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State Highway 9 Wildlife Crossings Mitigation Monitoring

APPLIED RESEARCH & INNOVATION BRANCH

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16. Abstract

This research monitored the effectiveness of a wildlife mitigation project on State Highway 9 in Grand County, Colorado. The purpose of the mitigation was to reduce wildlife-vehicle collisions (WVC) while providing permeability for wildlife across the highway. This five-year study used motion activated cameras and analyses of WVC crash and carcass data to evaluate mitigation effectiveness. The research documented 112,678 mule deer successful passages and a success rate of 96% across the seven structures. In addition to mule deer, sixteen other wildlife species successfully used the crossing structures. The wildlife crossings and fencing mitigation helped decrease WVC crashes by 92% and carcasses by 90% relative to preconstruction levels.

Implementation

Initial findings of the study were used to inform mitigation designs in the second construction phase, resulting in the addition of new escape ramp and wildlife guard designs. The final study results will help to inform the design of future mitigation projects. This research confirmed the value of wildlife crossings for reducing WVC and maintaining connectivity in mule deer winter range and found that both the overpass and underpass designs used on SH 9 were effective for mule deer. As WVC continue to occur south of the fence end, extending the mitigation farther south is recommended to fully encompass the WVC hotspot and ongoing at-grade wildlife movements across SH 9.

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Executive Summary

The State Highway 9 (SH 9) Colorado River South Wildlife & Safety Improvement Project installed seven large wildlife crossing structures and 10.3 miles of wildlife exclusion fence between Kremmling and Green Mountain Reservoir in Grand County, Colorado. The project was designed to improve motorist safety by reducing wildlife-vehicle collisions (WVC) while providing permeability for wildlife across the highway. The Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW) supported this five-year research study to determine how well these investments in mitigation infrastructure achieved these goals. From November 2015 through April 2020, this study used analyses of WVC crash and carcass data and photo data from 62 motion activated cameras to evaluate the effectiveness of two wildlife overpasses, five wildlife underpasses, 13 of 29 wildlife guards, 14 of 61 escape ramps, three pedestrian access points, and the south fence end.

The research documented 112,678 mule deer successful passages across the seven structures, with an overall success rate of 96% and demonstrated the success of the crossing structures in maintaining connectivity for mule deer across the highway for all age and gender classes of the population. The study also established the value of the wildlife crossings for a number of other species, including elk, pronghorn, moose, bighorn sheep, white-tailed deer, black bear, mountain lion, bobcat, coyote, and a variety of other meso and small mammal species.

Altogether, the wildlife crossings, continuous fencing, and associated mitigation features achieved major safety benefits, helping to decrease WVC crashes reported to law enforcement by 92% and supplementary carcass counts by 90% relative to preconstruction levels (Fig. E-1). As a result of this mitigation, an average of 13 crashes and 56 WVC mule deer mortalities were prevented each year since the construction was completed. Statistical analyses confirmed that the crossing structures and fencing were effective in producing this dramatic reduction in WVC within the mitigated segment relative to control segments. WVC continued to occur beyond the project area, south of the fence end where ongoing ungulate activity occurred, indicating that the project may not fully mitigate wildlife movements across SH 9.

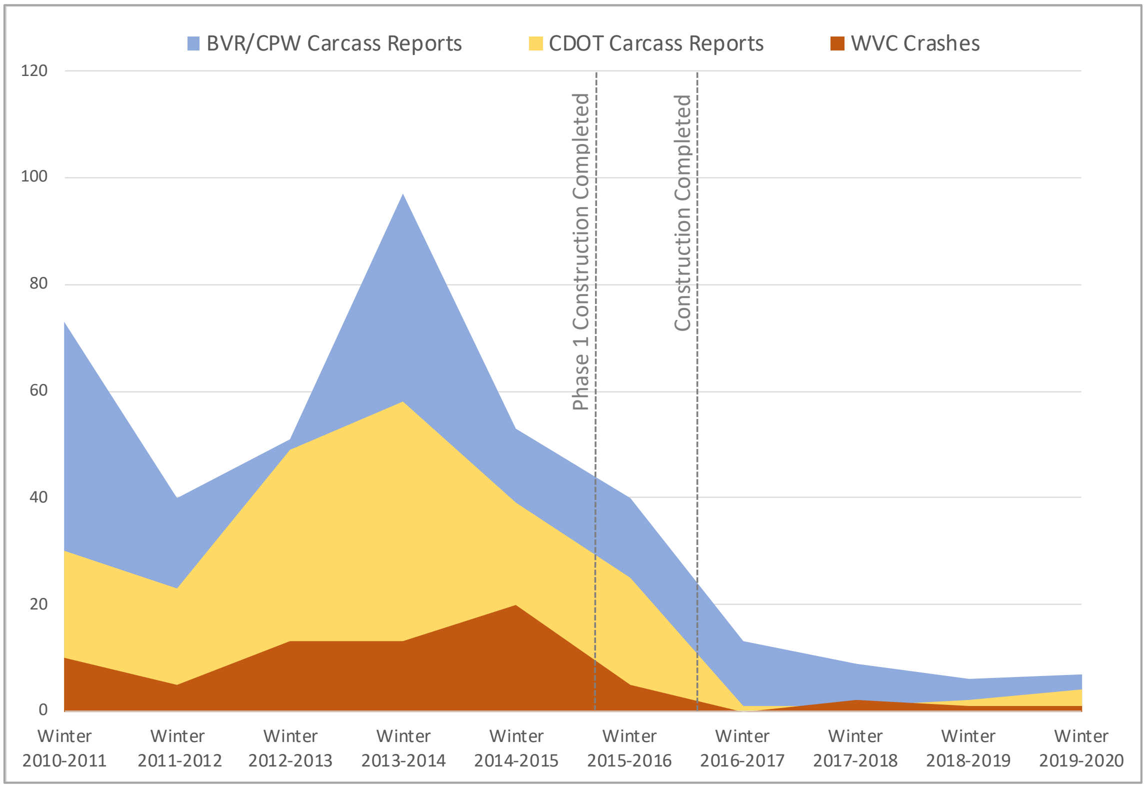

Figure E-1. Pre- and post construction WVC carcasses and crashes reported each winter as documented by BVR/CPW carcass reports, CDOT carcass reports, and CDOT crash reports. Mule deer activity and, correspondingly, WVC are highest during the winter months (November – April), which were the focus of the BVR/CPW carcass reporting effort.

The SH 9 study was unique from many other wildlife-highway mitigation studies in that the structures were located in mule deer winter range rather than along a migration path. This resulted in regular movements by many of the same animals throughout the winter months, corresponding with the arrival of migratory deer on winter range in November and their departure in April. Eighty-five percent of all mule deer successful passages occurred during these months.

Each year, there were an average of 29,873 mule deer successful passages over and through the seven crossing structures. This equated to an average of 17.5 successful passages at each structure, each day during the winter, with respect to the number of monitoring days. A portion of these successful passages represented the number of potential WVC that were avoided had the mitigation project not been implemented.

The number of mule deer successful passages generally increased each year post construction, and both the overpasses and the underpasses functioned extremely well for mule deer passage (Fig. E-2). While the total number of successful passages was higher at the five underpass structures than at the two overpass structures, statistical analyses found no discernable preference for one structure type over the other, suggesting that both the overpass and underpass designs used on SH 9 were effective for mule deer. Differential use of the crossing structures across the study area likely reflected variations in mule deer winter range habitat use – that is, structures located in portions of the winter range with the greatest density of mule deer received the most use, regardless of structure type.

