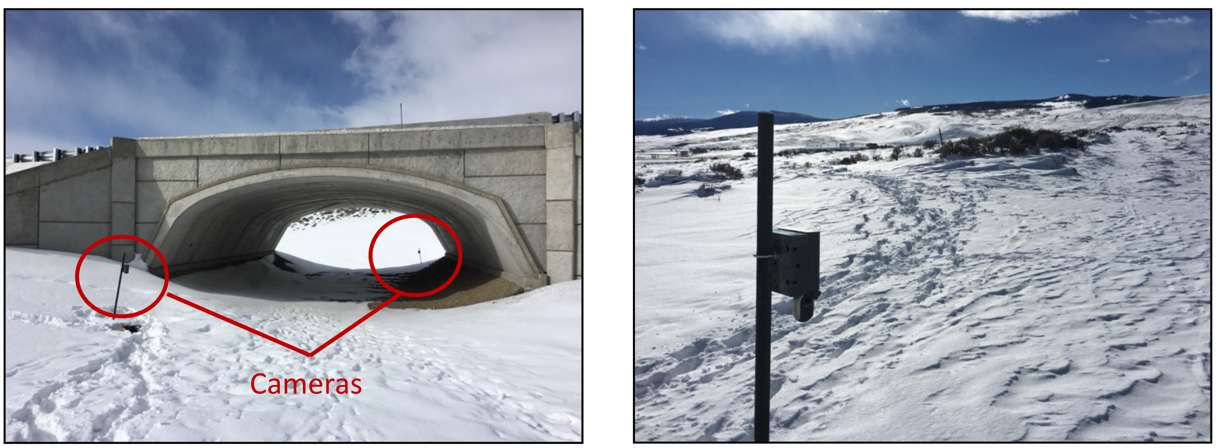

Figure 3. Two cameras were positioned at each underpass at opposite corners (left). Habitat camera placed 50-100 feet in front of a structure, facing out into the adjacent habitat (right).

Cameras at other monitoring locations were positioned to capture specific wildlife behaviors. At deer guards and pedestrian walk-through gates, cameras were placed to capture wildlife behavior in front of the guard or walk through gate (e.g., approaches, repels and breaches). Two cameras were set up at each monitored escape ramp, one at the base of the ramp to capture wildlife approaching the ramp or walking around the ramp; and one on the habitat side to capture wildlife at the top of the ramp, including successful jump downs as well as jump up attempts from the habitat side onto the ramp. At the south fence end, cameras were positioned to capture both wildlife movements into and out of the fenced right-of way, as well as movements that occurred beyond the fence end.

Photo Analysis

Cameras were visited every 4-5 weeks during the winter months and every 6-8 weeks the rest of the year to exchange memory cards and batteries. Photo data were systematically processed to identify movement events every time a camera is triggered. Events are defined by the movements of individuals or groups at crossing structures, deer guards, escape ramps, pedestrian gates, and the fence end. Events were defined as 15-minute time periods based on the methodology developed by Cramer (2012) because animals typically leave the camera area within 15 minutes. For each 15-minute timeframe, if an animal approached a structure multiple times without crossing, this was considered a single event until the animal crossed, repelled, or the 15-minute period ended, in which case a new event would be recorded. Events at all monitoring locations were recorded in a SQL database created for this research.

All events were categorized by time of day according to three time periods: day, night, and dawn/dusk. To account for the changes in the timing of dawn and dusk throughout the year, time of day was determined by the images themselves – color photos are taken during the day; black and white photos are taken at night; and black and white photos taken at dawn and dusk appear with a lighter background.

For each event at a crossing structure, the researchers identified, by species, the number of individuals and their gender (if possible), the direction of the movement, and their response to the crossing structure: through passage (success), repel or parallel movement. These were defined as follows:

Success – Movement all the way through the crossing structure.

Repel – Initial movements near the entrance to the crossing structure that resulted in the animal turning away from the structure rather than passing through.

Parallel – Animals moved near the structure but were either headed in a direction beyond the structure entrance or were grazing on vegetation, with behaviors that were not indicative of attempts to use the structure.

Total Movements were calculated for each wildlife crossing structure as,

Total Movements = Success Movements + Repel Movements + Parallel Movements

Unique movements by individual deer were tallied only once, even when two cameras recorded the movement. Individual repel and parallel movements were tallied only once when the same deer moved in front of a camera multiple times in a 15-minute event period.

Numbers for all non-mule deer species were tallied at the habitat cameras directed toward the habitat facing away from the road. Tallying species presence at habitat cameras allows comparisons of species composition and abundance in the habitat near a crossing structure with the species successfully using the crossing structure. Since these cameras are only meant to document species presence and abundance, the photos are analyzed without a categorization of animal behavior.

Three small culverts were monitored, including two 8' x 8' box culverts and one 8' diameter concrete pipe culvert. The pipe culvert also had an open-top concrete trench at the outlet, effectively increasing the structure length. One camera was placed at either the east or west entrance of each culvert. Success movements at small culverts were tallied when an animal entered and did not reemerge from the culvert within 15 minutes, or when an animal emerged from the culvert without previously having entered it.

At deer guards, animal movements were categorized as a breach, repel or parallel movement. A breach movement occurred when an animal jumped or walked over the guard or, by another method, was able to move from the habitat side of the guard into the highway right-of-way or vice versa. At escape ramps, movements inside the fenced right-of-way were categorized as walk around the base of the ramp, or ascend the ramp and either turn around or jump down. Additional tallies were made to document jump up attempts from the habitat side of the ramp. At the fence end, individual movements were categorized as movements into the fenced right-of-way, movements from the fenced-right-of way out to the adjacent habitat, or movements that occurred beyond the fence end.

The following indices were calculated for each monitoring location, as applicable. These indices were then used to evaluate performance as described below under *Performance Measures*.

- **Success rate** – For each species at a given crossing structure location, the total number of individual movements of the species that were recorded moving through the structure divided by the total movements by that species.
- **Repel rate** – For each species at a given crossing structure location, the total number of individual movements of the species that were recorded being repelled at a structure divided by the total movements by that species. Repel rate was also calculated for deer and elk at deer guards, pedestrian walk-through gates and fence ends. In these cases, a repel movement is the desired wildlife behavior response to the mitigation features, i.e., the total number of times deer/elk were repelled divided by the total number of times deer/elk approached the mitigation feature.
- **Parallel rate** – For each species at a given monitoring location, the total number of individual movements of the species that were recorded moving parallel to the mitigation feature divided by the total movements by that species. This metric is calculated for crossing structures, escape ramps, and pedestrian walk-through gates.
- **Intercept rate** –This metric is calculated for deer and elk at escape ramps. It is the total number of times deer/elk were recorded ascending an escape ramp divided by the number of times deer/elk approached an escape ramp.
- **Escape rate** – This metric is calculated for deer and elk at escape ramps. It is the total number of times deer/elk were recorded successfully jumping down from an escape ramp divided by the number of times cameras captured deer/elk walking up the escape ramp.
- **Breach rate** – This metric is calculated for deer and elk at deer guards, escape ramps, pedestrian walk-through gates, and fence ends. It is the total number of times individual deer/elk breached the mitigation feature divided by the total number of times deer/elk approached that mitigation feature. For example, at a deer guard, breaches occur when animals cross over the guard; at escape ramps, breaches occur when animals jump up onto an

escape ramp from the habitat side of the wildlife exclusion fencing; at a pedestrian walk-through gate, breaches occur when animals pass through the gate; at the fence end, breaches occur when animals enter into the fenced right-of way from beyond the fence end.

- **Average deer per day** – The total number of unique deer movements (not individuals) observed at the structure divided by the sampling effort. Sampling effort is calculated as the number of days a camera was in operation (or the average number of days for locations with two cameras) and is useful for standardizing the number of mule deer photographed when there is variation in the number of days that cameras were in operation at different monitoring locations. Deer per day may also be calculated for deer guards.
- **Average successful deer passages per day** – The total number of times deer successfully used a structure divided by sampling effort.

Adaptive Management between Construction Phases and Updates to the Research Study

The commencement of monitoring activities between Phases 1 and 2 of construction (Summer 2015 and Summer 2016, respectively) created a unique opportunity for the research team and CPW to recommend adaptations to the mitigation designs based on the preliminary results and observations from the first winter of monitoring (2015-16). Pre-completion monitoring documented initial wildlife responses to the Phase 1 mitigation features. The camera data provided a basis for the researchers to work with CDOT project engineers to integrate modifications into the Phase 2 project designs with regards to the deer guards and escape ramps to improve the performance of these mitigation features. In addition, the introduction of these experimental designs into this study allows the researchers to evaluate the effectiveness of the different designs for the remainder of the research study, an identified need in transportation ecology (Rytwinski et al 2015).

Specifically, the alterations were made at the recommendation of the research team:

- **Deer guards.** Deer breaches observed in Phase 1 were hypothesized to be the result of 1) deer being able to easily walk on the flat bars, and 2) snow getting trapped between the flat bars and creating a packed surface for deer to walk across. As a result, CDOT developed a round bar guard design that was installed at three locations in Phase 2 and was used to replace the flat bar guards at two locations in Phase 1. Beginning in fall

2016, both flat bar and round bar deer guards were monitored to evaluate the relative effectiveness of the two designs in preventing incursions into the fenced right-of-way by deer and other wildlife

- **Escape ramps**. Based on observations in Phase 1, the research team made several suggestions regarding escape ramp design and placement: 1) the 2:1 slope of the escape ramps may inhibit wildlife from ascending the ramps, 2) ramps placed at low points relative to the roadway, where deer trapped in the fenced right-of-way tend to congregate may be more effective than ramps at high points relative to the roadway, and 3) that the perpendicular rail fence on the ramps may not be functioning as intended and, instead, may obscure wildlife visibility at the top of the ramps. Consequently, all escape ramps in Phase 2 were constructed with a 3:1 slope instead of a 2:1 slope, and two new 3:1 slope ramps were constructed in Phase 1 to provide a comparison to the existing 2:1 slope ramps. In addition, six of the new ramps were constructed without guide rail fence. Beginning in fall 2016, monitoring was conducted at multiple locations featuring these design variables.
- **Small culverts.** Several small 8'x8' culverts in Phase 1 were not tied into the wildlife fencing and instead were 'fenced out'. These culverts were not identified as wildlife culverts and were not deemed valuable for wildlife passage in the original design plans. However, small culverts may provide passage for small- and medium-sized wildlife in the project area. With that in mind, small culverts in Phase 2 were tied into the wildlife fencing and the fencing around select culverts in Phase 1 was later reconstructed to tie into the culverts. Several of these small culvert locations were monitored to determine wildlife use.
- **Fence gap on North Overpass.** To prevent mule deer from crossing the overpass outside of the wildlife fence, as documented by camera monitoring, the researchers recommended that the gap between the fence and the structure edge be closed with wildlife fencing. These fence gaps were closed during Phase 2 construction.
- **Fence gaps.** Multiple fence gaps where the fencing did not come all the way down to the ground were observed in Phase 1. During Phase 2 construction, all fence gaps in both project phases were minimized to less than 8" (15 cm) to prevent wildlife incursions into the right-of-way.

Wildlife-Vehicle Collision Data Analysis

Wildlife-vehicle collision rates were analyzed using three independent datasets – WVC carcass data compiled by BVR and CPW; WVC carcass data recorded by CDOT maintenance patrols; and WVC accident reports compiled from law enforcement by CDOT Traffic and Safety. Blue Valley Ranch staff have recorded WVC carcass data north of Spring Creek Road (MP 128.5) to the town of Kremmling (MP 138) since 2005 and will continue to report these data through the duration of this research study. However, the 2005 data do not include month or day, and these data were excluded from further analysis. To complement these data, in 2013 CPW also began collecting carcass data south of Spring Creek Road to the southern end of the project area (MP 126). Carcass data were collected daily from November through April, when WVC are most common, with incidental reports compiled through the remainder of the year. Data collection included all species, with a focus on ungulates and large and medium-sized animals.

CDOT maintenance patrols have been recording carcasses due to WVC since 2005. Carcass reporting by maintenance personnel is non-compulsory. It is likely that reporting effort in the first years of the program was inconsistent. As the program became more established, reporting effort is believed to have become more consistent. WVC carcass pickups are reported year-round for all species, although the majority of carcass reports are deer and elk.

The study will also examine ten-year WVC accident reports compiled by CDOT Traffic and Safety. Wildlife-vehicle collision crashes, while underreported, are reported consistently statewide and offer a useful standard for comparing WVC accident rates inside the project area with those outside of the project area pre- and post-mitigation construction. However, 2017 data were not available at the writing of this report, precluding post-construction analysis of these data.

Winter was defined as the months of December through April for all WVC analyses. Each dataset was analyzed with respect to the date and location of WVC, and the species involved in these collisions. For this progress report, the researchers compared the five-year pre-construction WVC averages (Winter 2010-11 – 2014-15) for each dataset with the pre-completion WVC carcass rates (Winter 2015-16) and, for the two carcass datasets, post-construction WVC rates

(Winter 2016-17). Two segments are identified in the project area relative to this analysis: The Phase 1 pre-completion segment (MP 131-137), and the Phase 2 pre-construction segment (MP 126-130).

CDOT Maintenance carcass reports are available statewide. It was, therefore, possible to compare WVC rates beyond the project area, including SH 9 south and north of the project boundary, and on US Highway 40 (US 40) east and west of Kremmling. Both segments of highway are maintained by the same CDOT patrol eliminating potential data collection variations that may occur between patrols. Comparing WVC rates inside the project area with those beyond the project area, but within habitat used by the same ungulate herds and affected by the same weather patterns, helped the researchers to generalize reasons for potential changes in WVC in time and space, and the extent to which these changes may be due to the mitigation project. An increase in WVC from an annual baseline outside of the project area with a corresponding decrease in the mitigated area may suggest a shift in wildlife movement around the mitigated segment.

Performance Measures

Performance measures allow an evaluation of how well the wildlife mitigation accomplishes stated objectives of a highway improvement project. These measures help agencies take adaptive management actions to increase the effectiveness of the mitigation, or to inform future mitigation projects in other locations. It is essential to define measurable performance measures at the outset of a project to objectively evaluate project success. The wildlife mitigation system on SH 9 is evaluated with respect to wildlife connectivity and traffic safety. Specifically, wildlife connectivity performance measures address how well the crossing structures allow wildlife populations to access habitat on both sides of the highway; and traffic safety performance measures address how well the mitigation reduced WVC. Performance measures were generated by the researchers in conjunction with the research Study Panel.

The research team and study panel re-evaluated the performance measures following the first winter of post-construction monitoring (Winter 2016-17) in light of preliminary research results and recently published reports from comparable studies. No alterations were made to success thresholds established in Year 1 of the study. The team considered adding a measure evaluating intercept rates at escape ramps, but ultimately declined to do so; however, the team will report on intercept rates and escape rates at escape ramps. Performance Measure #12, which evaluates pedestrian walk-through gates, will be eliminated as the walk-through gates were closed off with swing gates in Fall 2017. The research team observed deer breaching the gates – in some cases moving back from the ROW side to the habitat side, as well as breaches into the ROW – and CPW determined that these gaps should be closed. No additional changes to the performance measures will be made for the duration of the study to ensure that the measures remain unbiased by the study results.

Wildlife Connectivity Performance Measures

Wildlife connectivity is assessed for large and meso mammal species. To evaluate how well the wildlife crossing structures facilitate species' use, performance measures are based on two rates: 1) success rates, and 2) the number of movements recorded through or over structures per year for each species (movements/year).

Success Rates

1. *Mule deer success rate at each structure will be a minimum of 60%, and have a goal of 80% success during the final year of the study* (based on Montana - Cramer and Hamlin 2016; Utah – Cramer 2014, 2016; Wyoming – Sawyer et al. 2012).

2. *Elk success rate at each structure will be a minimum of 60%, and have a goal of 75% success during the final year of the study* (based on Arizona – Gagnon et al. 2011).

3. *Success rate for all meso to large mammal species (other than deer and elk) detected near each structure will be a minimum of 60%, and have a goal of 80% success for each structure during the final year of the study* (based on Montana – Purdum 2013).

Movements per Year

4. *By the end of the study, male and female mule deer movements through all crossing structures will be in the same male:female proportions as are estimated for the local population* (based on population estimates as determined by CPW).

5. By the end of the study, male and female elk movements through all crossing structures will be in the same male:female proportions as estimated for the local population (based on population estimates as determined by CPW).

6. By the end of the study, the number of elk success movements at all structures annually, will be at least 50% of the number of elk movements captured at associated habitat cameras (i.e., documenting animals in the vicinity of the structures, but not necessarily using structures), irrespective of season (based on Arizona – Gagnon et al. 2011).

7. Each year there will be an increase in the number of mule deer movements at wildlife crossing structures annually until an overall equilibrium/plateau is reached (based on Arizona – Gagnon et al. 2011; Dodd et al. 2012; Utah – Cramer 2016; Montana – Cramer and Hamlin 2016).

8. Each year there will be an increase in the number of elk movements at wildlife crossing structures annually until an overall equilibrium/plateau is reached (based on Arizona- Gagnon et al. 2011; Dodd et al. 2012; Utah - Cramer 2016; Montana - Cramer and Hamlin 2016).

9. Each year, there will be at least one to several successful movements through or over crossing structures for every one of the less common species of large ungulates and carnivores in the study area that are documented by the habitat cameras. This may include bighorn sheep, pronghorn, moose, white-tailed deer (Odocoileus virginianus)*, mountain lion, black bear, bobcat, and other species* (Utah – Cramer 2016; Montana – Cramer and Hamlin 2016).

10. By the end of the study, at least 80% of the individual mule deer, elk and other ungulate approaches to each deer guard will be deterred from entering the road right-of-way (based on Utah – Cramer and Flower 2017; Flower 2016).

11. By the end of the study, 50% of the individual mule deer and elk that ascend an escape ramp will escape to the habitat side, and no animals will jump up onto the ramp from the habitat side. (based on Arizona – Arizona Game and Fish Department, unpublished data; Colorado – Siemers et al. 2015).

12. By the end of the study, 100% of the individual mule deer and elk approaches to each pedestrian walk-through gate will be deterred from entering the road right-of-way. This threshold will be reevaluated in Year 2 of the study.

13. By the end of the study, the proportion of ungulate movements at the south fence end that enter into the fenced right-of-way will decrease to 20% or less (based on Utah – Cramer unpublished data, 2016).

Traffic Safety Performance Measures

Traffic safety performance measures evaluate how well the wildlife mitigation reduced wildlife-vehicle collisions. This is measured with reported crashes and carcasses.

14. The annual average number of WVC reported crashes (CDOT Traffic and Safety data) within the mitigated area of the study will decrease by at least 80% during the final two years of the study when compared to the five-year pre-construction average (based on Alberta, Canada – Clevenger and Barrueto 2014; Wyoming – Sawyer et al. 2012; compiled study – Huijser et al. 2009).

15. The annual average number of wildlife carcasses reported by Blue Valley Ranch and Colorado Parks and Wildlife within the mitigated area of the study will decrease by at least 80% during the final two years of the study when compared to the five-year pre-construction average (based on Alberta, Canada - Clevenger and Barrueto 2014; Arizona – Gagnon et al. 2015; Washington – McAllister et al. 2013).

16. By the last year of the study, the average annual number of WVC reported crashes within one mile south of the south fence end will not increase over the five-year average annual pre-construction crash rate for this section of road (based on Arizona – Gagnon et al. 2015; Wyoming – Sawyer et al. 2012).

Results

Pre-Construction Monitoring

Mule deer were observed at all locations during pre-construction monitoring. Given their pervasiveness in the project area, mule deer presence and abundance was not tallied. Of all other wildlife species, elk and coyote were the most commonly documented species (Table 2). Elk were most common in the southern portions of the project area, at the future sites of Williams Peak Underpass and the South Overpass. In the northern portion of the project area, bobcat was the most commonly documented species (other than mule deer), and occurred only at the future North Underpass site. Other species detected during pre-construction monitoring included red fox, American badger (*Taxidea taxus*), hare/rabbit, striped skunk (*Mephitis mephitis*) and domestic dogs and cats.

Table 2. Wildlife presence by species other than mule deer during pre-construction at future wildlife crossing structure locations. Pre-construction monitoring was conducted at all locations from November 2014 – March 2015. Additional pre-construction monitoring was conducted in the Phase 2 (south) segment during Winter 2015-16.

Monitoring Location	Elk	Moose	Pronghorn	Mountain Lion	Bobcat	Coyote
Phase 1 (North) Segment						
MP 136.0 – North Underpass	1	0	0	0	26	10
MP 134.3 – North Overpass	0	0	0	0	0	0
MP 132.5 – Middle Underpass	0	0	0	0	0	0
MP 131.6 – Harsha Gulch Underpass	0	0	0	0	0	3
Total Non-Mule Deer Wildlife	**1**	**0**	**0**	**0**	**26**	**13**
Phase 2 (South) Segment						
MP 130.8 – BVA Underpass	0	1	0	2	1	8
MP 129.5 – South Overpass	25	0	1	0	1	50
MP 127.7 – Williams Peak Underpass	41	0	0	0	0	8
Total Non-Mule Deer Wildlife	**66**	**1**	**1**	**2**	**1**	**66**

Post-Construction Monitoring

Post-construction monitoring results include the pre-completion timeframe for the Phase 1 (north) segment and all locations across Phase 1 and Phase 2 following the completion of construction activities in November 2016. Cameras were in operation for 214 days during the non-winter months of 2016 (May – November) and 139 days during Winter 2016-17 (December

– April). Cameras were in operation for varying lengths of time depending on location. In some cases, cameras were removed during the summer months so as to not interfere with on-going construction activities or, in some cases, the cameras were not deployed until construction activities ceased later in the fall. Battery depletions and equipment malfunctions also decreased the number of monitoring days at a given location.

Since the start of this study in December 2015, monitoring cameras have recorded a total of 22,752 success movements by mule deer through or over the crossing structures. For the reporting period from May 2016 through April 2017, large and medium-bodied wildlife were recorded at crossing structures 16,325 times, including 15,667 success movements. Mule deer account for the bulk of this activity, having made 15,854 individual movements at crossing structures, resulting in 15,221 success movements. Mule deer activity was highest during the winter months, when deer descended from their summer range to the study area; however, some deer remained in the study area throughout the year. Species such as black bear, white-tailed deer and pronghorn were most commonly observed during non-winter months. Others, such as bobcat, coyote, elk, red fox, mountain lion and moose were observed throughout the year.

Mule Deer Use of Wildlife Crossing Structures

Table 3 summarizes the success rates, repel rates and parallel rates for mule deer, as well as the average number of successful deer passages per day at each crossing structure. Across all structure locations success rates ranged from 83% to nearly 100%. The highest success rate (nearly 100%) was observed at the South Overpass, which had less than a 0.5% repel rate. The lowest success rate was at the Williams Peak Underpass (83%). This location also had the highest rate of parallel movement (7%) and tied with the North Underpass for the highest repel rate (10%).

Mule deer activity varied substantially at each of the wildlife crossing structures during Winter 2016-17, the first season of post-construction monitoring (Fig. 4). The highest number of movements was captured at the North Overpass (4,474) – this location also recorded the highest number of movements during the previous winter. The second highest number of mule deer movements was recorded at the BVA Underpass (3,963) in its first winter post-construction.

Table 3. Mule deer movements at wildlife crossing structures.

Monitoring Location	Monitoring Timeframe	Total Move-ments	Success Move-ments	Average Deer per day	Average Success per Day	Success Rate	Repel Rate	Parallel Rate
Phase 1 (North) Segment								
MP 136.0 – North Underpass	Pre-Comp. Winter*	574	493	3.9	3.4	86%	10%	4%
	Pre-Comp. Non-Winter	71	66	0.4	0.3	93%	6%	1%
	Post-Constr. Winter†	753	674	5.4	4.8	90%	9%	1%
MP 134.3 – North Overpass	Pre-Comp. Winter	5164	5073	37.7	37	98%	0.5%	1.5%
	Pre-Comp. Non-Winter	1214	1167	5.7	5.5	96%	2.5%	1.5%
	Post-Constr. Winter	4474	4236	32.2	30.5	95%	5%	<0.5%
MP 132.5 – Middle Underpass	Pre-Comp. Winter	1127	1078	7.8	7.5	96%	3%	1%
	Pre-Comp. Non-Winter	417	401	1.9	1.8	96%	1%	3%
	Post-Constr. Winter	1565	1464	17	15.9	93%	3%	4%
MP 131.6 – Harsha Gulch Underpass‡	Pre-Comp. Winter	996	888	6.9	6.2	89%	6%	5%
	Post-Constr. Winter	779	755	5.6	5.4	97%	3%	<0.5%
Phase 2 (South) Segment§								
MP 130.8 – BVA Underpass	Post-Constr. Winter	3963	3904	28.5	28.1	98%	1%	1%
MP 129.5 – South Overpass	Post-Constr. Winter	2359	2350	16.9	16.6	99%	<0.5%	<0.5%
MP 127.7 – Williams Peak Underpass	Post-Constr. Winter	240	203	1.7	1.5	83%	10%	7%

**Pre-completion winter was the winter of 2015-16; Pre-completion non-winter was May – November 2016.*

†Post-construction winter was winter of 2016-17.

‡The Harsha Gulch Underpass cameras were removed during the pre-completion non-winter time frame due to construction activities.

§Cameras in the Phase 2 segment were deployed following construction in that phase in late November 2016.

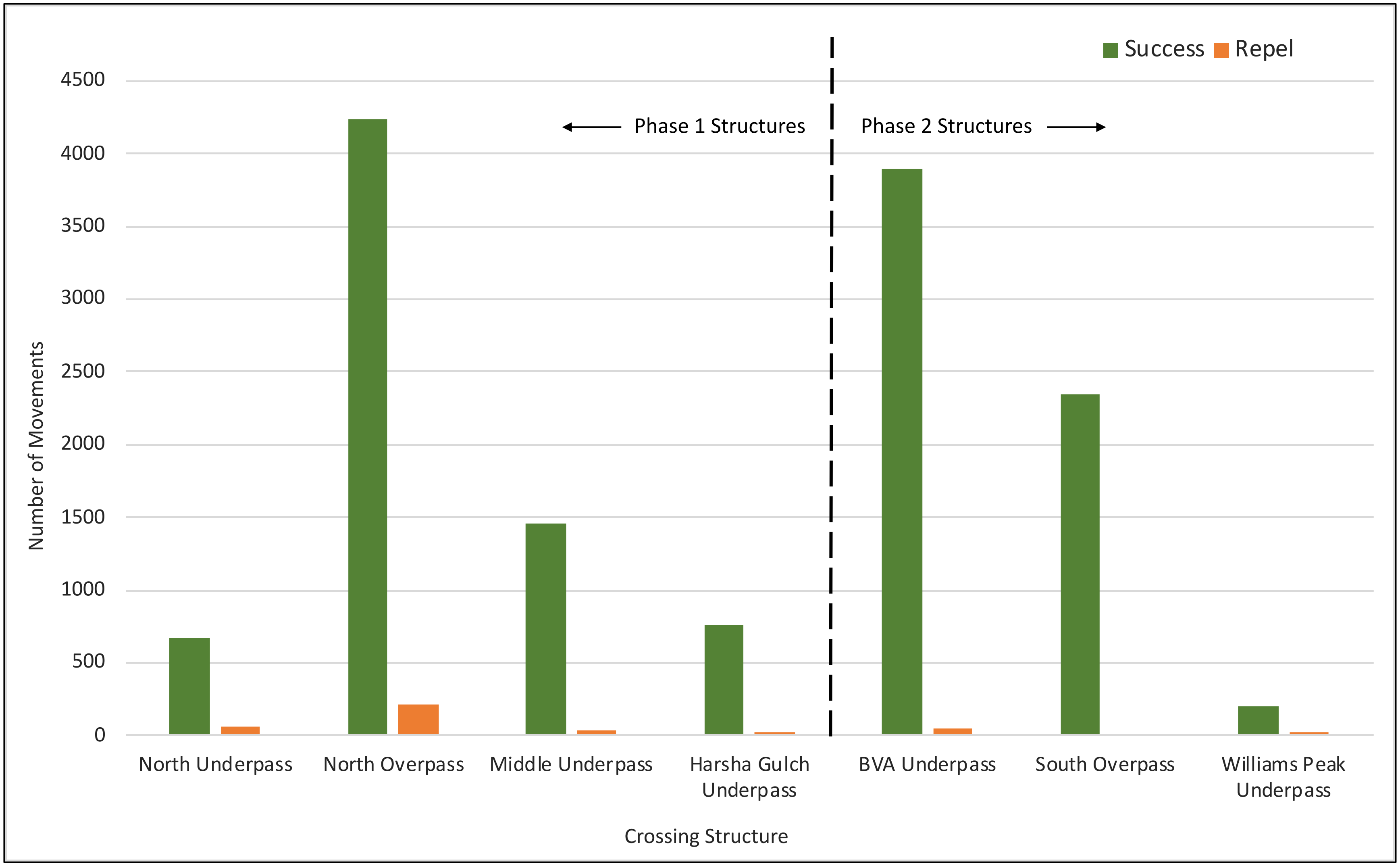

Figure 4. Total number of mule deer success and repel movements at each crossing structure location during Winter 2016-17.

The Williams Peak Underpass was the location with the lowest number of mule deer movements (240). Average rates of use were compared between overpass and underpass structures for Winter 2016-17 (Fig. 5). On average, mule deer were more than twice as likely to use an overpass structure than an underpass structure.

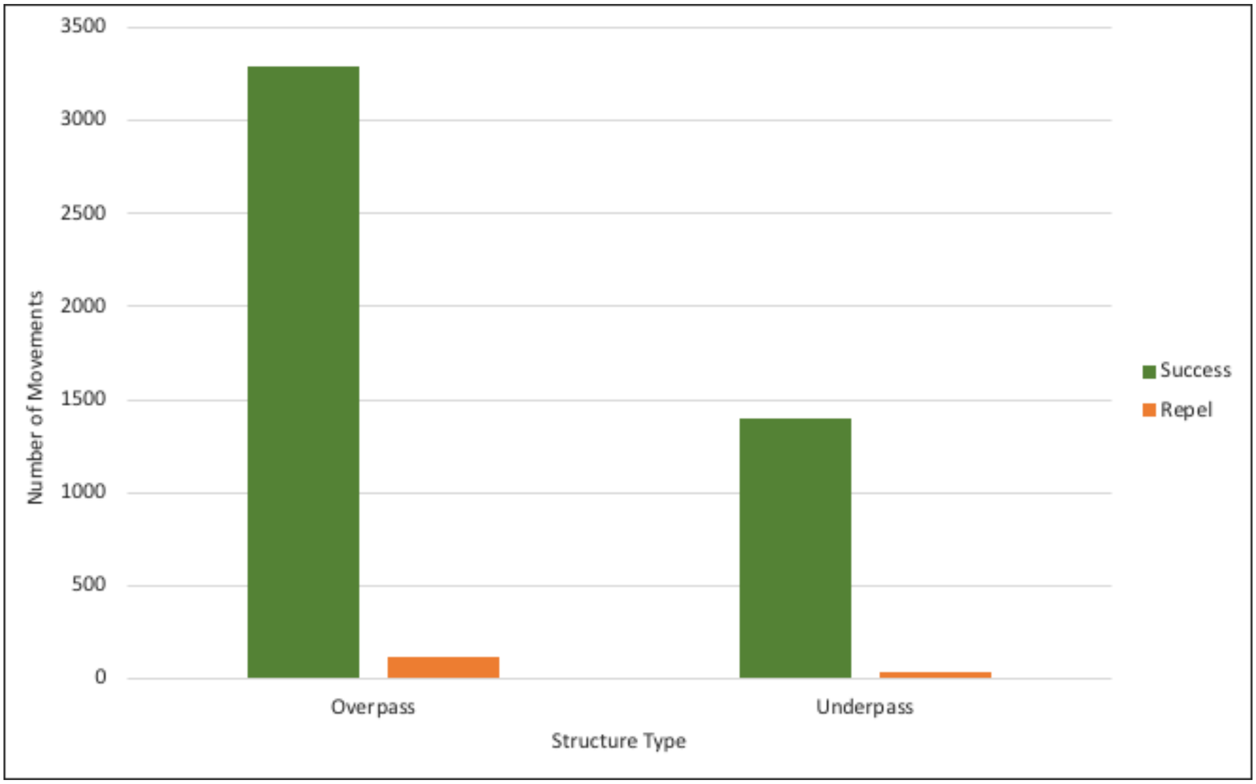

Figure 5. Average number of success and repel movements for mule deer at overpass versus underpass structures during Winter 2016-17.

Deer were recorded at all structures throughout the year where cameras were deployed, with most movements resulting in successful through-passage. The majority of movements at all structures occurred during the winter months, corresponding with deer arrival on winter range. A 52-week scale, beginning January 1, was used to compare movements across structures and between years. Figures 6-12 depict, for each crossing structure, the total number of mule deer movements detected relative to mule deer success movements by week of the year (note that the y-axis scale varies for each graph). For a given week, the closer the paired orange and blue bars are in height, the greater the success rate for that week.

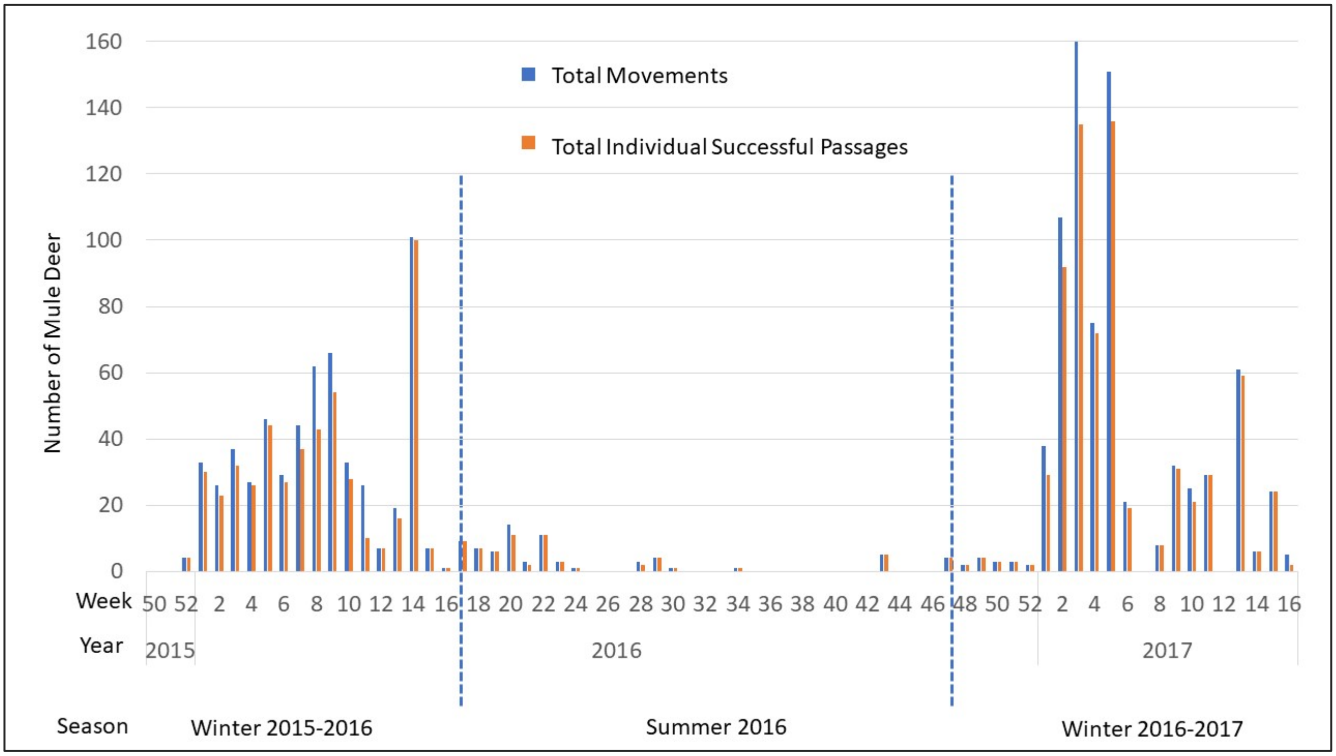

Figure 6. Mule deer total movements and success movements by weeks of the year at the North Underpass (MP 136). Note y-axis scale is 0-160.