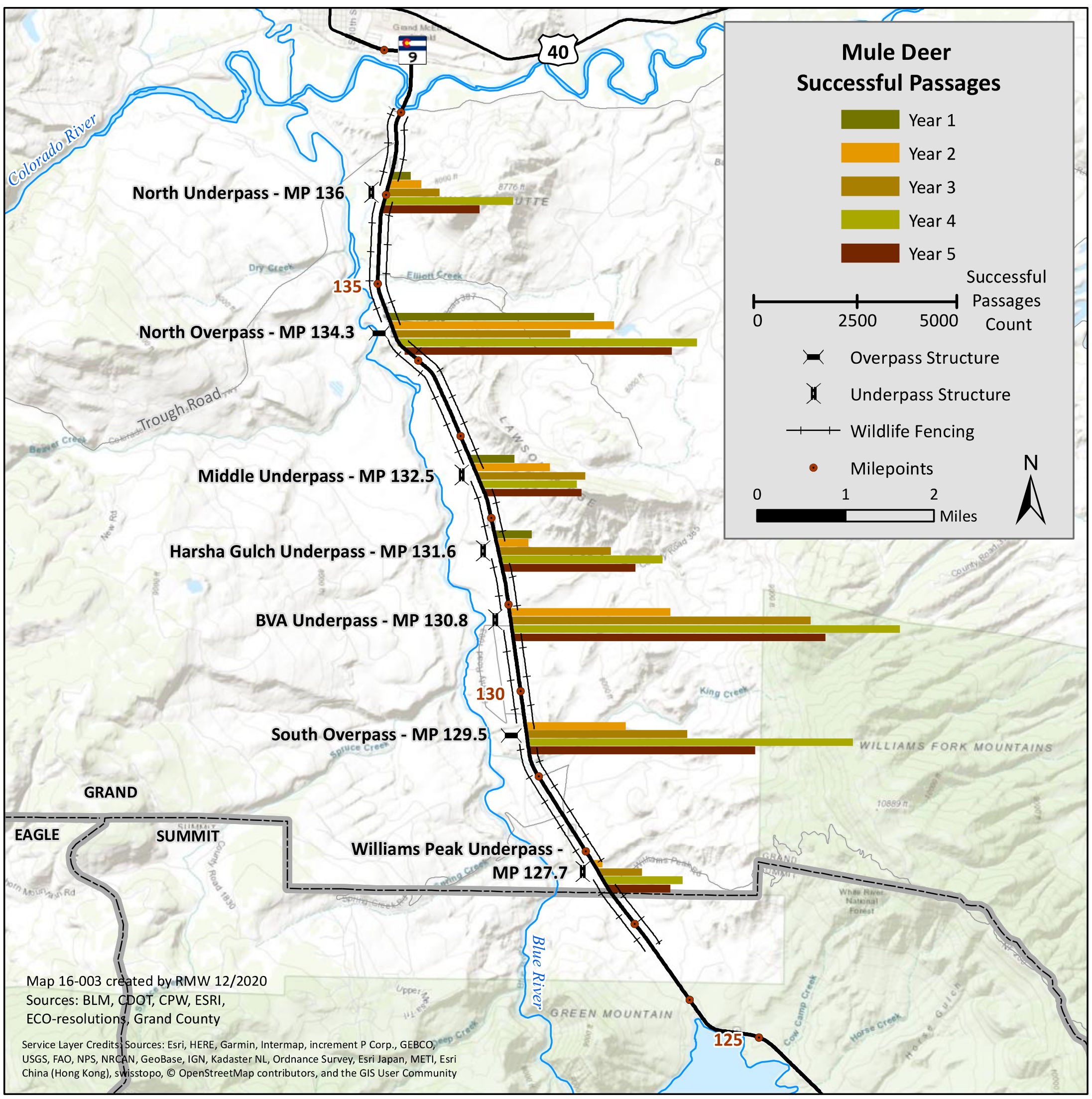

Figure E-2. Mule deer successful passages by study year at each crossing structure location. In total, the study documented 112,678 successful passages by mule deer.

In addition to mule deer, sixteen wildlife species successfully used the crossing structures during the five-year study, demonstrating the value of the mitigation system for a number of other species. The suite of species captured in this research encompasses the full array of meso and large mammal species known to be present in this landscape. While the total number of successful passages by these other species was much lower than for mule deer, success rates were high (80% or greater) for nearly every species documented, and all species showed stable or increasing crossing structure use during the five-year study period. The number of approaches and successful passages reflected the relative proportion of these species in this landscape and, in some cases, a longer adaption period to the crossing structures. Ongoing variability and increasing passage rates by many species in this study suggests that wildlife was still adapting to the mitigation and patterns in wildlife use of the crossing structures may continue to evolve over time. In particular, the first small herds of elk using the crossing structures weren't documented until the fourth winter of monitoring.

Researchers also evaluated the effectiveness of three different wildlife guard designs (round bar, flat bar, and flat bar with a pedestrian grate). Overall, the wildlife guards deterred animals with hooved feet (ungulates) from entering the fenced right-of-way 81% of the time. While the round bar guard design was more effective in deterring ungulate breaches (90% repel rate) than the flat bar guard design (83% repel rate), these differences were not statistically significant and both designs may be used to keep ungulates out of a fenced right-of-way. Conversely, the flat bar guard with a pedestrian grate repelled ungulates only 42% of the time and is not a recommended design for future mitigation projects, particularly given the much higher repel rates of the other two guard types. None of the wildlife guards were effective in preventing incursions into the right-of-way by carnivores, whose padded feet allow them to more easily breach the guards.

The SH 9 project also included 61 escape ramps that provided a one-way escape for wildlife that become trapped on within the fenced right-of-way. Researchers monitored intercept and escape rates for five escape ramp designs, including ramps with a 2:1 or 3:1 slopes and with or without perpendicular rail fence intended to guide animals up the ramp, and one jump down escape ramp that was built on a downward slope. Across all locations and ramp types, mule deer had an intercept rate of 51% and an escape rate of 10%, and elk had an intercept rate of 57% and an escape rate of 23%. Mule deer intercept rates were higher at ramps located below the road grade and at ramps without perpendicular rail fence. Ramp slope had little influence on mule deer intercept rates and future investigations of ramps slopes flatter than 3:1 are recommended to determine the slope threshold for improving intercept rates. Statistical analyses were limited by small sample sizes and variables influencing escape rates could not be determined. Nevertheless, the researchers suspect that the ramps were too high to encourage mule deer to jump down and successfully escape out of the fenced right-of-way. In 2020, CPW initiated an adaptive management approach and a two-year follow-up study to determine the effect of a reduced ramp height (by adding soil to the landing pad) on mule deer escape rates.

At the south end of the project, the wildlife fence angled in towards the roadway, leaving a 20' gap between the fence end and the edge of pavement, as a required safety measure. Small herds of mule deer and elk at the fence end were frequently documented making multiple approaches toward the roadway and being repelled by passing traffic. In total, 1,481 individual mule deer and elk movements were recorded at the south fence end after the completion of construction activities. The majority of all movements were by animals crossing SH 9 beyond the fence end (83%). The number of mule deer and elk documented moving around the fence end increased in the final year of the study, indicating that there was an ongoing need for wildlife movements across SH 9 beyond the mitigated project area.

The SH 9 mitigation project has met or exceeded most performance measures established at the outset of this research, both in terms of wildlife use of the crossing structures and reduction in WVC. A conservative benefit-cost analysis suggests that the mitigation investment on SH 9 will pay for itself in 56 years in terms of the costs of the WVC that are prevented – less than the minimum lifespan of 75 years of the wildlife crossings infrastructure. Overall, this study confirmed that the benefits derived from investing in the SH 9 wildlife crossings project outweigh the costs of construction and ongoing maintenance.

This study was instrumental in demonstrating the success of the SH 9 wildlife crossing structures and fencing mitigation for both wildlife and motorist safety. While a recent emphasis has been placed on migration paths in the western United States, monitoring research on SH 9 confirmed the need to also protect movements within winter range. Overall, the findings of this study and resulting recommendations will help transportation and wildlife agencies continue to site and design wildlife crossing mitigation systems for maximum success.

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APPENDICES

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List of Abbreviations

ANOVA	Analysis of Variance
BACI	Before-After-Control-Impact analysis
BLM	Bureau of Land Management
BVR	Blue Valley Ranch
CDOT	Colorado Department of Transportation
CPW	Colorado Parks and Wildlife
ROW	Right-of-way
WVC	Wildlife-vehicle collisions

Chapter 1. Introduction

Located between Kremmling and Green Mountain Reservoir in Grand County, Colorado, State Highway 9 (SH 9) runs north-south through the lower Blue River valley. The valley is characterized as a sagebrush ecosystem lying between the Gore Range to the west and the Williams Fork Mountains to the east. Each fall, migratory mule deer descend into the valley, which supports a high concentration of mule deer throughout the winter months. Resident mule deer and elk herds also inhabit the valley throughout the year. Other species inhabiting this landscape include moose, pronghorn, bighorn sheep, black bear, bobcat, red fox, coyote, and mountain lion. The highway travels along the valley bottom, bisecting wildlife habitat and resources, particularly mule deer winter range. These concentrations of deer and other wildlife have resulted in numerous wildlife-vehicle collisions (WVC), especially during the winter months.

In the five winters (November through April) prior to the onset of project construction in 2015, reported WVC crashes were the most common accident type on this segment of highway, accounting for 60% of all crashes reported to law enforcement. During this timeframe, 61 WVC crashes with mule deer or elk were reported, 2 resulting in injuries to humans. However, crash 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 (BVR) during this same time span recorded 314 WVC mule deer and elk carcasses – five times the number of reported crashes.