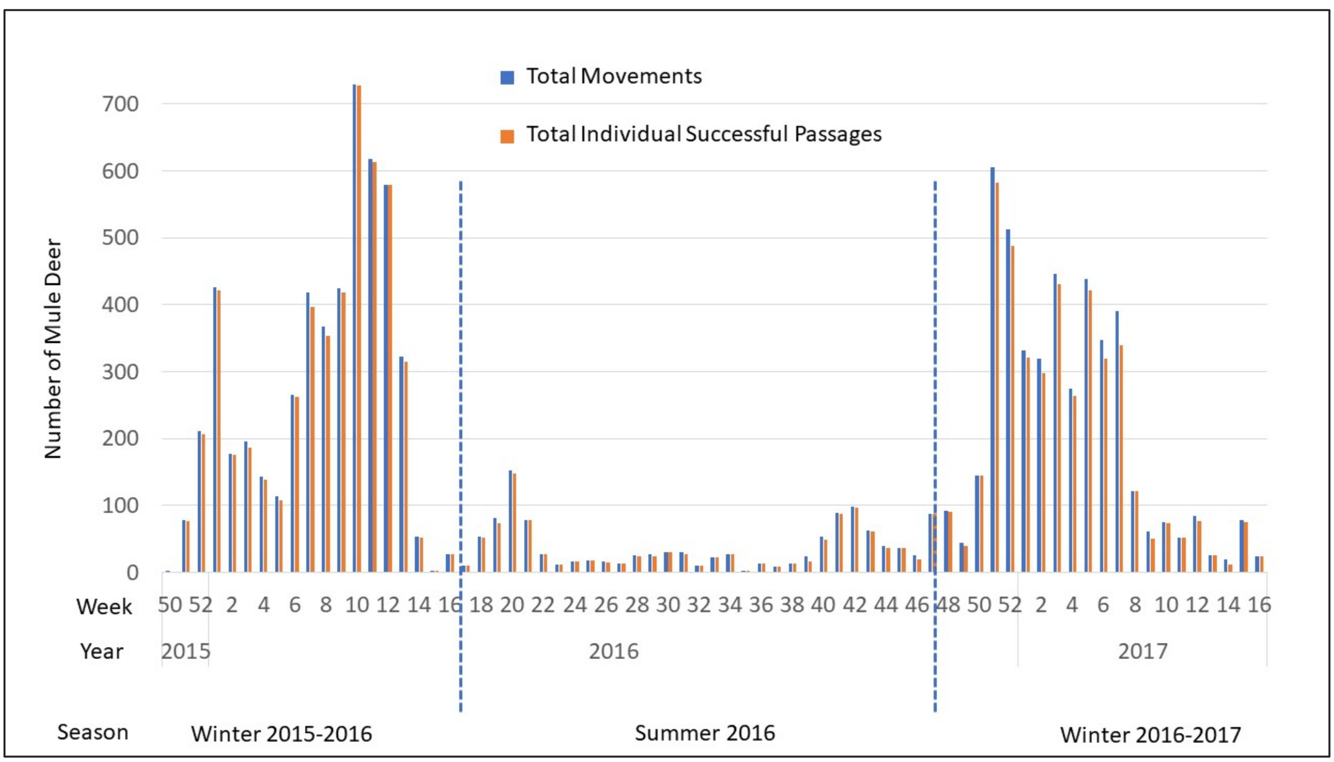

Figure 7. Mule deer total movements and success movements by weeks of the year at the North Overpass (MP 134.3). Note y-axis scale is 0-700.

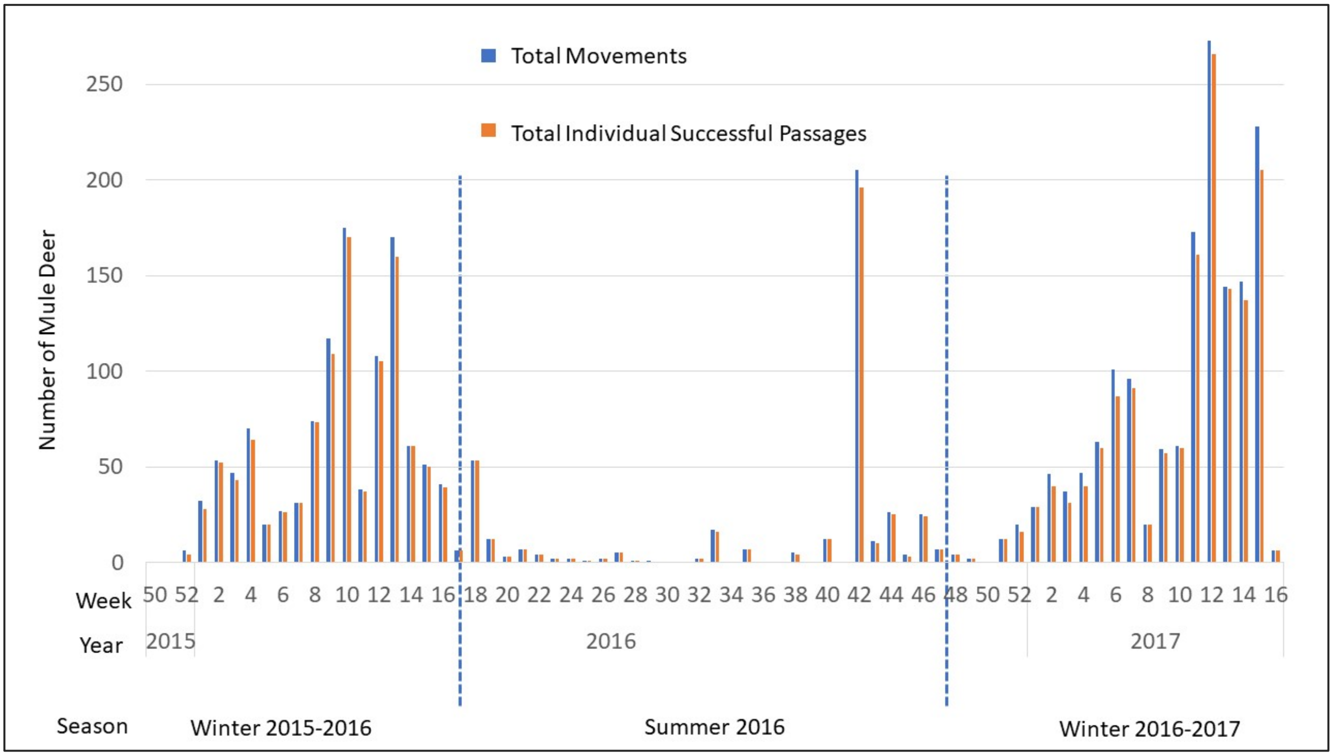

Figure 8. Mule deer total movements and success movements by weeks of the year at the Middle Underpass (MP 132.5). Note y-axis scale is 0-250.

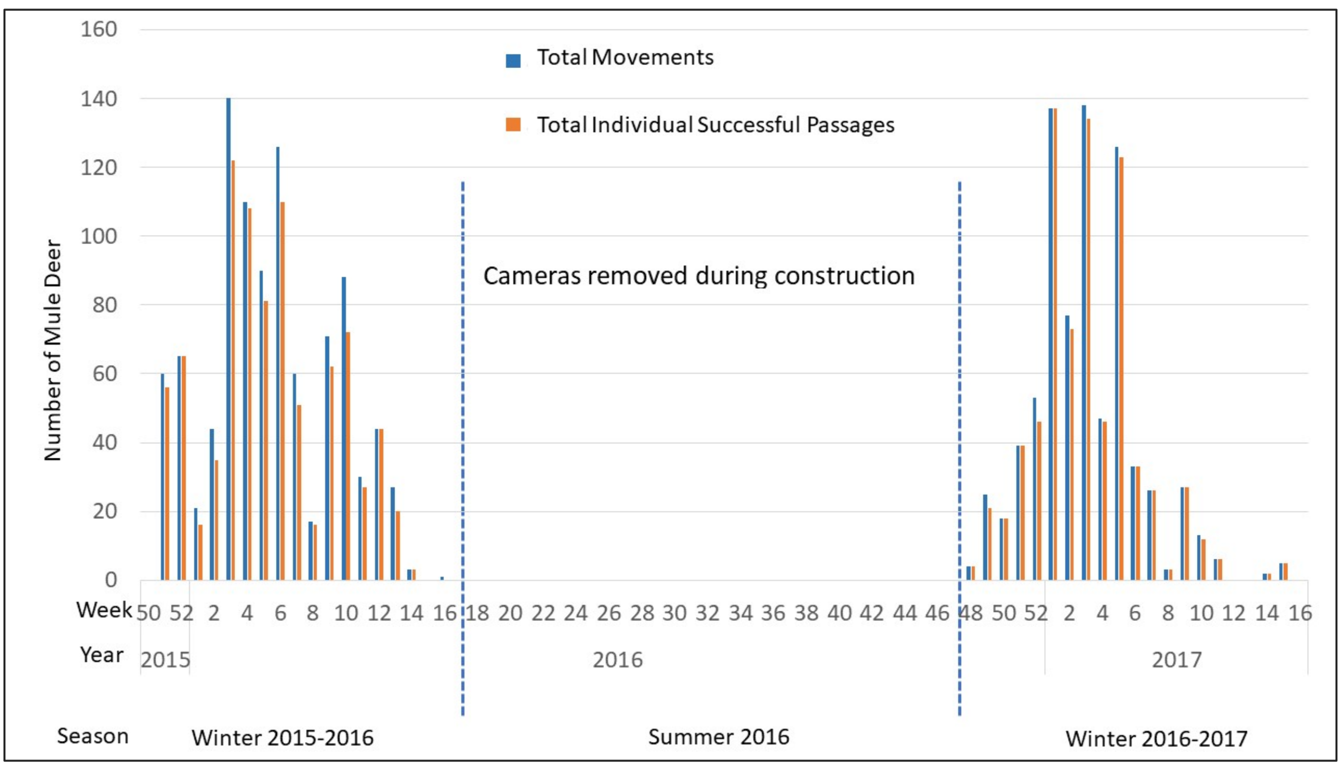

Figure 9. Mule deer total movements and success movements by weeks of the year at Harsha Gulch Underpass (MP 131.6). Note y-axis scale is 0-160.

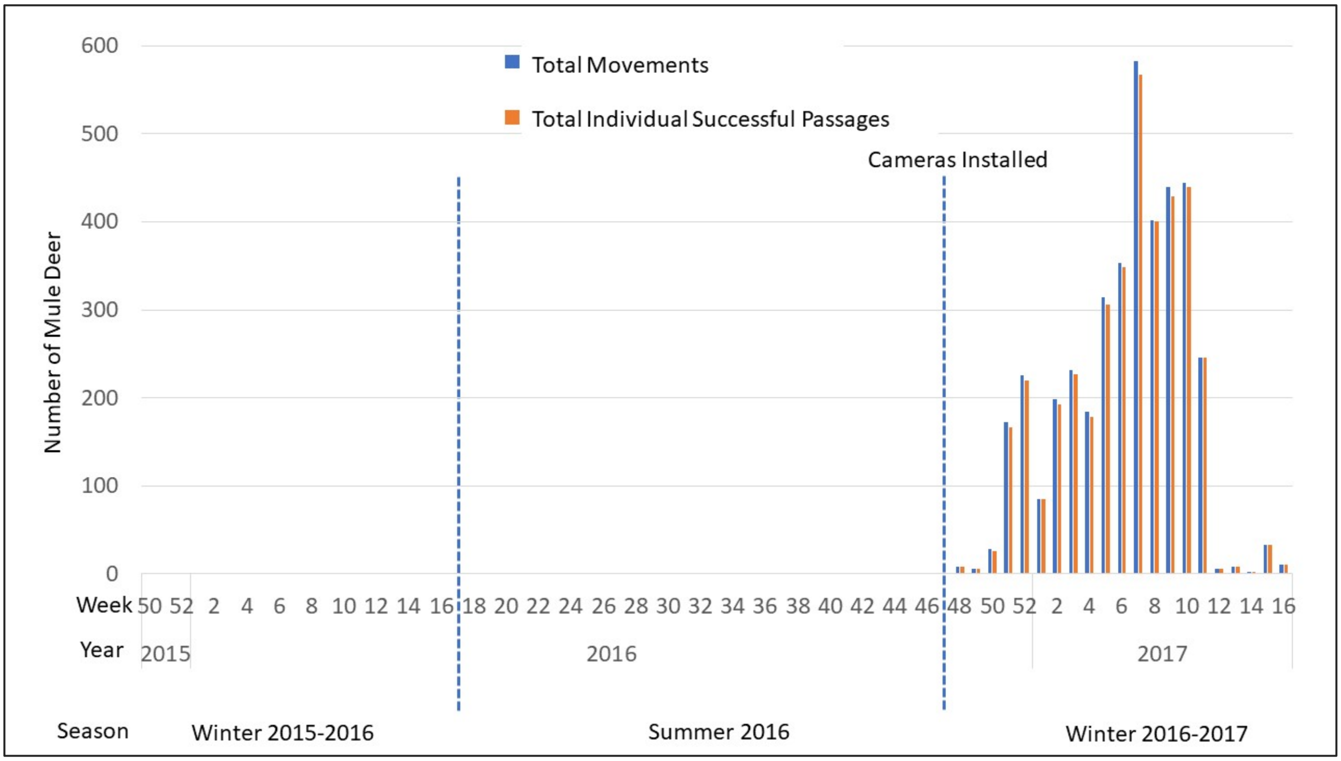

Figure 10. Mule deer total movements and success movements by weeks of the year at the BVA Underpass (MP 130.8). Note y-axis scale is 0-600.

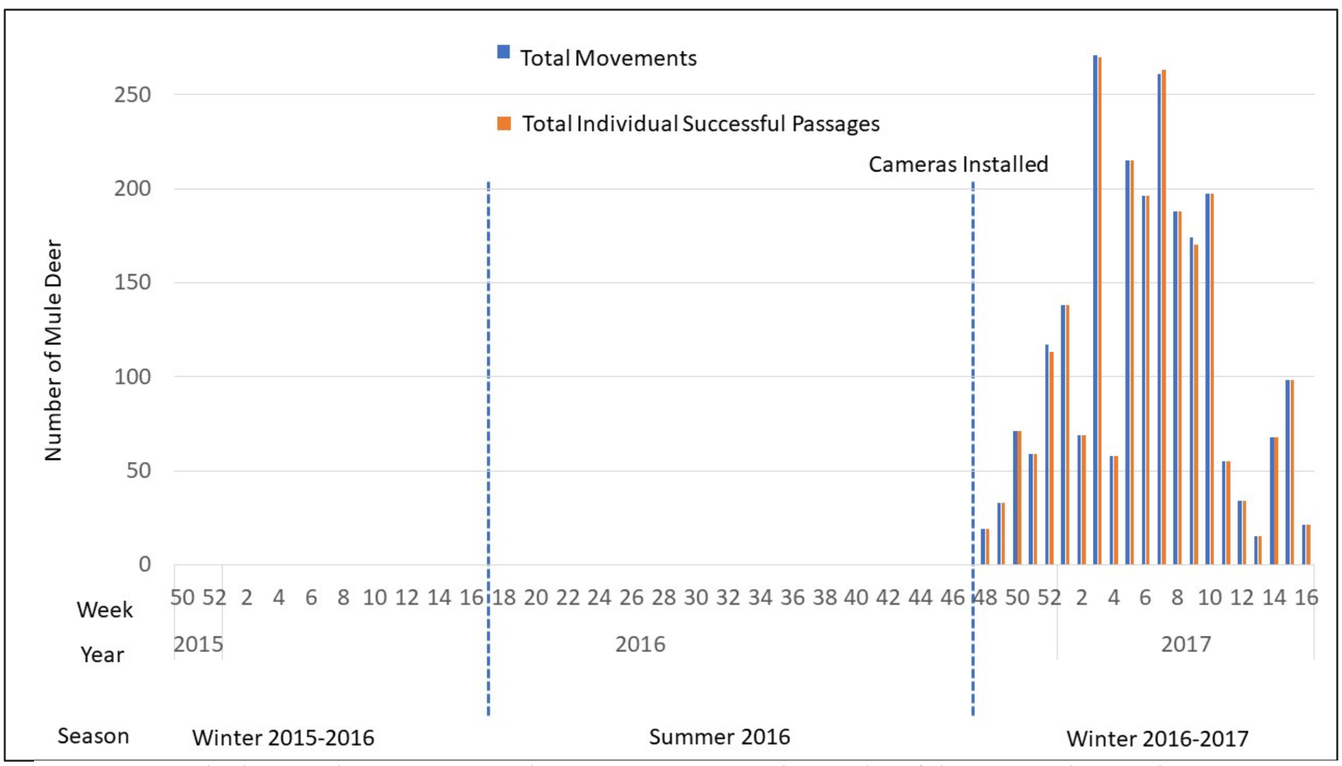

Figure 11. Mule deer total movements and success movements by weeks of the year at the South Overpass (MP 129.5). Note y-axis scale is 0-250.

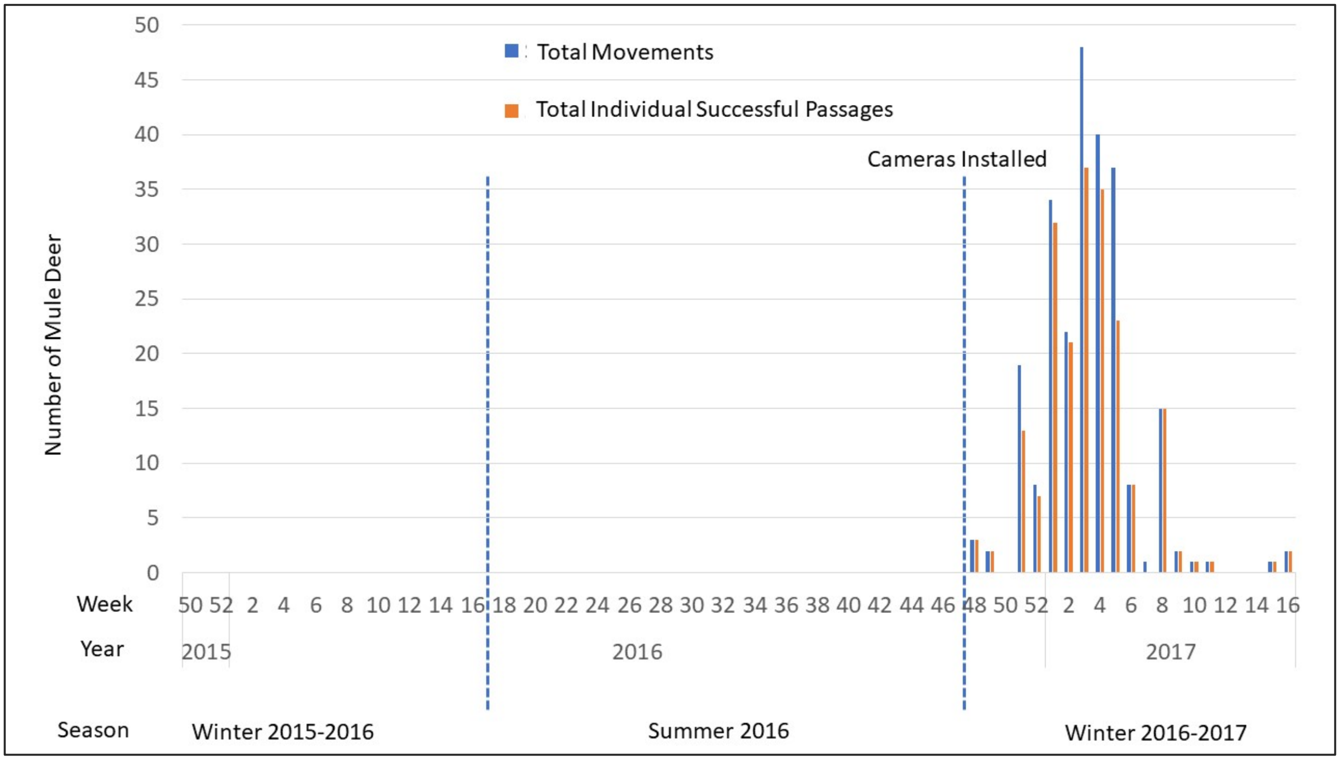

Figure 12. Mule deer total movements and success movements by weeks of the year at the Williams Peak Underpass (MP 127.7). Note y-axis scale is 0-50.