The goal of wildlife-highway mitigation was to reduce wildlife-vehicle collisions while providing permeability for animals to move safely through crossing structures below or over the highway. To meet these objectives, the SH 9 Colorado River South Wildlife & Safety Improvement Project installed seven large wildlife crossing structures, including two overpasses and five large arch underpasses, and 10.3 miles of wildlife fencing on either side of the highway (Fig. 1-1). All seven crossing structures are adjacent to a combination of state, Bureau of Land Management (BLM) and BVR lands. Blue Valley Ranch is a large working ranch over 25,000 acres in size; ranch parcels border both the east and west sides of SH9 throughout much of the study area.

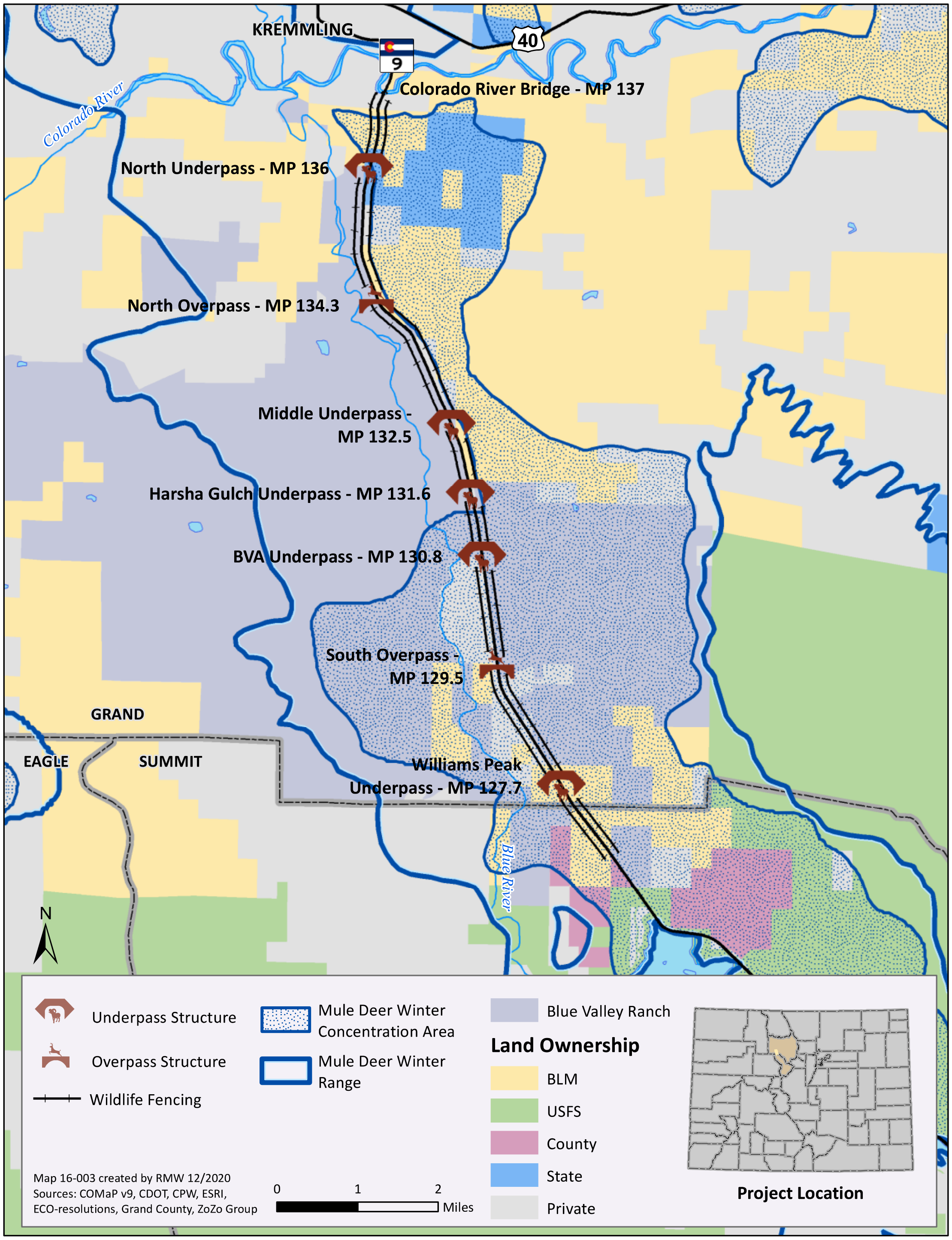

Figure 1-1. SH 9 study area map.

Other mitigation features include wildlife guards installed at all road intersections and private driveways, wildlife escape ramps, and pedestrian access points to provide a pathway for people through the wildlife fence. Large, ephemeral drainage culverts, including several medium-sized culverts (8' box or pipe culverts) that were integrated into the fencing, are also potential passageways for small or medium-sized fauna. The mitigation project was the culmination of a comprehensive and collaborative effort by the Colorado Department of Transportation (CDOT), Colorado Parks and Wildlife (CPW), BVR, and many other public and private partners.

CDOT and CPW supported this five-year research study to evaluate how well the mitigation achieved wildlife connectivity and traffic safety goals. This was the first long-term research study of wildlife use of wildlife crossing structures and other mitigation features in mule deer winter range. Motion-triggered cameras were used to monitor wildlife activity at wildlife crossing structures, wildlife escape ramps, wildlife guards, pedestrian access points and the southern terminus of the wildlife fence. In addition to camera monitoring, WVC rates were analyzed using three long-term datasets. Long-term datasets offer a preconstruction baseline to which post construction WVC rates may be compared. The findings of this study help CDOT and other agencies understand the most effective designs for wildlife crossing structures and other mitigation infrastructure.

RESEARCH OBJECTIVES

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

1. Quantify the effectiveness of wildlife and safety mitigation measures in reducing WVC.
2. Quantify the effectiveness of wildlife overpasses and underpasses in allowing wildlife, primarily ungulates, to move under or over the highway.
3. Quantify the ability of animals to use escape ramps to exit the fenced road area.
4. Determine if the fence end, pedestrian access points and wildlife guard designs are effective at deterring wildlife (ungulates primarily) from entering the fenced road area.
5. If utilization rates (i.e., success rates) differ among the crossing structures, determine why.

6. Determine if any of the wildlife mitigation features need modification to improve effectiveness.
7. Determine correlation of historic ungulate crossing patterns preconstruction to post construction crossing patterns.
8. Compare construction phase crossing rates to post construction overpass and underpass crossing rates.

STRUCTURE OF THE FINAL REPORT

This report is presented in nine chapters. Chapter 1 (this chapter) provides a brief introduction to the study area and research goals. Chapter 2 describes all study methods. Results and discussion are presented contiguously in six topic-oriented chapters that evaluate performance measures and explore specific research questions to inform future mitigation projects:

- Chapter 3: Mule deer use of crossing structures
- Chapter 4: Other species use of crossing structures
- Chapter 5: Wildlife guards
- Chapter 6: Escape ramps
- Chapter 7: Fence end and pedestrian access points
- Chapter 8: Wildlife-vehicle collisions and benefit-cost analysis

Recommendations that emerged from this study are presented in Chapter 9.

In addition, a literature review is provided as a supplement to this final report and is available on the CDOT Research website. In the first year of the study the research team compiled and summarized recent literature on the current state of the science and practice of WVC mitigation and monitoring with a focus on ungulates in the western United States.

Chapter 2. Research Methods

Mitigation effectiveness was evaluated through camera monitoring and the analysis of WVC data. The research methods used to evaluate these measures are presented in the following sections.

CONSTRUCTION AND RESEARCH TIMEFRAMES

The wildlife mitigation and other highway improvements were constructed in two phases spanning two years. Phase 1 construction, in the northern portion of the project area (milepost [MP] 131-137) was completed in November 2015. Year 1 monitoring activities commenced in the Phase 1 portion of the project area in December 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 two pedestrian access points. Phase 2, completed October 2016, was in the southern portion of the project area (MP 126.7-131), 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 three pedestrian access points.

Monitoring was conducted in two discrete phases. Preconstruction monitoring was conducted by CPW at the future wildlife crossing locations from November 2014 through the onset of Phase 1 construction in April 2015; at the Phase 2 crossing locations, preconstruction monitoring continued through April 2016, when Phase 2 construction began. At each location, a camera was set up on either side of the highway, facing parallel to or away from the highway, approximately 50’ from the pavement. Post construction monitoring was conducted following the completion of Phase 1 construction in December 2015 through April 2020. Post construction monitoring involved the deployment of 62 cameras at 48 locations. Seasonal and annual study timeframes were defined for the purpose of studying mule deer and other wildlife responses to mitigation features in winter range; these timeframes are used throughout the presentation and discussion of results (Table 2-1).

Table 2-1. Research study timeframes.