In Winter 2016-17, periods of peak mule deer activity differed depending on the crossing structure location. At most locations, peaks occurred between early January and mid-February. However, activity at the North Overpass peaked in late December, and at the Middle Underpass mule deer activity peaked between late March and mid-April. A comparison of activity in Winter 2015-16 with Winter 2016-17 at Phase 1 structures, where pre-completion monitoring was conducted, revealed that periods of peak mule deer movements varied from one year to the next.

Movements through or over the crossing structures occurred in both directions, originating from the east and moving west, or originating from the west and moving east. East-to-west movements were greater than west-to-east movements at all locations except Harsha Gulch and Williams Peak Underpasses, where west-to-east movements were greater. As the project area is located within winter range, many of the same animals are making regular movements through the structures to access the habitat and resources on either side.

Gender of mule deer was noted in photo analysis when possible. The numbers of male and female deer were recorded, although, in many cases, gender was undetermined, for example, in males who had shed their antlers or because of photo quality or animal position. In addition, all immature animals were recorded as unknown gender. Numbers and percentages for each gender of individual mule deer whose movements were detected are presented in Table 4. Across sites, males represented 11% of the movements at crossing structures on average.

Table 4. Gender of mule deer whose movements were detected at wildlife crossing structures.

Monitoring Location	Male	Female	Unknown	% Male	% Female
North Underpass	241	668	485	17%	48%
North Overpass	1002	4637	5213	9%	43%
Middle Underpass	345	1129	1610	11%	36%
Harsha Gulch Underpass	252	616	864	15%	36%
BVA Underpass	449	2135	1403	11%	54%
South Overpass	236	1098	1025	10%	47%
Williams Peak Underpass	33	104	107	14%	43%

Elk and Other Species Use of Wildlife Crossing Structures

In addition to mule deer, a variety of other species were documented using the wildlife crossing structures. Table 5 lists the total number of success, repel and parallel movements for each species across all crossing structures and the corresponding success and repel rates for those species. Success rates for all species ranged from 83-100%. The total number of movements for species such as bighorn sheep, moose, pronghorn and white-tailed deer were low; however, no repel movements were documented for any of these ungulates.

Elk successfully crossed the overpass structures on 17 occasions, 16 of which occurred at the North Overpass. No repel movements by elk were documented at either overpass. Twenty-two successful passages by elk were recorded at underpass structures, along with two repels. One repel occurred at the North Underpass, but this location also had the highest number of successful elk passages (13). The other repel occurred at the Harsha Gulch Underpass, which had three successful elk passages. Six successful elk passages and no repel movements were documented at the Middle Underpass. No elk were documented at either of the underpass structures located in the Phase 2 (south) segment.

Table 5. Movements by species other than mule deer at wildlife crossing structures. Success, repel and parallel movements are the total number of each movement across crossing structures. Success and repel rates are calculated for each species.

Species	Total Movements	Success Movements	Repel Movements	Parallel Movements	Success Rate (%)	Repel Rate (%)
Bighorn Sheep	2	2	0	0	100	0
Black Bear	63	62	1	0	98	2
Bobcat	14	14	0	0	100	0
Coyote	225	213	7	5	95	3
Elk	35	32	2	1	91	6
Fox, Red	52	43	2	7	83	4
Moose	7	7	0	0	100	0
Mountain Lion	42	42	0	0	100	0
Pronghorn	9	9	0	0	100	0
White-tailed Deer	20	20	0	0	100	0

Success movements by a variety of large and medium mammals (other than mule deer) were documented at each of the crossing structures (Fig. 13). However, because monitoring data for non-winter months are not yet available for the Phase 2 crossing structure locations, reported species diversity at these three locations (South Overpass and BVA and Williams Peak Underpasses) is comparatively lower than at the Phase 1 structure locations. Species such as black bear, mountain lion and pronghorn were only detected during the non-winter months, while other species have been detected year-round. Coyote was the only species other than mule deer that was documented using every crossing structure, while red fox was documented at six of the seven structure locations. Black bear movements were captured primarily at the Middle Underpass. While multiple individuals appear to have used this structure, it is likely that the same bear with her cubs were regularly passing back and forth through this structure, resulting in a higher number of black bear passages at this location. Individuals of other species may have also incorporated a given structure into their home range for regular movements to either side of SH 9, although such use cannot be confirmed.

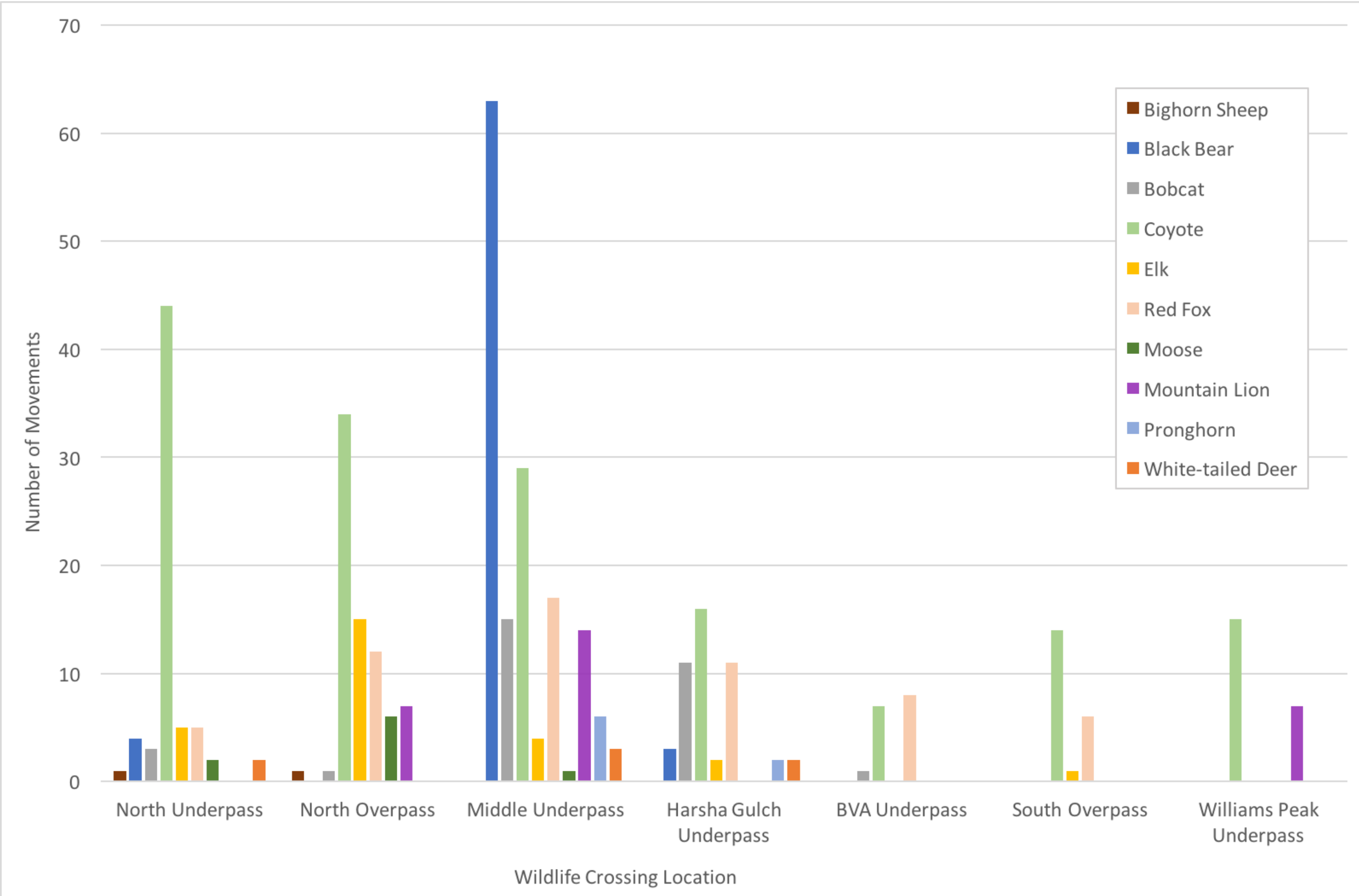

Figure 13. Success movements by non-mule deer species at each wildlife crossing structure from the onset of pre-completion monitoring in December 2015 through April 2017.

Wildlife movements at habitat cameras relative to movements at crossing structures for species other than mule deer are reported in Table 6. In general, wildlife that were captured at habitat cameras were also captured at crossing structures, although in a few cases wildlife that were not captured at the habitat cameras were documented at the structure. However, these events occurred in low numbers and are expected as the habitat cameras are unable to capture all wildlife activity in the vicinity of a structure.

Table 6. Comparison of species presence (other than mule deer) at wildlife crossing structures and habitat camera locations adjacent to wildlife crossing structures since May 2016. Note that movements at structures is the sum of all success, repel and parallel movements. Presence at habitat cameras does not imply that animals were moving to or from a crossing structure.

Species	Monitoring Location	North UP*	North OP*	Middle UP*	Harsha UP*	BVA UP†	South OP†	Williams Peak UP†
Bighorn Sheep	Structure	1	1	0	0	0	0	0
	Habitat	0	0	0	0	0	0	0
Black Bear	Structure	4	0	52	2	0	0	0
	Habitat	2	2	66	0	0	0	0
Bobcat	Structure	2	1	7	3	1	0	0
	Habitat	0	2	27	0	0	0	0
Coyote	Structure	42	36	23	15	7	14	15
	Habitat	5	94	44	1	2	8	18
Elk	Structure	4	16	1	1	0	1	0
	Habitat	7	13	2	1	0	2	0
Moose	Structure	2	3	0	0	0	0	0
	Habitat	0	1	4	0	0	0	0
Mountain Lion	Structure	0	7	14	0	0	0	7
	Habitat	0	2	0	0	0	1	8
Pronghorn	Structure	0	0	6	2	0	0	0
	Habitat	0	0	1	0	1	0	0
Red Fox	Structure	3	10	13	5	8	7	0
	Habitat	1	36	3	0	3	6	0
White-tailed Deer	Structure	2	0	3	2	0	0	0
	Habitat	0	0	7	0	0	0	0

**Counts at Phase 1 locations include the non-summer months of 2016 through Winter 2016-17*
†Counts at Phase 2 locations include only Winter 2016-17
UP = underpass
OP = overpass

Humans were recorded at all the crossing structures; this does not include researchers conducting camera checks. Human activity was most common at the North, Williams Peak and Middle Underpasses. In the first two years of the study some of this activity was due to ongoing construction and construction review activities, particularly during the non-winter months. As construction on this project is now closed, human activity in future years will more accurately represent non-construction related human activity. In future reports the researchers may evaluate the potential influence of humans on wildlife use of crossing structures.

Wildlife Movements at Small Culverts

The three small culvert locations included in this report were monitored for varying lengths of time. Monitoring at the BVR Pipe Culvert began at the on-set of pre-completion monitoring in December 2015 and continued through Summer 2016 for 306 monitoring days. The Culbreath Box Culvert was monitored from October 2016 through April 2017 for a total of 191 monitoring days. Monitoring at the BVR Box Culvert commenced late in the winter season of 2016-17 with only 42 monitoring days included in the timeframe of this report.

Wildlife activity at these small culvert locations occurred primarily during the non-winter months. Mule deer were documented at all three sites and a success movement was made on one occasion by a group of three deer through the BVR Pipe Culvert after much investigation and multiple attempts (Fig. 14). White-tailed deer visited the Culbreath Box Culvert site, although no attempts to pass through the culvert were observed.

Figure 14. Unusual movement by a group of three mule deer making a success movement through the BVR Pipe Culvert.

The highest levels of wildlife activity were documented at the BVR Pipe Culvert, which was regularly used by black bear and bobcat during the summer months (Fig. 15). Success movements were also documented by red fox, American badger and northern raccoon (*Procyon lotor*). At the Culbreath Box Culvert, the most success movements were made by red fox and one passage each by skunk and coyote. This culvert is located near a private ranch on the east side, and domestic dog and cat were also recorded here on multiple occasions. Due to the limited monitoring period at the BVR box culvert, little wildlife activity was documented.

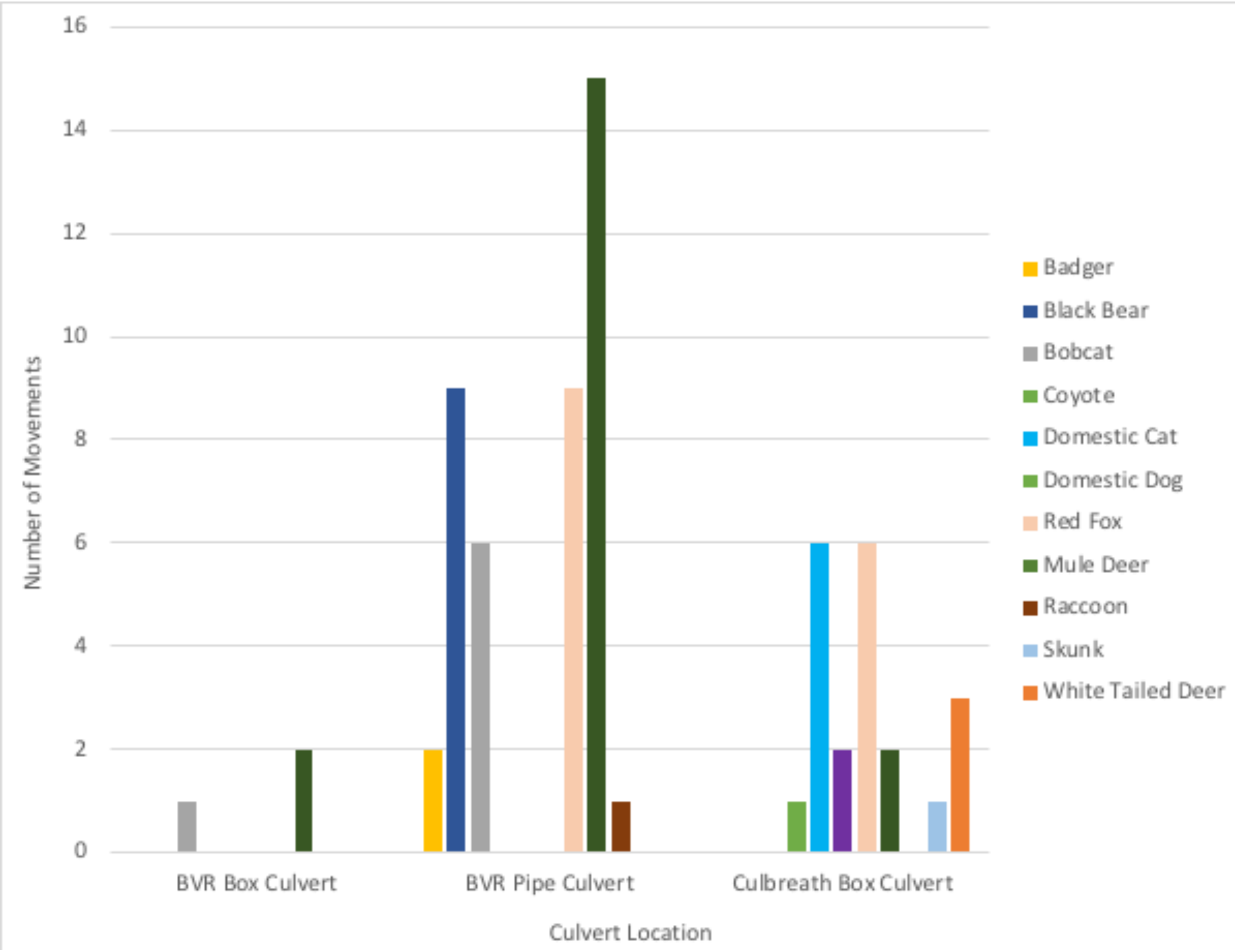

Figure 15. Species presence at small culverts, including success, repel and parallel movements.

Wildlife Movements at Other Mitigation Features

Deer Guards

Cameras were deployed at ten deer guard locations. Flat bar guards were installed at all locations during Phase 1 construction. In Phase 2 construction, round bar guards were installed at select locations and flat bar guards at the remaining sites. At two locations where flat bar guards were installed in Phase 1 (Thompson driveway and Culbreath driveway), the flat bar guards were replaced with round bar guards in the middle of August 2016 as a part of the adaptive management effort (Fig 16). Four round bar deer guards were installed at locations near flat bar deer guards. These parings help in evaluating wildlife responses to the deer guards where the motivations for breaching or repelling from the guards are expected to be similar, thereby helping to minimize confounding factors that may influence guard effectiveness. Deer guards are just under 16' long with the bars spaced 4" apart, and of varying widths, corresponding to the width of the road or driveway. The size of the deer guards and the spacing between bars is the same for both the flat bar and round bar designs.

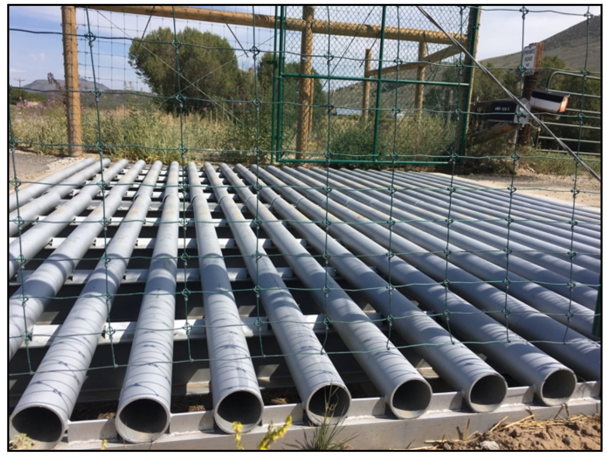

Figure 16. Round bar deer guard design installed at select locations during Phase 2 construction.