Season	Description	Phase
Winter	November 1 – April 30	All
Summer	May 1 – October 31	All
Study Year	**Description**	**Phase**
Year 1	November 2015 (WVC analyses) or December 2015 (camera monitoring) through April 2016 (Winter season only, following the completion of Phase 1 construction)	Construction
Year 2	May 2016 – April 2017 (Construction activities were ongoing in Phases 1 & 2 of the project area through Summer of Year 2)	Summer = Construction Winter = Post construction
Year 3	May 2017 – April 2018	Post construction
Year 4	May 2018 – April 2019	Post construction
Year 5	May 2019 – April 2020	Post construction

CAMERA MONITORING

Camera traps were used to evaluate wildlife activity and behavior at the mitigation infrastructure. Camera monitoring was conducted at all wildlife crossing structures, the south fence end, and at select wildlife guards, escape ramps, small culverts, and pedestrian access points. At various points during this research, monitoring cameras were relocated to different locations to optimize the use of a limited number of cameras. All camera monitoring locations and associated mitigation feature types and specifications, and the duration of monitoring activities at each location by study year are listed in Appendix A.

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 codelocked and secured with padlocks 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 a burst of 10 photos per trigger and continued triggering as long as movement was detected. Exceptions were at wildlife guards with heavy traffic, where cameras were set to 3 or 5 photos per trigger and were scheduled to trigger from before dusk to after dawn (from 4:30pm to 8am Mountain Daylight Time).

Preconstruction Monitoring

Fourteen preconstruction cameras, two at each future wildlife crossing location, documented species presence and abundance during Winter 2014-2015. At each location, a camera was deployed on either side of SH 9 approximately 50' 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. Therefore, preconstruction monitoring could only capture a snapshot of this dispersed wildlife activity near the roadway in the vicinity of the future structure locations. The objective of preconstruction monitoring was to compare species that were present near the roadway prior to mitigation construction with their relative abundance post-mitigation construction. Species presence was tallied without a categorization of animal behavior or direction of movement. Movements across SH 9 or repel movements from the highway right-of-way were not captured in preconstruction monitoring.

Post Construction Monitoring

Monitoring at Crossing Structures

Cameras were set up at each monitoring location to optimize capture rates and wildlife responses to the mitigation features. At crossing structures, cameras were placed at each entrance to a structure to determine successful passages through a crossing, repel and parallel movements (Fig. 2-1). Two cameras were placed at each underpass at opposite corners and set back approximately 20-30 feet from the structure entrances to capture wildlife behavior at the structure entrances. This distance represents the limit of the cameras' ability to detect and photograph at night. In addition, a habitat camera was placed on one side of each underpass, 50-100 feet from the structure entrance, facing away from the road toward the adjacent habitat. The objective of these habitat cameras was to document species present in the landscape adjacent to the crossing structures and to determine whether these species also approached the structures.

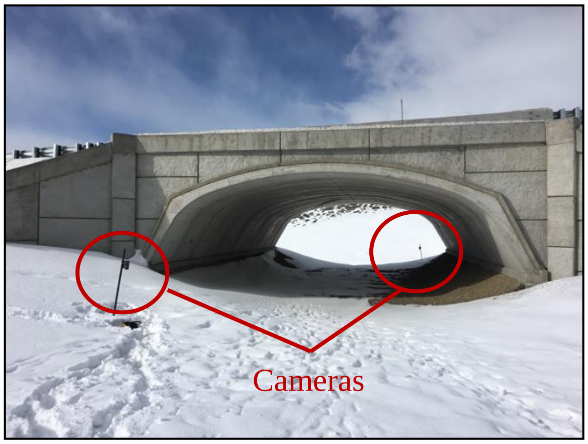

Figure 2-1. Two cameras were positioned at each underpass at opposite corners (left). Habitat camera placed 50-100 feet away from a structure, facing out into the adjacent habitat (right).

Additional cameras were placed at each overpass. The two overpass structures have steep approach slopes leading to the top of the structures, so in addition to the two cameras on top of each overpass, cameras were placed at the bottom of the slopes on either side of the structure. These approach cameras were more likely to capture repels and parallel movements, while the cameras on top of the overpasses could be used to confirm successful passages or repels on top of an overpass.

Monitoring at Wildlife Guards

Cameras were deployed at 12 wildlife guard locations, including six flat bar guards, five round bar guards, and three flat bar guards with a pedestrian grate (two flat bar guards monitored in Phase 1 were replaced with round bar guards in Phase 2). Wildlife guards were monitored for varying amounts of time and positioned to capture wildlife behavior at the guard (approaches, repels, breaches, and parallel movements). Flat bar guards were installed at all Phase 1 construction locations. In Phase 2, round bar guards were installed at five locations, including replacement of two flat bar guards that had been previously installed in the Phase 1 segment. Flat bar guards were installed at all remaining sites. Flat bar guards with a pedestrian grate were also installed at select driveway locations with swing gates in both project phases. The study monitored four round bar wildlife guards that were installed at locations in close proximity to flat bar wildlife guards that were also monitored. These pairings helped in evaluating wildlife responses to the wildlife 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. Wildlife guards were 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 wildlife guards and the spacing between bars were the same for both the flat bar and round bar designs. The round bar guards had angle iron on the support beams; this feature was not present on the flat bar guards.

Monitoring at Escape Ramps

Two cameras were set up at each monitored escape ramp, one at the base of the ramp in the right-of-way (ROW) to capture wildlife approaching the ramp or walking around the ramp; and one on the fence line looking across the top of the ramp to capture wildlife behavior at the top of the ramp, including successful escapes as well as jump up attempts from the habitat side onto the ramp. Throughout the study period, 13 escape ramps were 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, which did not have rail fence. Based on preliminary data, observations, and recommendations by the research team, in Phase 2 construction, all ramps were built with a 3:1 slope instead of a 2:1 slope (Fig. 2-2). 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 evaluate 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 were situated at lower topographic positions relative to the roadway, while the nearby 2:1 slope ramps were situated above the roadway. All of the ramps built in both construction phases were designed to be six feet high at the jumping off point, with a 16' wide fence gap; actual ramp heights range from 65 to 88 inches (5'5" to 7'4"). Over the course of the study, 13 escape ramps were monitored for varying lengths of time including four 2:1 slope ramps with rail fence, one 2:1 slope ramp without rail fence; two 3:1 slope ramps with rail fence; five 3:1 slope ramps without rail fence; and one jump down.

Figure 2-2. Example of an escape ramp with a 2:1 slope with perpendicular rail fence (left) and a ramp with a 3:1 slope without rail fence (right).

Monitoring at the 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 is at MP 126.7. At this fence end, the fence line angled in towards the highway, ending 20’ from the pavement edge so that it was not inside the clear zone. At the south fence end (Fig. 2-3), cameras were positioned to capture wildlife movements into and out of the fenced right-of way, as well as movements that occurred beyond the fence end.

Figure 2-3. Cameras encased in utility boxes at the south fence end.

Monitoring at Pedestrian Access Points

Cameras at pedestrian access points were set up on the habitat side of the fence, facing the entrance to the pedestrian access point, and positioned to capture wildlife approaches, breaches, repels and parallel movements.

Photo Analysis

Cameras were visited every 4-5 weeks during the winter months and every 6-8 weeks during the remainder of the year to exchange memory cards and batteries and maintain the cameras. Photo data were systematically processed to identify movement events every time a camera was triggered. Events were defined as 15-minute time periods based on the methodology developed by Cramer (2012) because animals may move within the view frame multiple time before concluding a movement, and typically leave the camera area within 15 minutes if they have not made a successful passage in that time. Events were delineated by the movements of individuals or groups at crossing structures, wildlife guards, escape ramps, pedestrian access points, and the fence end. For each 15-minute event, if an animal approached a structure multiple times without crossing, this was considered a single event until the animal passed through and was labeled a successful passage, repel, parallel movement, 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 with a flash are taken at night; and black and white photos taken at dawn and dusk appear with a lighter background and no flash.

Mule deer at the crossing structures were recorded as male, female, fawn or unknown. In many cases, gender was undetermined, for example, males who had shed their antlers, or because of photo quality or animal position relative to the camera made gender difficult to discern. Gender was recorded from June through December, when antlers are most apparent and before they are shed, rather than annual counts which reflect a high proportion of unknown gender. Young of the year were not classified by gender but were classified as fawns and excluded from gender totals.

For each event at a crossing structure, the researchers identified, by species (see Appendix B for a complete list of species observed in this study), the number of individuals and their gender (if possible), the direction of origin, and each individual's response to the crossing structure, which was recorded as successful passage, repel or parallel movement. These were defined as follows:

Successful Passage – Movement all the way through the crossing structure.

Repel – Initial movements near the entrance or into the crossing structure that resulted in the animal turning back the way it came from rather than fully passing through or over the structure.

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

Total Approaches – Calculated for each wildlife crossing structure as the sum of all successful passages, repel and parallel movements.

Unique movements by individual animals were tallied only once, even when the two structure cameras recorded the movement. 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. Human presence was recorded as a measure of time spent at a crossing structure with each 15-minute period recorded as a separate event. Each occurrence of humans at the crossing structures was recorded as a single event, regardless of the number of people present, and did not include researchers conducting camera checks.

Numbers for all non-mule deer species were tallied at the habitat cameras adjacent to each structure location. 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 were analyzed without a categorization of animal behavior.

Three small culverts were monitored, including two 8’ wide x 7.5-8’ high box culverts (99’ and 132’ long) and one 8’ diameter concrete pipe culvert (193’ long). 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. Successful passages 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.

At wildlife guards, individual 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 from the ROW side to the habitat side. A repel was when an animal approached the guard and then turned away. Some repel movements involved an animal making an initial attempt to breach the guard before turning back. Parallel movements were movements by an animal that walked in front of a guard but showed no interest in attempting to breach the guard.

At escape ramps, individual animal responses to the ramps were categorized as ignore, repel, escape, or breach, as follows:

Ignore – Animal that was photographed inside the right-of-way that did not ascend the ramp, but instead walked around the base of the ramp.

Repel – Animal that ascended the ramp and then turned back down the ramp inside the right-of-way

Escape – Animal that ascended the ramp and jumped down to the habitat side.

Breach Attempt – Animal that attempted to climb or jump up to the top of the ramp from the habitat side. Breach attempts were further categorized as successful or unsuccessful.

At the south fence end, individual animal responses 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. Movements into the fenced right-of-way occurred when animals moved from the habitat side of the fence and either walked around the fence end into the right-of-way on the same side of the road 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 fenced area of the right-of-way moved out to the habitat side of the fence. Movements beyond the fence include 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.

The following indices were calculated for each monitoring location, as applicable. These indices were then used to evaluate performance measures.

Success rate – For each species at a given crossing structure location, the total number of individual successful passages that were recorded moving through the structure divided by the total number of individual approaches by that species. Success and repel rates (defined below) allow for comparisons across crossing structures in this study and with other studies by correcting for species presence and relative population sizes.

Repel rate – For each species at a given crossing structure location, the total number of repel movements at a structure divided by the total approaches by that species. Repel rate was also calculated at wildlife guards, pedestrian access points and fence ends. In these cases, a repel movement was the desired wildlife behavior response to the mitigation features, i.e., the total number of times animals of a species repelled divided by the total number of approaches to the mitigation feature.

Parallel rate – For each species at a given monitoring location, the total number of parallel movements divided by the total number of approaches by that species. This metric was calculated for crossing structures, escape ramps, and pedestrian access points.

Intercept rate –This metric was calculated for ungulates inside the right-of-way at escape ramps: the total number of individual animals recorded ascending an escape ramp divided by the number of approaches by that species to an escape ramp.

Escape rate – This metric was calculated for ungulates at escape ramps. It is the total number of individual animals recorded successfully jumping down from an escape ramp divided by the number of animals walking up the escape ramp.

Breach rate – This metric was calculated for ungulates at wildlife guards, pedestrian access points, and fence ends. It is the total number of breaches divided by the total number of approaches by that species. At a wildlife guard, breaches occurred when animals cross over the guard; at escape ramps, breaches occurred when animals jumped up onto an escape ramp from the habitat side of the wildlife exclusion fencing; at a pedestrian access point, breaches occurred when animals passed through the access point; at the fence end, breaches occurred when animals enter into the fenced right-of-way from beyond the fence end.

Average deer per day (abundance) – For this metric the total number of mule deer approaches to a structure was divided by the sampling effort. Sampling effort was calculated as the number of days a camera was in operation (or the average number of days for locations with two or more cameras) and was useful for standardizing the number of mule deer photographed when there was variation in the number of days that cameras were in operation at different monitoring locations.

Average successful deer passages per day – The total number of successful mule deer passages at a structure divided by sampling effort.

Statistical Analyses of Camera Monitoring Data

Factors Influencing Mule Deer Use of Crossing Structures

Statistical analyses were performed to examine the relationship of structural and landscape variables on mule deer presence at the crossing structures (abundance), average successful passages per day, and success rates. Because all of the underpasses and the two overpasses each have the same dimensions, an analysis of the effect of structure dimensions was not performed. The landscape variables that were measured included vegetation cover types adjacent to crossing structures (percent bare ground, grass, brush, and trees), proximity to an ephemeral drainage, and distance to human disturbance (e.g., homes, barns, other centers of human activity). The structure variables that were measured at underpasses included approach slope and the presence of a drainage trough. Structural variables at overpasses were not evaluated because of the small sample size (n=2).

To accommodate unequal sampling effort, mule deer abundance at crossing structures and successful passages per monitoring day were assessed relative to the associated landscape variables using a linear model, assuming independence of locations as well as normality and homogeneity of variance. Model fitting used the lm function in base R (version 4.0.3). Means were estimated using functions in the emmeans package (version 1.5.3). Model assumptions were checked using functions in the DHARMa package (version 0.3.3.0).

The association between mule deer success rate and each landscape and structure variable was assessed using a generalized linear mixed model with a binomial distribution and a logit link, assuming independence of locations. To adjust for overdispersion, location was included as an observation-level random effect. Model fitting used the glmmTMB function in the glmmTMB package (version 1.0.2.1) in R (version 4.0.3). Means were estimated using functions in the emmeans package (version 1.5.3). Model assumptions were checked using functions in the DHARMa package (version 0.3.3.0). Statistical investigations into the differences in success rates between overpasses and underpasses were conducted using an analysis of deviance (Type II Wald chi square tests) of the overall post construction mean success rates.

The distributional assumptions were difficult to assess given a sample size of seven. Linearity was assumed for continuous-scale landscape variables; this assumption was also difficult to assess and may have been biologically implausible. The study provides limited information to assess relationships because of the small sample size and discrete measurements of landscape variables summarized across both sides of crossing structure.

An analysis was conducted to ascertain if human presence had an effect on mule deer daytime use of wildlife crossing structures. The relationship between the proportion of mule deer successful passages that occurred during the daytime and the number of human events at each structure was assessed using a generalized linear mixed model with a binomial distribution and a logit link. Number of human events was log transformed (base 2, with an additive increment of 1 to deal with zero counts). Monitoring location was included as a random effects factor to accommodate the clustering of monthly observations within location; the covariance of the repeated measurements was modeled with a first-order autoregressive structure.

Species Diversity at Crossing Structures

The diversity of species at the wildlife crossing structures was calculated based on the data from the last three years of the study (Years 3-5). The Shannon diversity index was used to take into account both species richness (the number of species) and species abundance. The association between the Shannon diversity index value at each structure location and each landscape (land cover types) and structural variable (underpass approach slope and presence of a drainage trough) was assessed using a linear model, assuming independence of locations as well as normality and homogeneity of variance. The distributional assumptions were difficult to assess given a sample size of seven structures. Linearity was assumed for continuous-scale landscape variables; this assumption was also difficult to assess and may be biologically implausible as variability exists across any given landscape.

An ANOVA (Analysis of Variance) was performed to measure the effect of distance to drainage and structure type (underpass versus overpass) on species diversity. The study provides limited information to assess relationships because of the small sample size and discrete and imprecise measurements of landscape variables. Model fitting used the lm function in base R (version 4.0.3). Means were estimated using functions in the emmeans package (version 1.5.3). Model assumptions were checked using functions in the DHARMa package (version 0.3.3.0).

Factors Influencing Ungulate Breaches at Wildlife Guards

The influence of wildlife guard characteristics and landscape variables on breach, repel, and parallel rates of mule deer and ungulates were assessed using a generalized linear model with a beta-binomial distribution (to accommodate overdispersion) or a binomial distribution (when the beta-binomial model fails to converge), with a logit link, assuming independence of locations. The distributional assumptions were difficult to assess given the small number of guard locations. The assumption of linearity for the continuous scale variables was difficult to assess and may be biologically implausible.

Guard characteristics included guard type and guard width. Landscape variables included distance to the nearest wildlife crossing structure and distance to human disturbance. The analysis focused on the last three years of the study to account for the initial adaptation period to the new mitigation infrastructure immediately following construction. The study provides limited information to assess relationships because of the small sample size and that the predictor variables studied were not evenly distributed across their full range.

There was only one flat bar guard with a pedestrian grate that was monitored during the analysis time frame. Relative to the other guards, this guard had a high breach rate, and consequently low repel and parallel rates. This observation was highly influential in statistical analyses and was omitted from these analyses.

Model fitting used the glmmTMB function in the glmmTMB package (version 1.0.2.1) in R (version 4.0.3). Means were estimated using functions in the emmeans package (version 1.5.3). Model assumptions were checked using functions in the DHARMa package (version 0.3.3.0).