Wildlife movements, including breaches and repels were tallied, and breach rates and repel rates for each species were calculated (Table 7). Most approaches to the deer guards were from the habitat side of the fencing; however, in some cases animals approached the guard from the highway side. Species such as black bear and red fox were observed breaching the guards in either direction. Because these data include only one summer season, a complete evaluation of breach rates and success rates for species that are more active during non-winter months cannot be made at this time, particularly at the round guard locations, which were installed late in the summer. Raccoon, skunk, hare and domestic dogs and cats were also recorded at the deer guards.

The primary objective of the deer guards is to prevent ungulate incursions into the fenced right-of-way, particularly mule deer, elk and moose. Mule deer were the most commonly recorded species at deer guards. Mule deer were recorded 292 times at flat bar deer guards and 158 times at round bar guards. Of these, mule deer breached flat guards on 86 occasions for a breach rate of 29%; at round guards mule deer breaches were recorded on 21 occasions, resulting in a breach rate of 13%. Most breaches at flat bar guards were by deer walking on snow that was packed into the guards or by deer walking on top of the bars (Table 8). Deer were also observed jumping the guard and walking on the support beams. At locations with a pedestrian grate, 20% of breaches were by deer using the grate. The remaining breaches were by walking on top (47%) or by jumping (33%). At the round guards, mule deer most commonly breached the guards by jumping (86%). In no cases were mule deer observed walking on top of the round bar guards.

Table 7. Breach and repel rates for each species at deer guards with flat bars (8 locations) versus round bars (4 locations).

Species	Deer Guard Type	Total Approach Movements	Breach Rate (%)	Repel Rate (%)
Badger	Flat Bar	1	0	100
	Round Bar	0	n/a	n/a
Black Bear	Flat Bar	3	100	0
	Round Bar	0	n/a	n/a
Bobcat	Flat Bar	5	100	0
	Round Bar	0	n/a	n/a
Coyote	Flat Bar	69	78	22
	Round Bar	6	67	33
Elk	Flat Bar	12	8	92
	Round Bar	1	100	0
Moose	Flat Bar	5	0	100
	Round Bar	1	0	100
Mountain Lion	Flat Bar	1	100	0
	Round Bar	0	n/a	n/a
Mule Deer	Flat Bar	292	29	71
	Round Bar	158	13	87
Red Fox	Flat Bar	148	92	8
	Round Bar	23	87	13
White-tailed Deer	Flat Bar	1	0	100
	Round Bar	0	n/a	n/a

Mule deer breaches were recorded at all monitoring locations but occurred most frequently at County Road 1000 (flat bar), County Road 33 (flat bar), Culbreath (flat bar, prior to being replaced with a round guard) and Spring Creek (flat bar). The Thompson deer guard had the fewest breaches, both as a flat guard and later, after it was replaced with a round guard. The majority of the breaches that occurred by walking on snow occurred at County Road 1000, a flat bar guard location (29 breaches out of 34 total). The remainder occurred at Trough Road (flat bar) and County Road 1002 (round bar). Walking on top of the guard was the most common method of breaching at County Road 33 and Spring Creek, both flat bar locations. At round bar guards, breaches by jumping were recorded at all locations. The Culbreath flat bar deer guard was the only monitoring location with a pedestrian grate. Half of all mule deer breaches at this guard were by deer walking on top of the bars, while the remainder were by deer walking across the pedestrian grate or jumping across the guard.

Table 8. Breach type for Mule Deer at deer guards with flat bars (7 locations), flat bars with a pedestrian grate (1 location), and round bars (4 locations).

Deer Guard Type	Walk on Top	Walk on Support Beams	Walk on Snow	Jump	Walk on Grate
Flat Bar	23	3	36	9	n/a
Flat Bar with Pedestrian Grate	6	0	0	3	3
Round Bar	0	1	2	18	n/a

Escape Ramps

To date, twelve escape ramps have been monitored for varying lengths of time. In the Phase 1 (north) segment, all ramps were constructed with a 2:1 slope and perpendicular rail fence, except for the North Overpass Escape Ramp, on which rail fence was not constructed. Based on preliminary observations and recommendations by the research team, during Phase 2 construction all ramps were constructed with a 3:1 slope instead of a 2:1 slope (Fig. 17). In general, ramps were constructed with perpendicular rail fence, except for select locations where rail fence was omitted per the request of the researchers, who wanted to test the effectiveness of ramps with and without perpendicular rail fence. In addition, two new 3:1 slope escape ramps were constructed in the Phase 1 segment near existing 2:1 slope ramps. These two ramps are also situated at lower topographic positions relative to the roadway, while the 2:1 slope ramps are at

Figure 17. Examples of escape ramp with 2:1 slope and rail fence (left) and 3:1 slope with no rail fence (right).

higher topographic positions above the roadway. All of the ramps built in both construction phases are six feet high at the jumping off point, with a 16' wide fence gap.

Elk and mule deer movements at escape ramps occurred from December through March. Little activity was reported during the non-winter months, when the winter populations moved to their summer ranges. Four different types of movement were recorded at escape ramps, 1) animals walking along the fence line inside the right-of-way that did not ascend (intercept) the ramp, but instead walked around the base of the ramp; 2) animals that ascended the ramp and then turned back down the ramp; 3) animals that ascended the ramp and jumped down (escape) to the habitat side; and 4) animals that attempted to climb or jump up to the ramp from the habitat side.

When an animal approaches an escape ramp on the right-of-way side of the fence, it either walks around the ramp or ascends (intercepts) it. Table 9 summarizes elk and mule deer approaches and intercept rates for different escape ramp types. Mule deer were documented at all 12 monitored escape ramp locations, with the highest frequencies at the North Overpass Escape Ramp (2:1 slope with no rail fence), the East Fence End Escape Ramp and Badger Road Escape Ramp (both 3:1 slope with no rail fence). Across the study area, intercept rates for mule deer varied greatly, from 0-100%, depending on the location.

Table 9. Intercept rate by elk and mule deer at escape ramps with 2:1 versus 3:1 slopes and with or without perpendicular rail fence. Intercept rate is the percentage of animals that ascended the ramp relative to the total number of animals that approached the ramp.

Species	Escape Ramp Type	Total Approaches	Intercept Rate (%)
Elk	2:1 slope with rail fence (n=2)	3	33
	3:1 slope with rail fence (n=1)	0	n/a
	3:1 slope without rail fence (n=2)	168	54
Mule Deer	2:1 slope with rail fence (n=4)	27	15
	2:1 slope without rail fence (n=1)	98	71
	3:1 slope with rail fence (n=1)	61	36
	3:1 slope without rail fence (n=6)	181	61

Elk were documented at five ramp locations, with most approaches occurring at the East Fence End Escape Ramp (3:1 slope with no rail fence). Of 162 total elk approaches at this ramp, 90 resulted in elk ascending the ramp for an intercept rate of 55%. Notably, a large portion of this tally is accounted for by a single large group of elk that was trapped on the right-of-way side of the fencing and made multiple movements both around and ascending the ramp over the course of one night. Seven individuals ultimately escaped by jumping down from the ramp to the habitat side; the remainder are presumed to have exited the right-of-way via the nearby fence end.

Animals whose movements were intercepted by a ramp either walked up and turned around or jumped down to the habitat side. Table 10 summarizes jump down (escape) rates for deer and elk at each of the different escape ramp types. The highest number of mule deer escapes were at the North Overpass Escape Ramp and the Badger Road Escape Ramp, with escape rates of 16% and 21%, respectively. The highest number of elk escapes were at the East Fence End Escape Ramp. In a single event a group of seven elk ascended the ramp and, after two attempts, successfully escaped to the habitat side. No elk were documented approaching the West Fence End Escape Ramp (3:1 slope with rail fence), located on the opposite side of the highway. The only other successful escape by elk was at the Trough Road 2:1 Escape Ramp (with rail fence).
Moose, bighorn sheep or pronghorn were not recorded using the escape ramps, although one of the researchers observed a successful escape by a moose at the Spring Creek Escape Ramp (3:1 slope without rail fence). Humans were recorded in low numbers at each of the ramps, and in most cases appear to be curious passersby, including people on foot, dirt bikes, ATVs, and snow mobiles.

Table 10. Escape rates by elk and mule deer at escape ramps with 2:1 versus 3:1 slopes and with or without perpendicular rail fence. Escape rate is the percentage of animals that escaped to the habitat side of the fencing relative to the total number of animals that ascended the ramp.

Species	Escape Ramp Type	Total Ascend Ramp	Escape Rate (%)
Elk	2:1 slope with rail fence (n=4)	1	100
	2:1 slope without rail fence (n=1)	n/a	n/a
	3:1 slope with rail fence (n=2)	0	n/a
	3:1 slope without rail fence (n=5)	90	8
Mule Deer	2:1 slope with rail fence (n=4)	4	0
	2:1 slope without rail fence (n=1)	70	16
	3:1 slope with rail fence (n=2)	22	18
	3:1 slope without rail fence (n=5)	110	6

A number of ungulates, other wildlife and domestic cows were documented on the habitat side of the escape ramps. No ungulates attempted to jump up onto the ramp from the habitat side. On one occasion a bighorn sheep ewe appeared to investigate the ramp from the habitat side of the fence but made no attempt to jump up.

Pedestrian Walk-Through Gates

The purpose of the pedestrian walk-through gates is to allow people to cross through the fence line without use of a gate or ladder. The design of the gate should allow people to walk through a series of sharp angles in the fencing while precluding wildlife, in particular ungulates. The pedestrian walk-through gates used for the SH 9 project are derived from the Y-shape design used by the Montana Department of Transportation (Fig. 18*a*). Because the wildlife fence follows the CDOT right-of-way, the Y-shape would have infringed on the adjacent lands. To preclude issues with landowners, CDOT created a modified right-angle design (Fig. 18*b*).

Figure 18. a) Y-shaped pedestrian gate design used in Montana (left, photo credit: M. Huijser); b) modified right-angle design used by CDOT (above).

Three pedestrian walk-through gates were monitored – two in the Phase 1 segment and one in the Phase 2 segment. The State Wildlife Area (SWA) Pedestrian Gate (MP 135.9) and Bureau of Land Management (BLM) Pedestrian Gate (MP 132.4) were monitored in Year 1. In Year 2, monitoring continued at the SWA Pedestrian Gate, but not at the BLM gate. The Summit County Pedestrian Gate (MP 128.0) in the Phase 2 segment was added in Year 2. Mule deer were the most frequently observed species at pedestrian walk-through gates. In total, 32 breaches were captured, both from the habitat side of the fencing to the right-of-way side and vice versa. In some cases, it appeared that deer breached the gate, foraged on the right-of way side of the fence, and then returned to the habitat side the same way. Most animals documented by the cameras were making parallel movements. These animals were in the vicinity of a walk-through gate but did not investigate it or attempt to breach. Table 11 lists total movements across all locations by species and their corresponding breach, repel and parallel rates.

Table 11. Breach, repel and parallel rates at pedestrian walk-through gates.

Species	Total Movements	Breach Rate (%)	Repel Rate (%)	Parallel Rate (%)
Bobcat	1	0	100	0
Coyote	7	0	0	100
Elk	47	4	6	89
Mountain Lion	1	0	0	100
Mule Deer	304	11	8	81
Red Fox	2	0	0	100

South Fence End

Wildlife exclusion fence runs along the right-of-way line throughout the project area. The northern terminus ties into the Colorado River Bridge south of Kremmling. The southern terminus ends at MP 126.6. The end of the fence line angles in towards the pavement, ending 20' from the pavement edge so that it is not inside the clear zone. The temporary fence end at the southern terminus of the Phase 1 (north) segment (MP 131.0) was removed when the fencing was extended into the Phase 2 (south) segment. Monitoring at the permanent south fence end commenced on October 10, 2016 for a total of 169 monitoring days in this reporting period. The objective of monitoring at this location was to observe the number of mule deer, elk and other wildlife that approached the highway as if to cross without regard for fencing, versus those that entered the fenced right-of-way, versus those that exited the fenced right-of-way via the gap at the fence end.

A total of 298 movements were recorded of deer and elk at the south fence end (Fig. 19). Movements into the fenced right-of-way occurred when animals moved from the habitat side of the fence and either walked around the fence into the right-of-way or crossed the road and entered the right-of-way on the opposite side. Movements out of the fenced right-of way occurred when animals already inside the wildlife fence moved out to the habitat side of the fence. Movements beyond the fence includes movements where animals crossed the road beyond the fence end as well as those where the animal did not cross the road, but repelled from the road and remained beyond the fence end. Most movements for both deer and elk occurred beyond the fence end (91.6%).

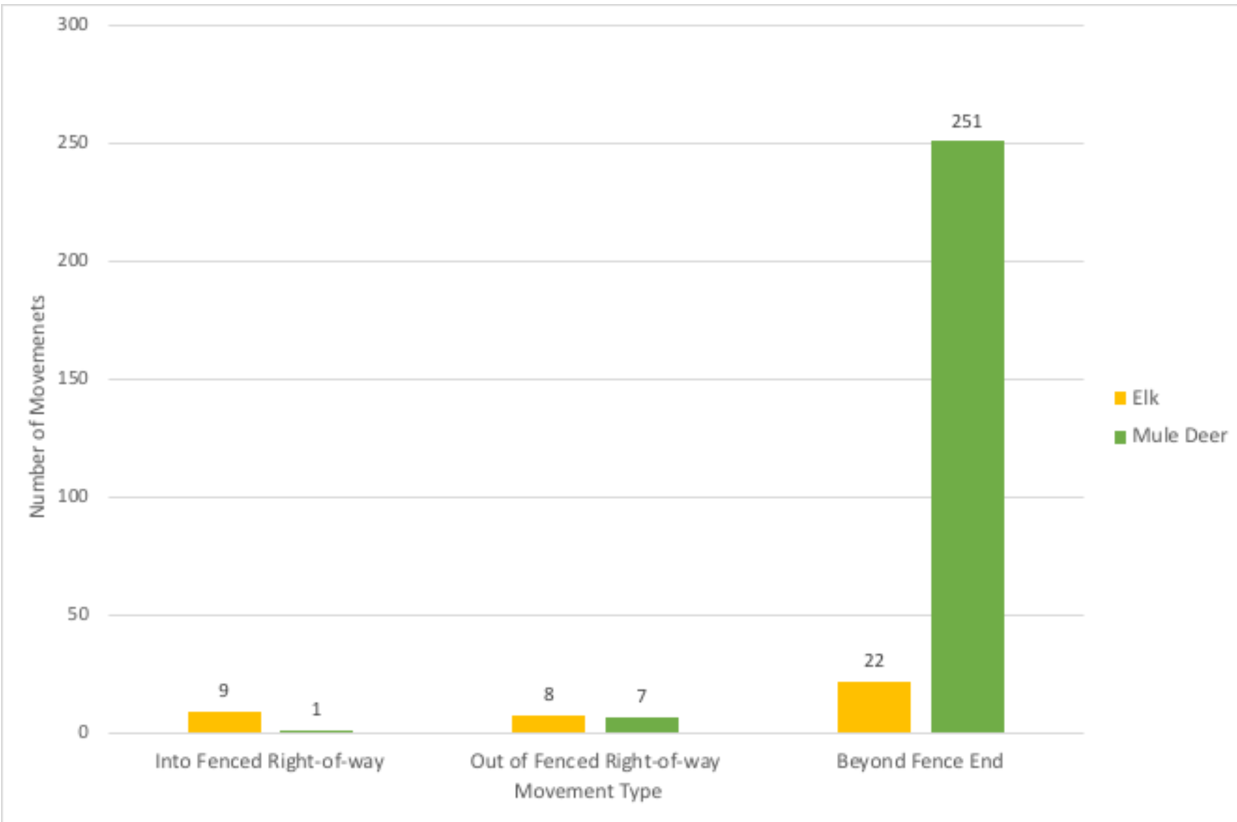

Figure 19. Elk and mule deer movements at the south fence end.

Seven of the nine elk movements into the fenced right-of-way were by a single group of elk that upon becoming trapped on the right-of-way side of the fencing, found the East Fence End Escape Ramp and successfully jumped down back to the habitat side. Some human movements were documented at the fence end, primarily of ATVs, dirt bikes or snowmobiles driving around the fence end on the west side.

Wildlife-Vehicle Collision Rates

Wildlife-vehicle collision rates were analyzed using three independent datasets – WVC carcass data compiled by BVR and CPW; WVC carcass data recorded by CDOT maintenance patrols; and WVC accident reports compiled from law enforcement by CDOT Traffic and Safety. Prior to 2013, BVR only collected carcass data during the winter months, and focused on the area north of Spring Creek Road (MP 128.5) to the town of Kremmling (MP 138). Winter was defined as the months of December through April for all WVC analyses; non-winter months include May through November. Analyses of all three datasets focused on the winter timeframe; however, non-winter months were included in the analysis of reported WVC accidents to demonstrate the seasonality of WVC in the project area. Because CDOT maintenance reports are collected statewide, this dataset was selected for additional analyses of SH 9 one mile north and south of the project area and on a nearby segment of US 40 to identify a potential influence of the project on WVC rates beyond the project area.

BVR/CPW Carcass Data

Blue Valley Ranch and CPW recorded a total of 285 WVC carcasses within the project area during the five winters prior to mitigation construction (2010-11 – 2014-15). Ninety-eight percent of recorded carcasses during this timeframe were mule deer. One percent was elk, and the remainder were coyote, fox and mountain lion. Mule deer and elk carcass counts varied from year to year, with an average of 56.4 carcasses per year pre-construction. In the Phase 1 segment, the annual winter carcass tally dropped from a high of 45 carcasses to three in Winter 2015-16, and continued to drop to two carcasses in Winter 2016-17. In the Phase 2 segment, which was not constructed until 2016, the Winter 2015-16 tally was 30 deer carcasses. In Winter 2016-17 the tally in this segment dropped to six carcasses post-construction. Across the project area, BVR/CPW carcass reports document a decrease in WVC of 41% during pre-completion and 86% post-construction relative to the five-year pre-construction average (Fig. 20).