Factors Influencing Ungulate Intercept Rates and Escape Rates at Escape Ramps

Associations of ungulate intercept rate and escape rate over the five years of the study and the structural characteristic of the escape ramps (ramp height, ramp slope, and presence of a guide fence) and the corresponding landscape variables (ramp position relative to the roadway, distance to crossing structure, and distance from road) were analyzed (Table 6-2). For each rate, the response variable was constructed as a ratio of counts, the number of successful passages out of the number of approaches. To accommodate overdispersion, a generalized linear model with a beta-binomial distribution was used; when the beta-binomial model failed to converge, a generalized linear mixed model with a binomial distribution and an observation-level random effect was used. Both models used a logit link and assumed independence of escape ramp locations. There was only one jump down location (Harsh Gulch); this location was omitted from analyses of ramp slope. The distributional assumptions were difficult to assess given the small number of escape ramp locations. Linearity was assumed for continuous-scale variables; this assumption was also difficult to assess and may be biologically implausible. The study provides limited information to assess relationships because of the small sample size and inefficient distribution of predictor variables. Model fitting used the glmmTMB function in the glmmTMB package (version 1.0.2.1) in R (version 4.0.3). Means for categorical predictors (ramp position, ramp slope, and guide fence) were estimated using functions in the emmeans package (version 1.5.3).

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 crash reports compiled from law enforcement by CDOT Traffic and Safety. From 2006 through the duration of this study, BVR staff recorded WVC carcass data on SH 9 from Spring Creek Road (MP 128.5) north to Kremmling town limits (MP 137.5). To complement these data, in 2013 CPW also began collecting carcass data south of Spring Creek Road to MP 126, just beyond the southern end of the project area. These data were combined for the BVR/CPW carcass dataset. Carcass data were collected three to seven days a week 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 carcass data since 2005. Carcass reporting by maintenance personnel is non-compulsory. It is likely that reporting effort in the first years of the reporting 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.

WVC crash reports compiled by CDOT Traffic and Safety were also examined. Wildlife-vehicle collision crashes, while underreported, are consistently reported statewide and offer a useful standard for comparing WVC crash rates inside the project area with those outside of the project area pre- and post construction.

Before-after analyses were conducted to compare the annual average number of WVC pre- and post construction. Annual averages were used to compare changes in WVC throughout the study relative to a five-year preconstruction average. These before-after analyses did not account for annual variation due to fluctuations in herd sizes, winter severity, or other factors.

Before-After-Control-Impact (BACI) analyses were conducted using linear mixed models to assess the effect of the mitigation on the frequency of WVC reported carcasses and crashes. A BACI study design helps to isolate the effects of the mitigation from other sources of variation, giving the analysis greater inferential strength (Roedenbeck et al. 2007). In a BACI analysis, the control and impact (mitigated) segments are compared during the same time periods, and in the same landscape, to help control for these potential variations. While the BVR/CPW carcass dataset was the most comprehensive and accurate of the three datasets, this dataset was only collected within the project area and only collected during the winter months and best suited to only a before-after analysis of WVC rates as a result of the mitigation. Despite being less comprehensive, the CDOT crash dataset and carcass dataset were best suited for BACI analysis because these data are collected statewide and available for the impact segment and two control segments. All analyzed segments are maintained by the same CDOT maintenance patrol eliminating bias due to reporting effort that may occur between patrols.

The BACI carcass analysis was based on ungulate (deer, elk, and pronghorn) carcasses collected during winter months in each of five years preconstruction (2010-2011 through 2015-2015) and three years post construction (2017-2018 through 2019-2020). BACI analysis compared carcass averages pre- and post construction on three highway segments including two control segments (one on SH 9 south of the project area and one on U.S. Highway 40 [US 40], an east-west highway north of the project area) and one impact segment (the mitigated project area on SH 9).

The response variable was the number of carcasses or crashes per mile on each segment in each winter season; the response was log transformed prior to analysis to better meet model assumptions of normality and homogeneity of variance. Project area (control or impact) and period (before or after) were incorporated as fixed effects factors. Random effects factors were segment and interaction of segment and period; years within segments and periods were considered to be subsamples. Model fitting used the glmmTMB function in the glmmTMB package (version 1.0.2.1) in R (version 4.0.3). Means were estimated using functions in the emmeans package (version 1.5.3). Model assumptions were checked using functions in the DHARMa package (version 0.3.3.0). The goal of the analyses was to discern if the changes in averages of carcasses and crashes in the control and impact segments were statistically different and that decreases in WVC could have been attributed to the wildlife mitigation.

PERFORMANCE MEASURES

Sixteen performance measures were developed by the researchers in conjunction with the research Study Panel at the outset of the study to provide objective measures for evaluating project success (van der Grift et al. 2013). Well-defined performance measures establish the goals of mitigation and help agencies take adaptive management actions to increase the effectiveness of the mitigation or inform future mitigation projects in other locations.

The wildlife mitigation system on SH 9 was evaluated with respect to wildlife connectivity and traffic safety. Wildlife connectivity performance measures evaluated how well the wildlife crossing structures facilitated use by meso to large mammal species. These measures were based on 1) success rates (total approaches divided by total number of successful passages), 2) the number of successful passages recorded through or over structures per year for each species (passages/year), and 3) the prevention of breaches into the fenced right-of-way detected through camera monitoring. Traffic safety performance measures evaluated how well the wildlife mitigation reduced WVC relative to reported carcass data and WVC crashes reported to law enforcement. A summary of the evaluation of performance measures is presented in Appendix C.

Chapter 3. Mule Deer Use of Wildlife Crossing Structures

RESULTS

Mule Deer Successful Passages

From December 2015 through April 2020, monitoring cameras recorded a total of 112,678 mule deer successful passages through or over the seven wildlife crossing structures. Over the course of the study, the active monitoring timeframes varied at each crossing structure location due to construction phasing, occasional battery depletions or equipment malfunctions. Following the completion of construction activities in Summer of Year 2, each structure was monitored for an average of 1,382 days, ranging from 1,319 days at the Middle Underpass to 1,416 days at the North Overpass. In the final two years of the study, there was little variation in the number of monitoring days among the crossing structure locations (range=732-742 days).

Mule deer approaches and successful passages increased each of the first four years of the study with a decrease from the peak in Year 4 to Year 5 (Fig. 3-1). The number of successful passages recorded increased by 106% from Year 1 to Year 2 (when construction was completed for the final three crossing structures); 52% from Year 2 to Year 3; 55% from Year 3 to Year 4; and decreased by 19% from Year 4 to Year 5. Following the completion of construction activities and the initial adaptation timeframe, in Years 3-5, there were an average of 29,873 mule deer successful passages each year at the crossing structures with an overall success rate of 96%.

Year 2 data primarily reflect winter movements. Ongoing construction during the summer months resulted in a temporary cessation of monitoring activities at several locations in the Phase 1 portion of the project area and crossing structures in the Phase 2 portion of the project area were still under construction. While the total number of mule deer approaches and successful passages was lowest during the Construction Phase (Winter of Year 1 through Summer of Year 2), mule deer made 9,173 successful passages during this timeframe (7,531 in Year 1 and 1,642 in Summer of Year 2) with a success rate of 96%.

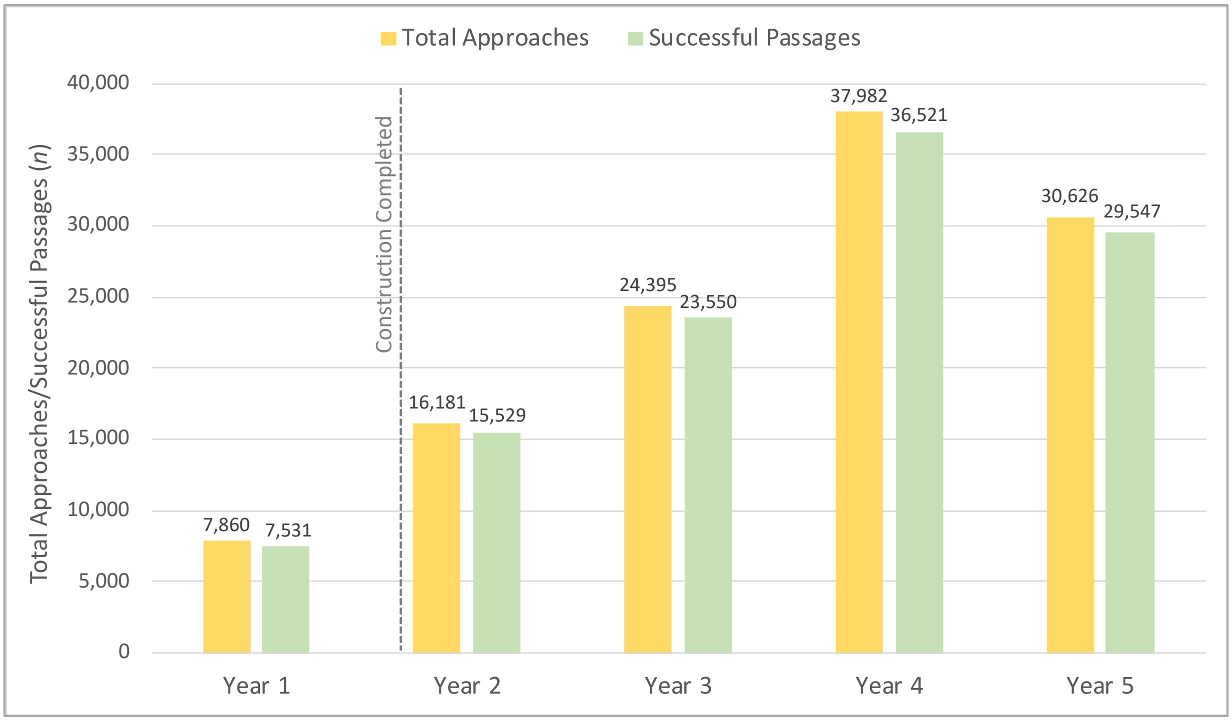

Figure 3-1. Total number of mule deer approaches and successful passages at the seven wildlife crossing structures each year of the study. For each year, the closer the yellow and green bars are in height, the higher the success rate. Four crossing structures were monitored in Year 1. Construction was completed at the end of Summer of Year 2, marking the onset of post construction monitoring at all seven crossing locations.

Each year, mule deer activity was highest during the winter months, corresponding with deer arrival on winter range in November and their departure in April. Eighty-five percent of all successful passages occurred during these months. Mule deer activity during the summer months reflected movements made by year-round resident animals. These resident deer made 16,961 (15%) successful passages during the non-winter months of the study.

Mule Deer Passages by Location

Mule deer successful passages varied among the crossing structures and from year-to-year (Fig. 3-2). Following the completion of construction activities in Year 2, the greatest number of successful passages was consistently documented each year at the BVA Underpass (MP 130.8). However, both overpass structures recorded substantially higher numbers of successful passages than the other underpass structures. Overall, these three structures accounted for 69% of all successful passages. Figure 3-3 plots the annual number of successful passages by location to demonstrate the spatial distribution of mule deer activity at the crossing structures. Detailed results from each crossing structure location are presented in Appendix D.

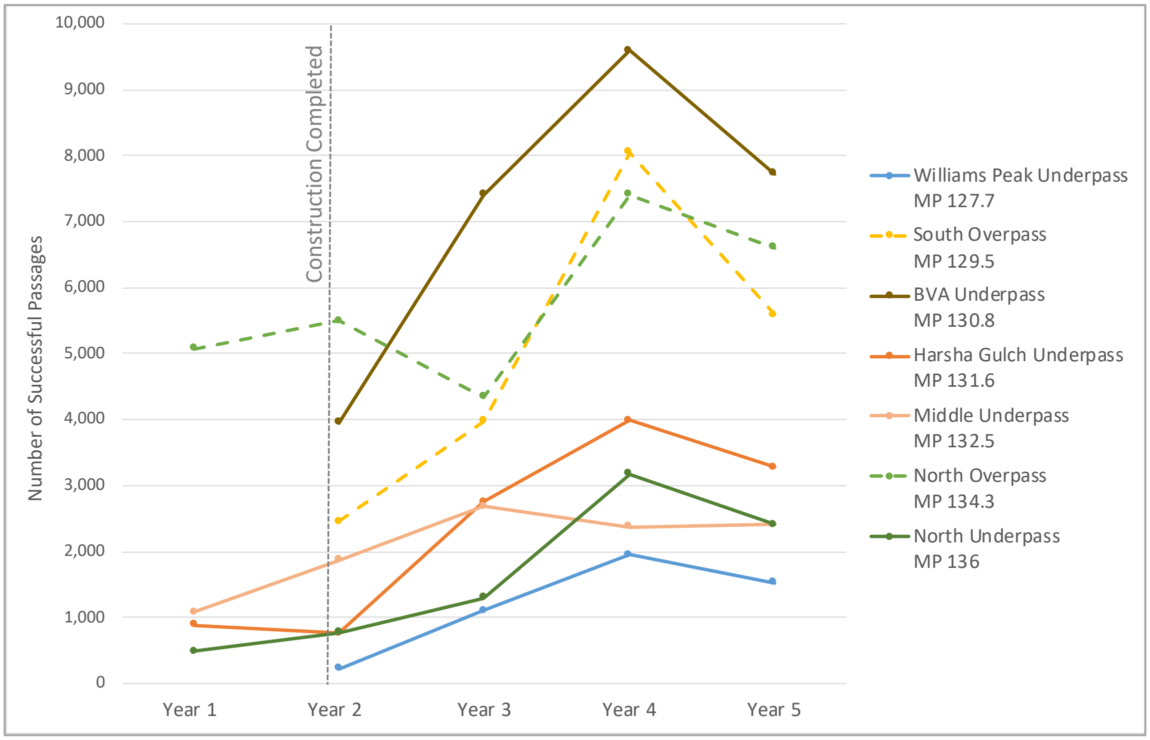

Figure 3-2. Annual number of mule deer successful passages at each crossing structure each year of the five-year study.

Overall, the greatest number of mule deer successful passages occurred at the North Overpass, followed by the BVA underpass (Table 3-1). However, the total number of monitoring days was greater at the North Overpass, which was constructed in 2015, than at the BVA Underpass, where construction was completed in 2016. Standardized by the number of monitoring days at each location, there were 23.2 mule deer successful passages per day at the BVA Underpass, compared with 18.1 per day at the North Overpass and 16.1 at the South Overpass. At all other underpass locations, the average number of mule deer successful passages per monitoring day ranged from 3.8 (Williams Peak Underpass) to 8.4 (Harsha Gulch Underpass). When considered with respect to winter daily means, when migratory mule deer are present on their winter range, the BVA Underpass saw an average of 35.8 mule deer successful passages a day in winter, followed by the North Overpass (27.8) and the South Overpass (26). Each of the other four underpass structures saw 11 or fewer successful passages a day in winter. On average, there were 11.4 success movements per crossing structures each day of the study (adjusted for the number of monitoring days at each location) and 17.5 success movements each winter day.