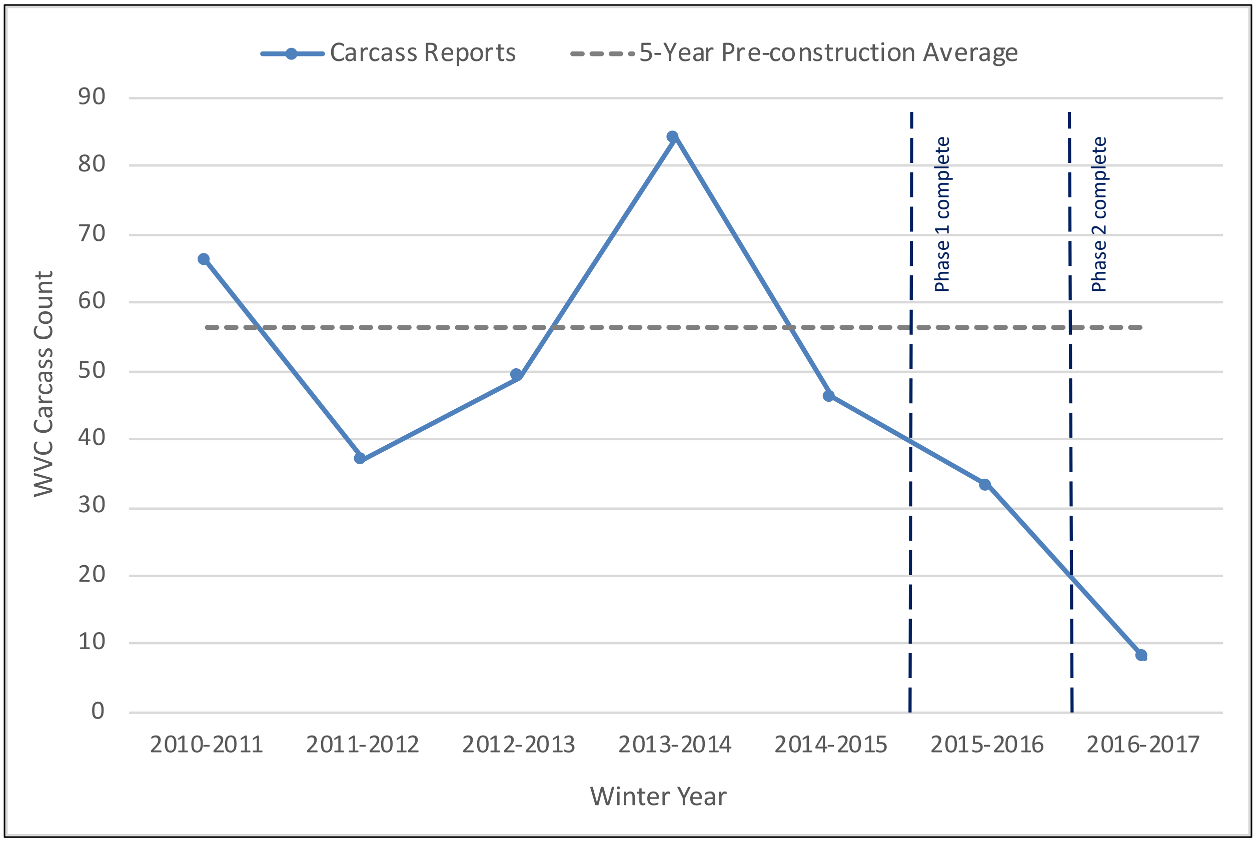

Figure 20. Mule deer and elk carcass counts recorded by BVR and CPW during winter, pre-construction to post-construction.

CDOT Maintenance Carcass Data

CDOT Maintenance recorded a total of 193 WVC carcasses within the project area during the five winters prior to mitigation construction (December through April, 2010-11 – 2014-15). Similar to the BVR/CPW reports, 97% of recorded carcasses during this time frame were mule deer. Both the BVR/CPW and the CDOT Maintenance carcass datasets documented four elk WVC within the project area during this timeframe. Four additional elk carcasses were recorded one mile north and south of the project area. Annual carcass reports during pre-construction ranged from a low of 22 in Winter 2011-12 to high of 54 in Winter 2013-14 in the project area (Fig. 21). The five-year winter pre-construction average was 38.2 carcasses. During pre-completion (Winter 2015-16), reported carcasses dropped to one carcass in Phase 1, but remained at 21 carcasses in the Phase 2 segment. Following the completion of Phase 2, carcass reports dropped to 0 in both Phase 1 and Phase 2, and three carcasses were reported in the mile south of the fence end (MP 126.6). Across the project area, CDOT Maintenance carcass reports document a decrease in WVC of 42% during pre-completion and 100% one year post-construction relative to the five-year pre-construction average.

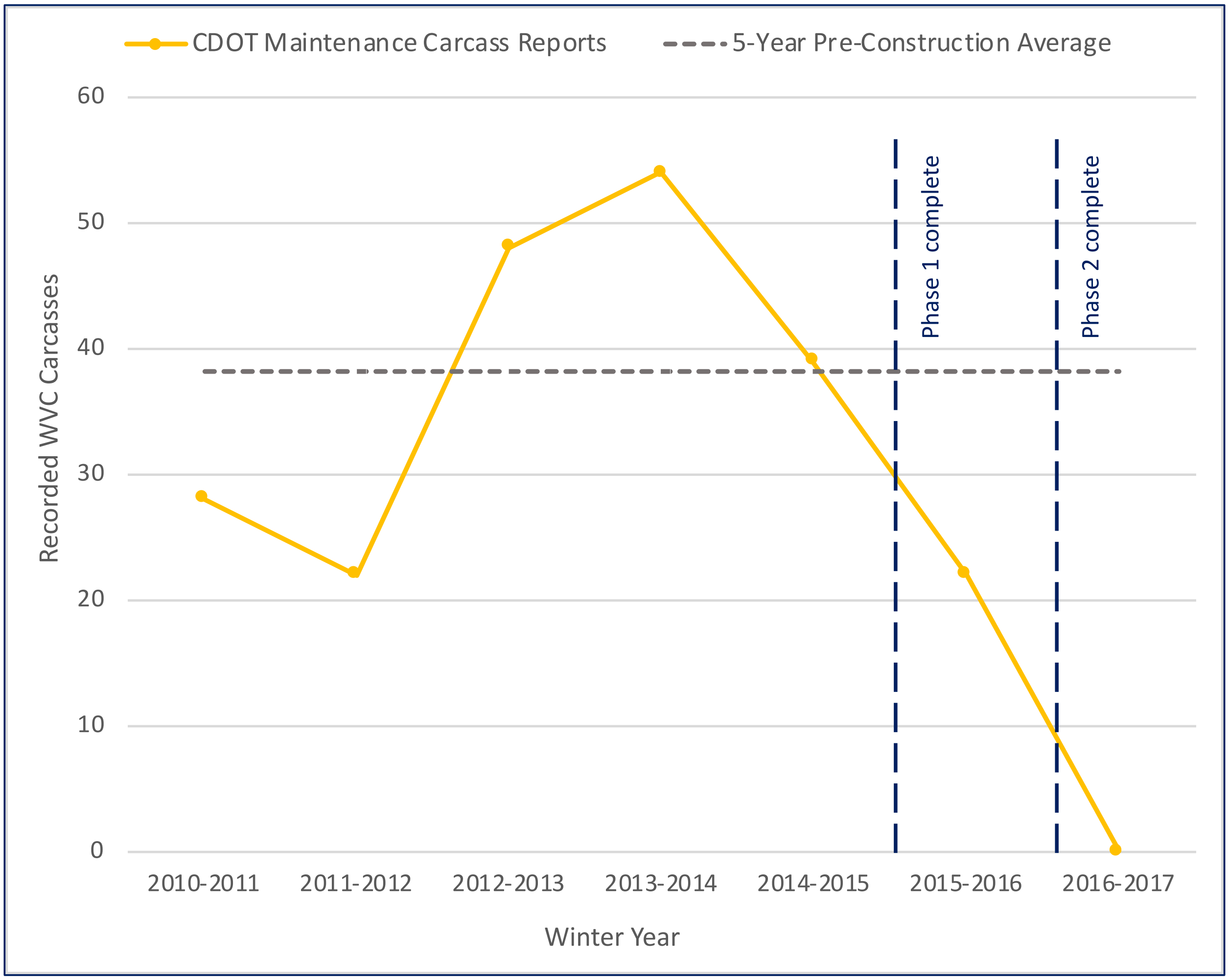

Figure 21. Mule deer and elk carcass counts recorded by CDOT Maintenance pre-construction to post-construction.

The CDOT WVC carcass dataset was also examined with respect to mileposts, including one mile south and north of the project area (Fig. 22). Pre-construction, the highest WVC carcass rates occurred inside the project area. Pre-completion, high WVC rates continued to occur in Phase 2, where mitigation construction had not yet commenced, and WVC decreased in Phase 1, where mitigation construction was completed. Few WVC carcasses were reported north of the project area pre-construction or pre-completion.

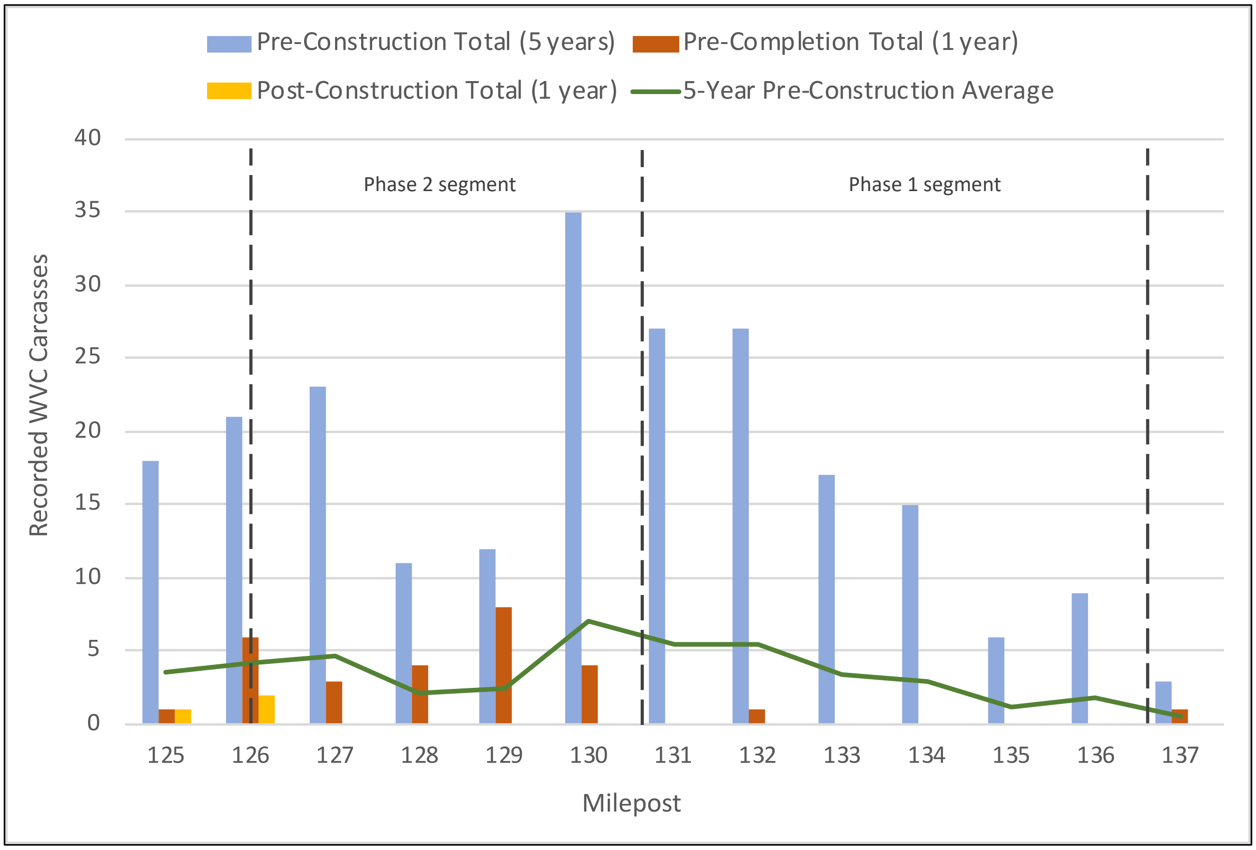

Figure 22. Mule deer and elk carcass counts recorded by CDOT Maintenance by milepost. Pre-construction totals comprise 5 years; pre-completion and post-construction totals comprise 1 year each. The 5-year pre-construction average was calculated for each one-mile segment.

Traffic and Safety Accident Report Data

During the five winters prior to mitigation construction (December through April, 2010-11 – 2014-15), reported WVC were the most common accident type on this segment of highway, accounting for 60% of all accidents reported to law enforcement. WVC accidents varied annually and seasonally, with the highest WVC rates occurring during the winter months (Fig. 23). Across the project area, Traffic and Safety accident reports document a decrease in WVC of 70% during pre-completion (Winter 2015-16). Post-construction data were not available at the time of this analysis. No accidents were reported in the Phase 1 segment during pre-completion, while three accidents were reported in the Phase 2 segment during this timeframe.

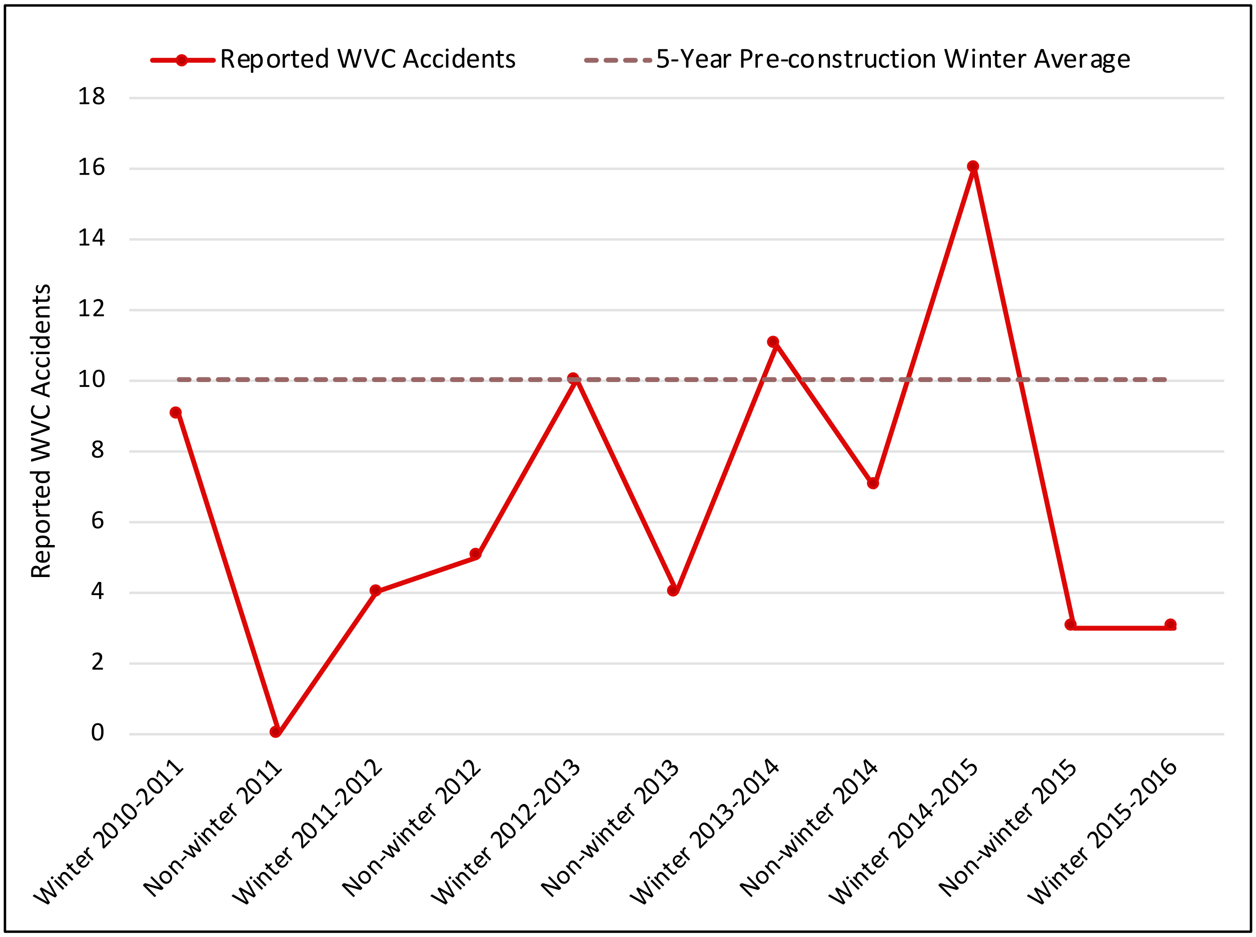

Figure 23. Accidents reported to law enforcement involving mule deer or elk relative to the 5-year pre-construction average.

It is commonly understood that accident reports capture only a small portion of all WVC. Figures 24 and 25 demonstrate the variation in these three WVC datasets. The BVR/CPW dataset is the most comprehensive. Traffic and Safety accident reports and CDOT Maintenance carcass reports account for 18% and 68%, respectively, of the data recorded by BVR and CPW (Table 12).

Table 12. Comparison of WVC data from Accident Reports, CDOT Maintenance carcass reports and BVR/CPW carcass reports. This comparison is based on five winters of pre-construction data.

Data Source	Total 5-year Winter WVC Count	Average Recorded WVC per Winter	Reporting Rate
Accident Reports	50	5	18%
CDOT Maintenance	191	19	68%
BVR/CPW	282	28	100%

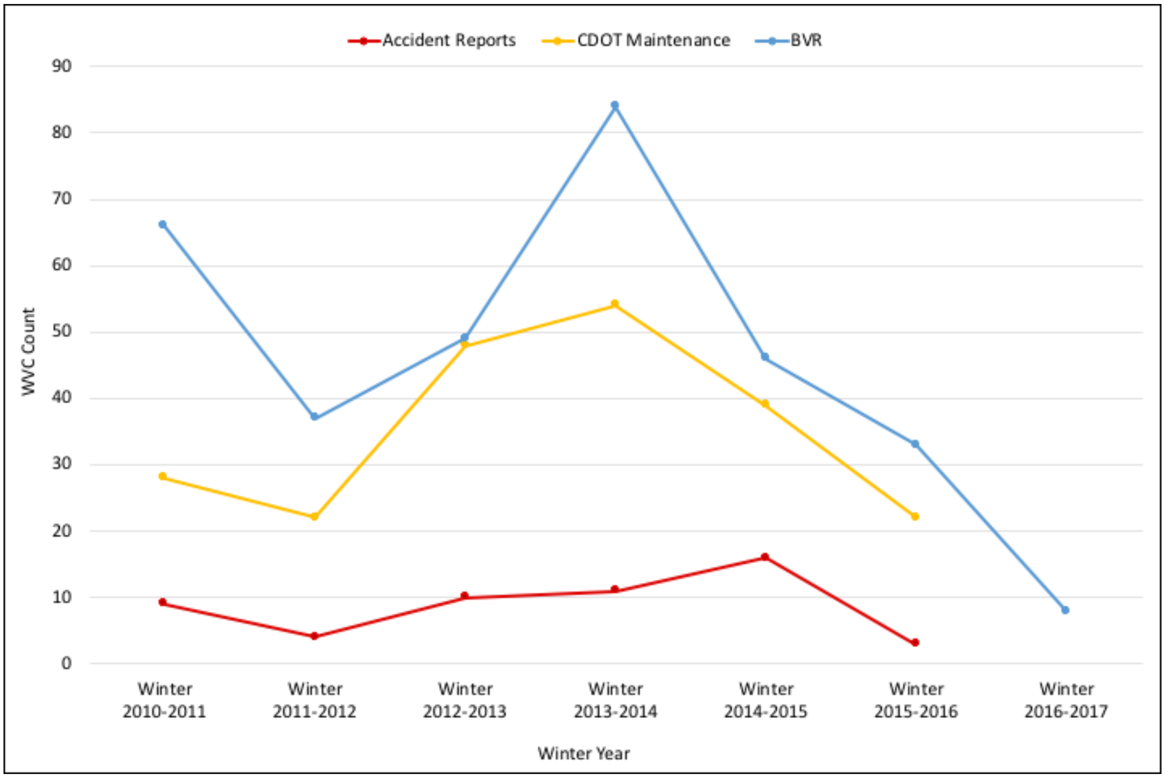

Figure 24. Comparison of WVC data from Accident Reports, CDOT Maintenance carcass reports and BVR/CPW carcass reports. Accident data for 2017 were not available at a the time of this analysis.

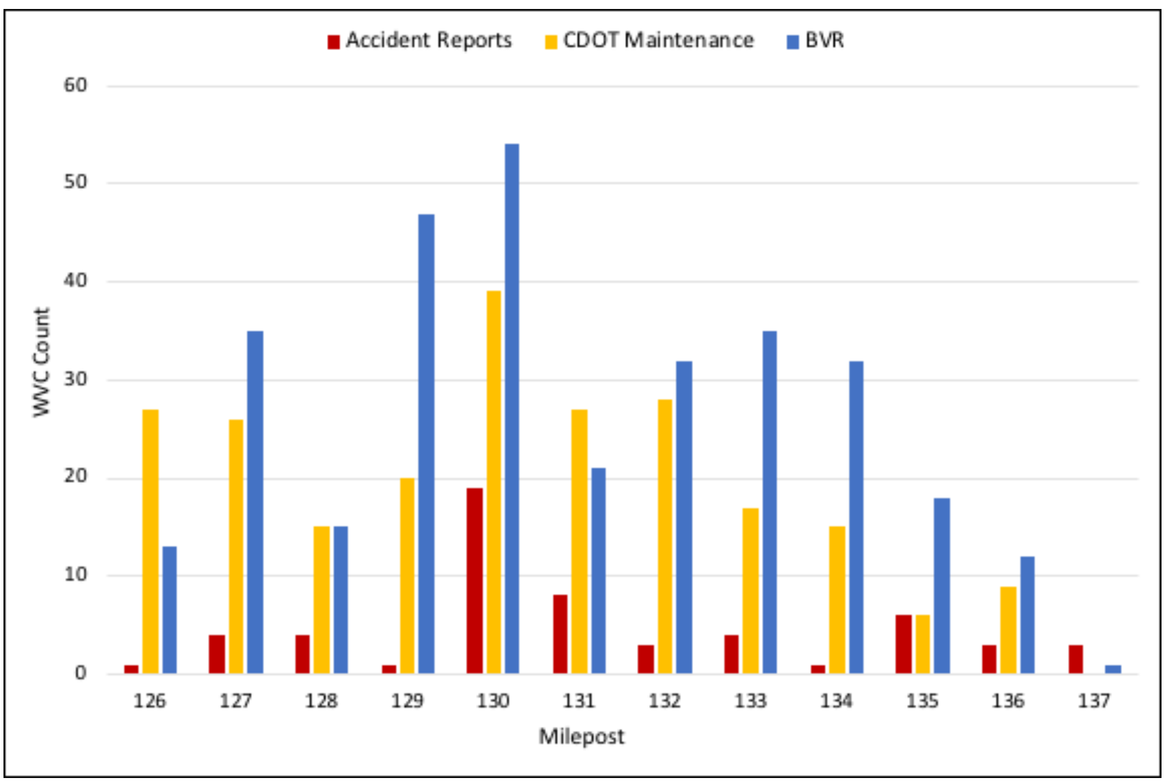

Figure 25. Comparison of WVC data from Accident Reports, CDOT Maintenance carcass reports and BVR/CPW by milepost for five years pre-construction and one year pre-completion.

Wildlife-vehicle Collision Rates on US 40

In addition to WVC rates on SH 9, the researchers also analyzed the CDOT Maintenance carcass dataset for US 40 from MP 182-190, an east-west highway that runs through the town of Kremmling. Comparisons were made between the five-year pre-construction average number of mule deer and elk carcasses, and those reported during the winters of 2015-16 and 2016-17, following construction of the Phase 1 and Phase 2 segments, respectively (Fig. 26). This comparison was made to determine whether the mitigation on SH 9 may have contributed to a shift in wildlife movements, particularly elk, from SH 9 north across US 40, with a resulting increase in WVC on US 40.

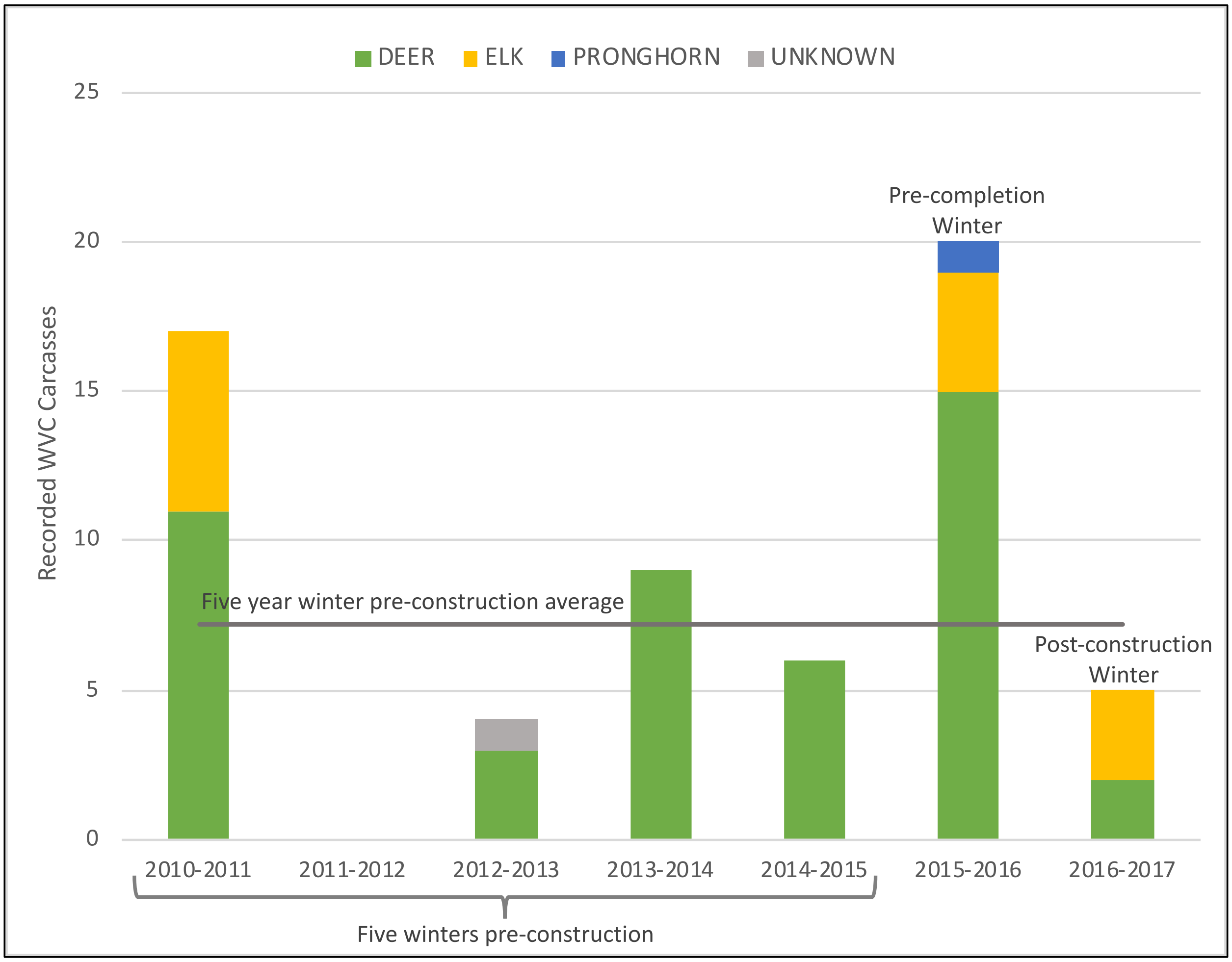

Figure 26. Ungulate carcass counts recorded by CDOT Maintenance on US 40 east and west of Kremmling for five winters prior to mitigation construction, one winter following the construction of the Phase 1 segment (pre-completion) and one year post-construction. The solid line represents the five-year pre-construction average number of carcasses (7.2).

Milepost 189, four miles east of Kremmling, and MP 183, west of Kremmling, had the highest number of mule deer and elk carcasses pre-construction. No carcass data were recorded by CDOT Maintenance in Winter 2011-12. Six elk carcasses were recorded on US 40 over five years prior to the construction of wildlife mitigation features on SH 9 both east and west of Kremmling. Following construction of the Phase 1 segment, four carcasses were recorded in Winter 2015-16 and three in Winter 2016-17 following completion of mitigation construction.

Discussion

Wildlife Use of Crossing Structures

The research results provide evidence that the wildlife crossing structures are performing well in facilitating mule deer and other species movement above and under the highway, and in demonstrating that major decrease in WVC in the study area. These results have also been used to assist CPW and CDOT to adaptively manage the mitigation infrastructure between the two construction phases as well as following the completion of the construction project, where needed.

From the onset of the study (December 2015) through April of 2017, monitoring cameras recorded a total of 22,752 mule deer success movements through or over the wildlife crossing structures. Mule deer success rates at the seven structures ranged from 83-99% in Winter 2016-2017. Overall, the early success seen in the first winter of post-construction monitoring in the Phase 1 segment continued through the second winter of Phase 1 post-construction monitoring, and is also reflected in post-construction monitoring in the Phase 2 segment. The high number of movements captured, particularly during the winter months, reflect regular movements appearing to be made by many of the same individuals on winter range.

Mule deer movements varied among crossing structures. Mule deer movements at the two overpass structures accounted for 48% of all deer movement at crossing structures, and resulted in predominantly success movements over the structures (95-99%). In the Phase 1 segment, which was in the second year of post-construction monitoring during Winter 2016-17, mule deer movements ranged from less than 800 at the North Underpass and Harsha Gulch Underpass, to 4,474 at the North Overpass. The BVA Underpass and the South Overpass also saw high levels of mule deer activity in their first winter of post-construction monitoring (3,963 and 2,359 movements, respectively). Whereas the Williams Peak Underpass recorded the lowest number of movements (240). Given the relatively homogenous nature of the project area (rolling terrain and sagebrush vegetation) and that the structure designs for the overpasses and underpasses were the same throughout the project, this spatial variation in mule deer use of crossing structures may be due to a combination of factors, such as the location of each structure relative to where mule deer wintered, local terrain features at each structure, or variability in mineral composition and forage quality (e.g., Peterson 2008). A comparison of mule deer use of overpass structures versus underpasses during Winter 2016-17 indicates that, on average, mule deer were more than twice as likely to use an overpass structure than an underpass structure.

In general, mule deer movements at Phase 1 structure locations (2 winters post-construction monitoring) reflected similar patterns in Winter 2015-16 and Winter 2016-17. The highest number of total movements and success movements were at the North Overpass in both winters and, of the underpass locations, at the Middle Underpass. Success rates varied from one winter to the next at the Phase 1 structure locations. At the North Underpass and Harsha Gulch Underpass, success rates increased from four and eight percentage points, respectively. At the North Overpass and the Middle Underpass success rates were lower in Winter 2016-17 than they were in Winter 2015-16, decreasing by three percentage points at each location. Regardless of this variation, success rates were high at all locations and during all monitoring periods, indicating that mule deer have adapted quickly to these mitigation features.

Mule deer movements at crossing structures varied seasonally, with the greatest number of movements occurring during the winter months. Year-round monitoring, however, captured mule deer activity throughout the year, as some animals are resident and do not migrate to summer range. Of the locations where data were available, the number of movements during the non-winter months (May – November) ranged from 11-29% of the number of winter movements (December – April). At each of these locations, success rates were higher during the non-winter months than the corresponding winter-time success rates, indicating that the resident population that remained in the study area year-round adapted to the mitigation features more completely than the total winter population. The North Overpass was the only location where mule deer movements were recorded every week of the year.

Periods of peak mule deer activity varied by location and from one winter to the next. During Winter 2016-17, peak activity occurred between early January and mid-February at most locations, although peak activity at the North Overpass was in late December and, at the Middle Underpass, this peak occurred towards the end of the winter season. Fluctuations in snowfall is a likely contributor to annual variability.

The relative percentages of male mule deer at the different structures suggests a potential preference among male deer for underpass structures. While buck mule deer movements comprised 11-17 % of total mule deer movements at the five underpass structures, they were only 9-10% of movements on the two overpasses. Notably, most movements at all structures were by deer of unknown gender (which included fawns), and male deer movements may be underestimated, particularly after antlers have been shed. The final report for this study will compare the ratio of bucks and does using the crossing structures to the buck:doe ratio for this herd. The buck:doe ratio will be derived from a subset of the data, when antler growth is sufficient to determine gender until antler drop mid-winter.

Movements by all other species occurred in much lower numbers than mule deer. Activity by some of these species (e.g., bighorn sheep, black bear, pronghorn and white-tailed deer) was highest during the non-winter months, while other species were active year-round (e.g., coyote, elk, red fox). Mountain lion, bobcat and moose were documented primarily during the winter months. Success rates for each of these species were high, ranging from 83-100%.

In Winter 2016-17, elk were documented at all the Phase 1 structures, but in the Phase 2 segment, they were documented only once, at the South Overpass. Elk success movements were greatest at the North Overpass (n =16). While the number of movements varied across structures, the success rate for elk was 91%. No elk were documented at either of the underpass structures in the Phase 2 (south) segment, and just one elk success movement was recorded at the South Overpass, even though during pre-construction monitoring (2014-15) the highest number of elk were recorded at the Williams Peak Underpass and the South Overpass. The South Overpass pre-construction camera was deployed along a game trail where the cameras recorded animals regularly approaching the roadway and then repelling from the road, crossing back in front of the camera. Regardless, the higher number of elk movements captured in the Phase 2 segment during pre-construction monitoring may suggest that more elk move east-west across the highway in the southern portion of the study area (Phase 2) than in the northern portion (Phase 1). Over time, there may be increased elk use of these two southern-most crossing structures.

Elk activity at Phase 1 locations increased in Winter 2016-17 in comparison to Winter 2015-16. During the first winter (2015-16), a total of 7 movements (all success movements) were made at all three Phase 1 underpass locations. Over the summer, 12 success movements occurred, all at the North Overpass. The following winter (2016-17), success movements increased to 19 across all Phase 1 locations, with the most movements occurring at the North Underpass. These results may suggest that elk are slowly adapting to the crossing structures. Overall, the number of elk movements photographed at crossing structures or by the habitat cameras remained low throughout the study area. The low number of elk movements documented to date may result from 1) mild winter conditions, which may have resulted in fewer elk in the study area; 2) elk may take longer to adapt to new mitigation features than mule deer; 3) camera positions may not be opportune for capturing elk movements because the animal may be repelling from the structures prior to reaching the cameras in front of the structure entrances and are therefore not captured; and 4) elk in the project area may be making more north-south movements than east-west movements across the highway. The research study will continue to explore these factors over time.

Moose movements were detected at the North Overpass, North Underpass and, on one occasion, the Middle Underpass. Moose were not documented at any structure or habitat cameras in the Phase 2 segment. One moose was recorded during pre-construction monitoring at the BVA Underpass site. Overall, moose movements were low, though where moose were detected at crossing structures, all resulted in success movements through the structures (n=7). These passages were made by bull moose, and cows with calves.

While movements by the more uncommon species of ungulates such as bighorn sheep (Fig. 27), white-tailed deer, and pronghorn were not photographed during Winter 2015-16, ongoing monitoring through the non-winter months of 2016 and Winter 2016-17 documented activity by each of these species. These species occur in lower numbers in the study area, and adaptation periods for these species may also be longer than for mule deer. In addition, movements by these species were recorded primarily during non-winter months, only one season of which is included in this report. Reporting of wildlife presence and

Figure 27. Bighorn ram on the North Overpass.

use of structures during non-winter months for the Phase 2 segment will be updated in future progress reports. To date, where documented, the success rate through the crossing structures was 100% for each of these species. However, this may overestimate the effectiveness of the crossing structures for these species. For example, in April 2017, a small group of bighorn sheep were observed running along the fence line near the Williams Peak Underpass and the south fence end but were not documented at either monitoring location.

The highest species diversity was documented at the Middle Underpass. Black bear movement, in particular, was concentrated at this location, which is located at an ephemeral drainage and has greater vegetation diversity than the other structures. Many of these movements were likely made by the same individuals, including a sow and her two cubs, indicating that they were using the structure regularly as a part of their home range. Bobcat movements were similarly highest at this location.

Small culverts that were monitored were used most by red fox, black bear and bobcat. Mule deer were the most frequently documented species at small culverts (Fig. 28) and on one occasion, a success movement was made by three mule deer at the BVR Pipe Culvert. However, overall, 58% of all mule deer approaches to small culverts (n=19) resulted in repel behavior, 26% were parallel movements, and 16% were success movements. White-tailed deer were photographed near small culverts but did not approach or attempt passage. Badger is the only species photographed at a small culvert that has not been seen at any of the crossing structure locations. Of two badger movements at the BVR Pipe Culvert, one resulted in a success movement and the other in a repel. The most activity was recorded at the BVR Pipe Culvert as this location was active the longest during this monitoring period. An increase in wildlife activity and species diversity at small culvert locations may be expected in future progress reports as the summer months are included in monitoring at more culvert locations. Domestic cats and dogs

Figure 28. Mule deer repelling at the BVR Pipe Culvert.

were most commonly photographed using the Culbreath Box Culvert, which is near a private ranch and home site.

Wildlife Activity at Other Mitigation Features

Deer Guards

In general, deer guards deterred ungulates from entering the fenced right-of-way 77% of the time. Across monitoring locations, mule deer were most commonly photographed approaching the guards. The breach rate for mule deer at round bar guards was 13% compared to a breach rate of 29% for deer at flat bar guards (Fig. 29). Elk repelled from both types of guards at a rate of 85% (n=13). The only elk to approach to a round deer guard resulted in a breach, which it made by jumping rather than walking on top of the bars. Moose repelled from both guard types 100% of the time (n=6).

Figure 29. Mule deer approaching and ultimately repelling from the round deer guard at County Road 1002.

Mule deer at flat bar guards were more likely to breach the guard by walking over snow-filled guards or by walking on top of the bars, whereas at round guards, no deer were recorded walking on top of the bars. Instead, mule deer at round guards were more likely to attempt jumping the guard (Fig. 30). These results suggest that because the round bars prevent deer from walking on top of the guard, deer attempting to breach the gap to the other side of the wildlife exclusion fence must jump the guard. The researchers are concerned that attempts to jump across the guard may result in injuries to the animals when they fall between the bars, but no evidence of injury has been documented.

Non-ungulate species had high breach rates at both the flat bar and round bar guards. Black bear (n=3), bobcat (n=5) and mountain lion (n=1) were infrequent visitors to the guards, but breached the guards 100% of the time when they did approach. Red fox (n=171) and coyote (n=75) approached the guards more frequently, with breach rates ranging from 67-92% depending on the guard type. For both of these species, breach rates were lower at the round bar guards compared to the flat bar guards (87% and 92% for red fox, and 67% and 78% for coyote). As the deer guards are designed to primarily target ungulates (the species most frequently involved in WVC) to prevent them from entering the fenced right-of-way, these breaches by non-ungulate species are unsurprising, as their paws can more easily traverse the guards.

Figure 30. Mule deer jumping across the Triangle Road round bar deer guard.

Most wildlife approached the deer guards from the habitat side, which is intuitive because the wildlife fence is designed to keep wildlife on the habitat side and out of the right-of-way. However, animals that had become trapped inside the fenced right-of-way, either due to an earlier breach, a gap in the fence or other reason, approached the deer guards from the right-of-way side and, in some cases, successfully breached back to the habitat side. This was most common with species that easily breached the guard, such as red fox, coyote and raccoon. Mule deer also approached the deer guards from the right-of-way side of the fencing 18 times, though this accounted for a small proportion of all deer guard approaches by mule deer. In future reports, the breach rate into the fenced right-of-way will be reported separately from the escape rate of animals inside the fenced right-of-way breaching the guard back to the habitat side.

Snow plow damage has occurred at several of the flat bar guard locations. The round bar guards appear less susceptible to this type of damage. In addition, the flat bar design was more likely to get snow packed in between the bars during plowing, resulting in a continuous surface which can be more easily breached, as the photographic data displayed.

Escape Ramps

For mule deer, escape ramps without rail fence had a higher intercept rate (65%) than those with rail fence (30%), regardless of the ramp slope. The ramp with a 2:1 slope without rail fence had the highest intercept rate for mule deer (71%); however, this result is based on just one location and may also be influenced by other landscape factors. Ramp slope appeared to have less influence on mule deer intercept rates, averaging 59% for 2:1 slope ramps and 55% for 3:1 slope ramps, but these ranged from 0-100%, depending on the location (n=12). Notably, ramps with intercept rates of 0% for either mule deer or elk (2 locations for deer; 3 locations for elk) or with intercept rates of 100% (2 locations for deer; 1 location for elk) all had a low number of total approaches for those species. For example, at the Trough Road 2:1 Escape Ramp, only one elk was documented approaching this ramp and it ascended the ramp and successfully jumped down to the habitat side, giving this location a 100% intercept rate and escape rate for elk. Overall, intercept rates for mule deer varied greatly by location. However, these preliminary results suggest that multiple variables may influence intercept rate, including 1) species; 2) ramp location; 3) landscape situation; 4) ramp slope; and 5) presence or absence of perpendicular rail fence. These variables will continue to be evaluated through this research.

Escape rates for mule deer were low across locations. In total, mule deer were documented making successful escapes on 22 occasions (11% escape rate) and elk were documented on eight occasions (9% escape rate). Five ramps had escape rates of 0%. The highest escape rates for mule deer were at the West Fence End Escape Ramp (40%; 3:1 slope with rail fence – Fig. 31) and the Spring Creek Escape Ramp (33%; 3:1 slope without rail fence). Elk were mainly documented at just one ramp location, the East Fence End Escape Ramp (n=162; 3:1 slope with rail fence). The escape rate for elk at this location was 8%. These escapes are all accounted for in a single event that occurred in January 2017, in which this group of elk was documented entering into the fenced right-of-way from the south fence end. After two attempts ascending the ramp, the entire group

Figure 31. Successful mule deer escape at the West Fence End Escape Ramp.

ultimately jumped down from the ramp to the habitat side (Fig. 32). This example underscores the value of escape ramps near fence ends.

Figure 32. Group of elk ascended the East Fence End Escape Ramp and after several attempts successfully escaped to the habitat side.

Because of the adaptive management effort and for the purpose of experimental design, there are two locations with a 2:1 slope escape ramp with rail fence near a ramp with a 3:1 slope with no rail fence. In general, few approaches were recorded at any of the four ramps. The Trough Road 2:1 Escape Ramp had the highest number of approaches by mule deer (16), but all of these animals walked around the ramp for an intercept rate of 0%. Only four approaches were documented at the Trough Road 3:1 Escape Ramp, three of which ascended the ramp. A similar pattern is seen at the Culbreath ramps – four of seven mule deer walked around the 2:1, while of five approaches at the 3:1 ramp, all animals ascended the ramp and turned around. There were no successful escapes at any of these locations.

The number of times mule deer and elk used the monitored escape ramps to escape to the habitat side of the wildlife exclusion fence, (n=30), was a small fraction of the total number of times they were photographed at the ramps in the right-of-way (n=538). These results are typical of other study results (Cramer, unpublished data; Arizona Game and Fish Department, unpublished data). As time goes on, the mule deer and elk may adapt to the ramps and use them more often, but the best result is a lowered number of deer in the right-of-way that would be approaching those ramps.

The high number of parallel movements documented by the cameras on the habitat side of the fence line by mule deer, elk and other wildlife indicates that animals had many opportunities to breach the wildlife exclusion fencing by jumping up from the back side of a ramp, but no such attempts were made, suggesting that the ramp height of six feet is sufficient in discouraging a jump up attempt by deer or elk. However, given the low escape rates even at ramps with higher intercept rates, the six-foot height may be too high to encourage successful escapes.

Each monitored escape ramp location has two cameras – one on the right-of-way that is positioned to capture animals approaching the ramp and their subsequent behavior; and the other on the habitat side, positioned to capture animals at the top of the ramp that may jump down, as well as animals on the habitat side that may attempt to jump up. Even with both these cameras, monitoring can only capture a portion of all approaches to the ramp, especially at the 3:1 slope ramps, which have a broader base. Due to observations made by research team members and BVR staff, the researchers also suspect that the cameras are not capturing all escapes; especially when animals are moving quickly, the cameras appear to be missing some movements, despite the use of rapid-fire settings.

Wildlife Exclusion Fence and South Fence End

Wildlife exclusion fencing requires ongoing maintenance and a rapid response to fixing holes in the fencing to prevent wildlife incursions through gaps in the fence. Gaps may result from vehicles that run off the road (Fig. 33*a*), people that cut holes through the fence, wildlife damage, or normal wear and tear. In 2017, three cars ran off the road creating holes in the wildlife fence. Law enforcement, CPW and CDOT are called upon when wildlife incursions occur, requiring extensive labor on the part of these personnel to ensure that wildlife escape back to the habitat side of the fencing and are not involved in a WVC (Fig. 33*b*).

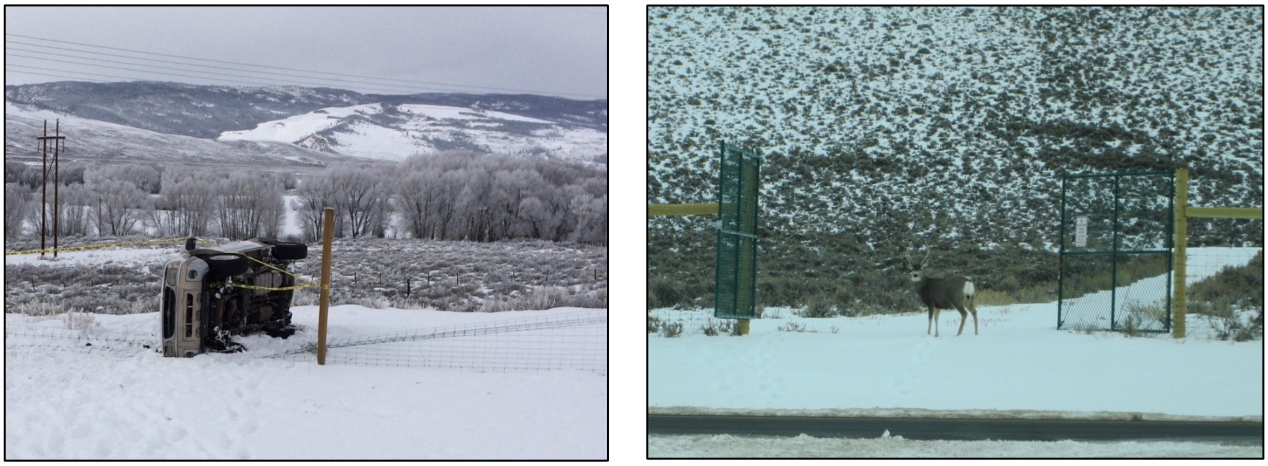

Figure 33. a) Gap in wildlife exclusion fence due to a vehicle that ran off the road (left). *b*) Mule deer exiting through a swing gate left open by CPW to allow the animal to safely exit the fenced right-of-way under their supervision (right).

At the south fence end, the vast majority of ungulate movements occurred beyond the fence end (91.6%), that is animals that approached and potentially crossed the highway at-grade without entering into the fenced right-of-way (Fig. 34). Most of these movements were made by mule deer (n = 251), although elk were also photographed beyond the fence end (n = 22).

Figure 34. Mule deer buck moving beyond the south fence end.

More mule deer were documented exiting the fenced right-of-way than were captured entering it. This may indicate that animals entered the fencing at other locations (e.g., deer guards, gates left open, or a hole in the fence that hadn't yet been repaired) and were able to escape via the fence end; or, it may suggest that some movements of deer entering into the fenced right-of-way were not captured by the cameras. Elk movements into and out of the fenced right-of-way were nearly equal. No other wildlife species were photographed at the fence end.

Pedestrian Walk-through Gates

Figure 35. Mule deer breach at the BLM Pedestrian Walk-through Gate.

Breach rates for mule deer at pedestrian walk-through gates ranged from 5-21% across the three monitored pedestrian walk-through gate locations. Most mule deer breaches occurred at the Summit County Gate (n = 19), which had the widest opening. This location also captured the greatest number of deer movements (n = 176). The highest breach rate for mule deer, however, was at the BLM Gate (21%; n = 43), which, unlike other pedestrian walk-through gates, lacked a fence section on the right-of-way side that requires animals to make two right-angle turns to complete a breach and acts as a visual barrier (Fig. 35). However, at all locations, most movements were parallel movements where animals did not approach the gate at all.

Of animals that investigated a gate, the breach rate for mule deer was 56% and for elk 40%. Overall, breach rates at pedestrian gates were lower for elk than mule deer. Most elk movements were detected at the State Wildlife Area Gate (n = 44), whereas no elk were detected at the Summit County Gate. No breach movements by other species of wildlife were documented.

Figure 36. Pedestrian walk-through gate equipped with swing gate.

Since the onset of this study, 32 breaches were made by mule deer and 2 by elk out of a total of 304 and 47 movements, respectively. CPW determined that these breaches – and potential WVC – could be eliminated all together with the installation of swing gates across the gate openings. By September 2017, all of the walk-through gates were equipped with additional swing gates to block ungulates (Fig. 36) and monitoring cameras were removed from these locations. Consequently, performance measure number 12, which was established to determine the effectiveness of the pedestrian walk-through gates will no longer be evaluated.

Traffic Safety

Both the BVR/CPW dataset and the CDOT Maintenance dataset describe a decreasing trend in WVC post-mitigation construction. Accident data from 2017 are not yet available from CDOT to make a similar comparison with the accident dataset. Across the project area, WVC have decreased 86% post-construction compared to the five-year pre-construction average (based on BVR/CPW carcass reports). Since the completion of the Phase 2 segment, WVC decreased in both project phases in Winter 2016-17. While BVR/CPW recorded 30 carcasses in the Phase 2 segment in Winter 2015-16, this number decreased to 6 carcasses in Winter 2016-17 post-construction. These preliminary results support the assertion that wildlife crossing structures and other mitigation features were effective in reducing WVC along SH 9, while also providing wildlife connectivity.

Wildlife-vehicle collisions did not appear to increase beyond the fence ends north and south of the project area. CDOT Maintenance data recorded only one WVC carcass in the mile south of the project area and one WVC carcass in the mile north of the project area post-construction. While this is based on just one year of post-construction data, these WVC rates are lower than the five-year pre-construction averages for these mile segments. It is unknown whether the mitigation on SH 9 had an effect on WVC on SH 40. Wildlife-vehicle collisions on US 40 were relatively high in Winter 2010-11 and again in Winter 2015-16, but were low in each of the intervening years. Further analysis is needed to determine whether this increase in Winter 2015-16 was a result of the recently completed mitigation in Phase 1 on SH 9, or whether it was due to other factors.

The three WVC datasets show considerable variation. CDOT Maintenance carcass reports captured 68% of the carcasses recorded by BVR/CWP, while accident reports only captured 18% of these data. These results are comparable to other studies. Olson (2013) calculated a multiplier of 5.26 carcasses for each reported WVC accident on Utah roads. On this segment of SH 9, BVR/CPW recorded 5.64 carcasses for each reported WVC accident.

Next Steps

Preliminary monitoring of mitigation effectiveness on SH 9 is encouraging. Several performance measures for the mitigation project regarding mule deer use of crossing structures have already been achieved and will hopefully maintain or further improve through the duration of the study. Other objectives, for example, regarding elk use of crossing structures or mule deer use of escape ramps, have not yet been achieved, but will continue to be monitored and evaluated. The research team will continue post-construction monitoring through Winter 2019-20.

References

Clevenger, AP, and M Barrueto (eds.). 2014. Trans-Canada Highway wildlife and monitoring research, final report, part B: Research. Report to Parks Canada, Radium Hot Springs, British Columbia, Canada. Summary of 17 years of wildlife-highway mitigation research on the Trans-Canada Highway.

Cramer, P. 2016. US 89 Kanab-Paunsaugunt Wildlife Crossings and Existing Structures Research Project 2016 Spring Report to Utah Department of Transportation. October 2016. 45 pp.

Cramer, P. 2014. Wildlife crossings in Utah: determining what works and helping to create the best and most cost-effective structure designs. Report. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Cramer, P. 2012. Determining wildlife use of wildlife crossing structures under different scenarios. Final Report to Utah Department of Transportation, Salt Lake City, UT. 181 pp.

Cramer, P. and J. Flower. 2017. Testing new technology to restrict wildlife access to highways. Report No. UT-17.15 Utah Department of Transportation, Salt Lake City, UT. 59 pp.

Cramer, P., and R. Hamlin. 2016. Evaluation of wildlife crossing structures on US 93 in Montana's Bitterroot Valley. MDT # HWY – 308445-RP. Final Report to Montana Department of Transportation, Helena MT.

Dodd, N. L., Gagnon, J. W., K. S. Ogren, and R. E. Schweinsburg. 2012. Wildlife-vehicle collision mitigation for safer wildlife movement across highways: State Route 260. Final report from the Arizona Game and Fish Department to the Arizona Department of Transportation. Final Report 603. 134 pp.

Flower, J. P. 2016. Emerging technology to exclude wildlife from roads: Electrified pavement and deer guards in Utah, USA. Master's Thesis. Utah State University, Logan, UT. 130 pp.

Gagnon, J.W., N. L. Dodd, K. S. Ogren, and R. E. Schweinsburg. 2011. Factors associated with use of wildlife underpasses and importance of long-term monitoring. Journal of Wildlife Management, 75 (6):1477-1487.

Gagnon, J., C. Loberger, S. Sprague, K. Ogren, S. Boe, and R. Schweinsburg. 2015. Cost-effective approach to reducing collisions with elk with fencing between existing highway structures. Human-Wildlife Interactions. 9(2):248-264.

Huijser, M. P., J. W. Duffield, A. P. Clevenger, R. J. Ament, and P. T. McGowen. 2009. Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. Ecology and Society 14:15.

McAllister, K., M. Reister, R. Bruno, L. Dillin, D. Volsen, and M. Wisen. 2013. A wildlife barrier fence north of Wenatchee, Washington: learning experience involving rugged country and custom designed wildlife guards and jumpouts. Proceedings of the 2013 International Conference on Ecology and Transportation. Retrieved from http://www.icoet.net/ICOET_2013/proceedings.asp

Olson, D. D. 2013. Assessing vehicle-related mortality of mule deer in Utah. PhD Dissertation, Graduate School of Utah State University. Paper 1994.

Peterson, C. C. 2008. Conservation implications of winter-feeding policies for mule deer in Utah. PhD Dissertation, Graduate School of Utah State University. Paper 108.

Purdum, J. P. 2013. Acceptance of wildlife crossing structures on US Highway 93, Missoula, Montana. Master’s Thesis. University of Montana, Missoula, MT.

Rytwinski, T., R. van der Ree, G. M. Cunnington, L. Fahrig, C. S. Findlay, J. Houlahan, J. A. G. Jaeger, K. Soanes, and E. A. van der Grift. 2015. Experimental study designs to improve the evaluation of road mitigation measures for wildlife. Journal of Environmental Management 154:48-64.

Sawyer, H., C. LeBeau, and T. Hart. 2012. Mitigating roadway impacts to migratory mule deer – a case study with underpasses and continuous fencing. Wildlife Society Bulletin 36(3):492-498.

Siemers, J. L., K. R. Wilson, and S. Baruch-Mordo. 2015. Monitoring wildlife-vehicle collisions: analysis and cost-benefit of escape ramps for deer and elk on U.S. Highway 55. Report No. CDOT-2015-05. Colorado Department of Transportation, Denver, CO. 45 pp.