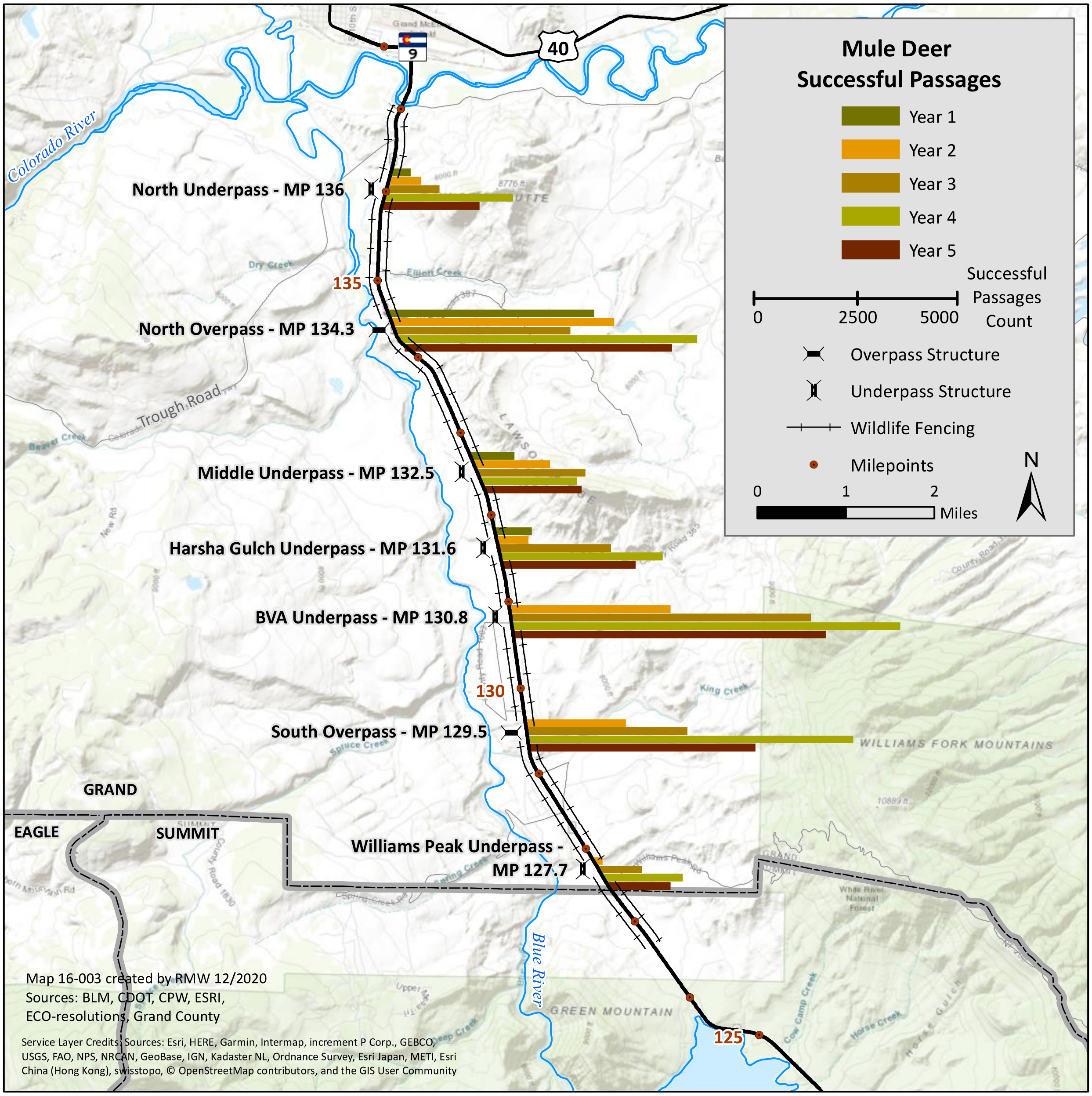

Figure 3-3. Mule deer successful passages by study year at each crossing structure location.

Table 3-1. Mule deer total approaches, successful passages, and daily successful passage rates at the crossing structures. The average number of Successful Passages per Monitoring Day and per Winter Day are calculated based on the total number of active camera monitoring days and the number of monitoring days during the winter months, respectively. Preconstruction detections were derived from CPW's camera monitoring prior to the start of this study.

	Total Approaches	**Total Successful Passages**	**Post Construction Monitoring Days**	**Average # Successful Passages per Day**	**Average # Successful Passages per *Winter* Day**	**Pre-construction Detections**
MP 127.7 Williams Peak Underpass	5,270	4,799	1,247	3.8	5.1	366
MP 129.5 South Overpass	20,341	20,053	1,247	16.1	26	2,129
MP 130.8 BVA Underpass	29,580	28,677	1,239	23.2	35.8	486
MP 131.6 Harsha Gulch Underpass	12,127	11,669	1,397	8.4	10.3	272
MP 132.5 Middle Underpass	10,898	10,417	1,555	6.7	11	166
MP 134.3 North Overpass	30,233	28,919	1,598	18.1	27.8	902
MP 136.0 North Underpass	8,595	8,144	1,573	5.2	8.8	211

Preconstruction monitoring conducted by CPW reveals a similar pattern in mule deer activity to post construction. The three locations with the highest number of mule deer during both the preconstruction and post construction timeframes were the South Overpass, the North Overpass, and the BVA Underpass. However, the Williams Peak Underpass, which had the lowest number of post construction mule deer approaches and successful passages, ranked in the middle in terms of the number of mule deer detections during preconstruction.

Mule Deer Success Rates

The overall success rate for mule deer across all of the crossing structures was 96%. Success rates ranged from 83% (Williams Peak Underpass, Year 1) to 99% (South Overpass, Years 2, 4 & 5), and tended to increase over time at each crossing location (Fig. 3-4). In the final year of the study mule deer success rates ranged from 94% to 99%. While a small decrease in success rate was observed at the North Overpass in Year 5, this decrease was not significant, and across all years of the study the success rate at this location was 94% or greater. Both overpasses, the BVA Underpass, and the Middle Underpass had success rates around 95% or higher throughout the time that they were monitored. At the remaining underpass structures, success rates were lowest in the first year of monitoring and increased in the second year. The greatest variability in success rate was observed at the Williams Peak Underpass, which had the highest repel rate (7.5%). The number of parallel movements relative to the total number of approaches was greatest at the North Underpass, the Middle Underpass, and the BVA Underpass. In general, parallel movements represented a small proportion of the overall activity at the crossing structures.

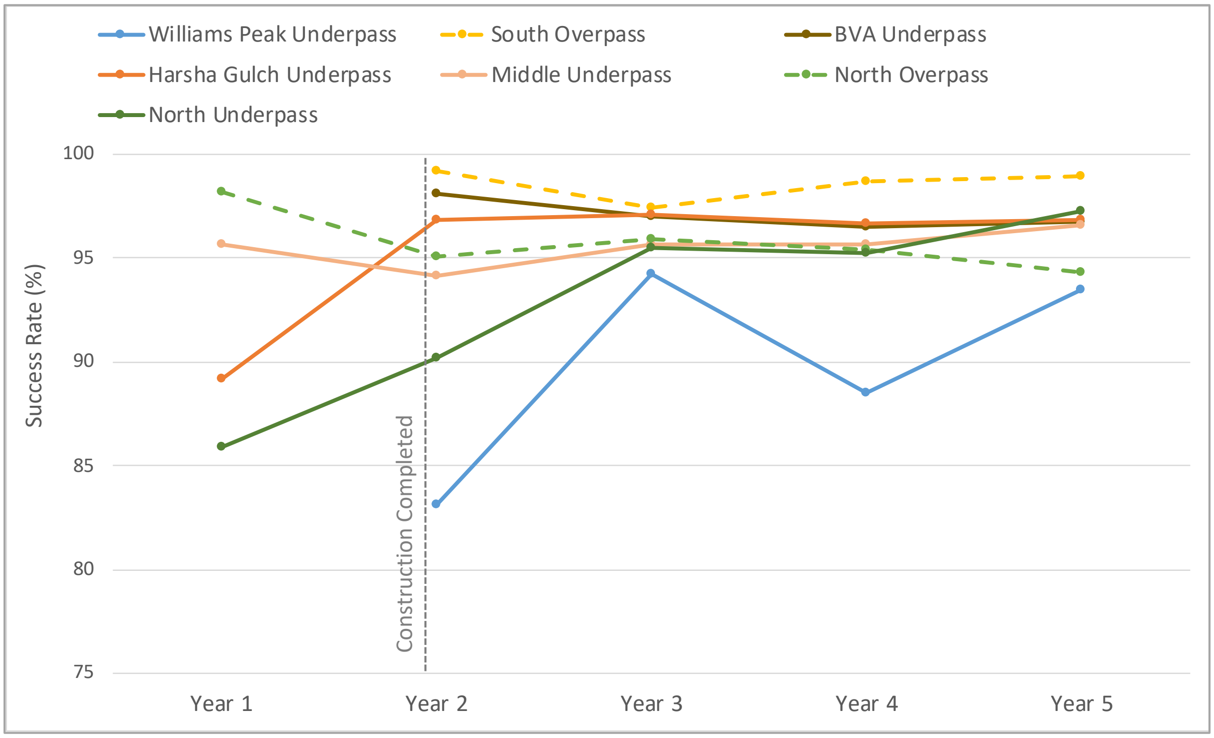

Figure 3-4. Mule Deer success rates at each of the crossing structures each year of the study.

Successful Passages and Success Rates at Overpasses versus Underpasses

Only two crossing structure types, each with the same dimensions, were evaluated in this study – overpasses (100' wide by 66' long) and underpasses (42' wide by 14' high by 66' long). Fifty-seven percent of all successful passages by mule deer were through the five underpasses, and 43% of successful passages were across the two overpasses; however, raw counts do not account for the unequal number of overpasses and underpasses. The annual number of mule deer successful passages standardized by the number of overpasses (*n*=2) and underpasses (*n*=5) demonstrates that the number of mule deer passages at overpasses was greater than at underpasses relative to their availability in the landscape. A standardized comparison of the total successful passages per day and annual average number of successful passages per day at the underpass structures and the overpass structures was created based on the number of monitoring days at each structure type (Table 3-2). Further standardization was conducted to account for the number of each crossing structure type. Each year, the mean number of successful passages per monitoring day was greater at overpasses than at underpasses (Fig. 3-5), accounting for 65% of mule deer crossing structure use.

Table 3-2. Comparison of total and annual average mule deer successful passages, number of monitoring days, and number of successful passages per structure per monitoring day at the two overpasses versus the five underpasses. The average number of successful passages per monitoring day per structure was calculated based on the total number of active camera monitoring days and standardized by the number of each structure type.

	Total Successful Passages	**Annual Average # Successful Passages**	**Post construction Monitoring Days**	**Average # Successful Passages *per Structure* per Monitoring Day**
Overpasses (*n*=2)	48,972	9,794	2,845	8.6
Underpasses (*n*=5)	63,706	12,741	7,010	1.8

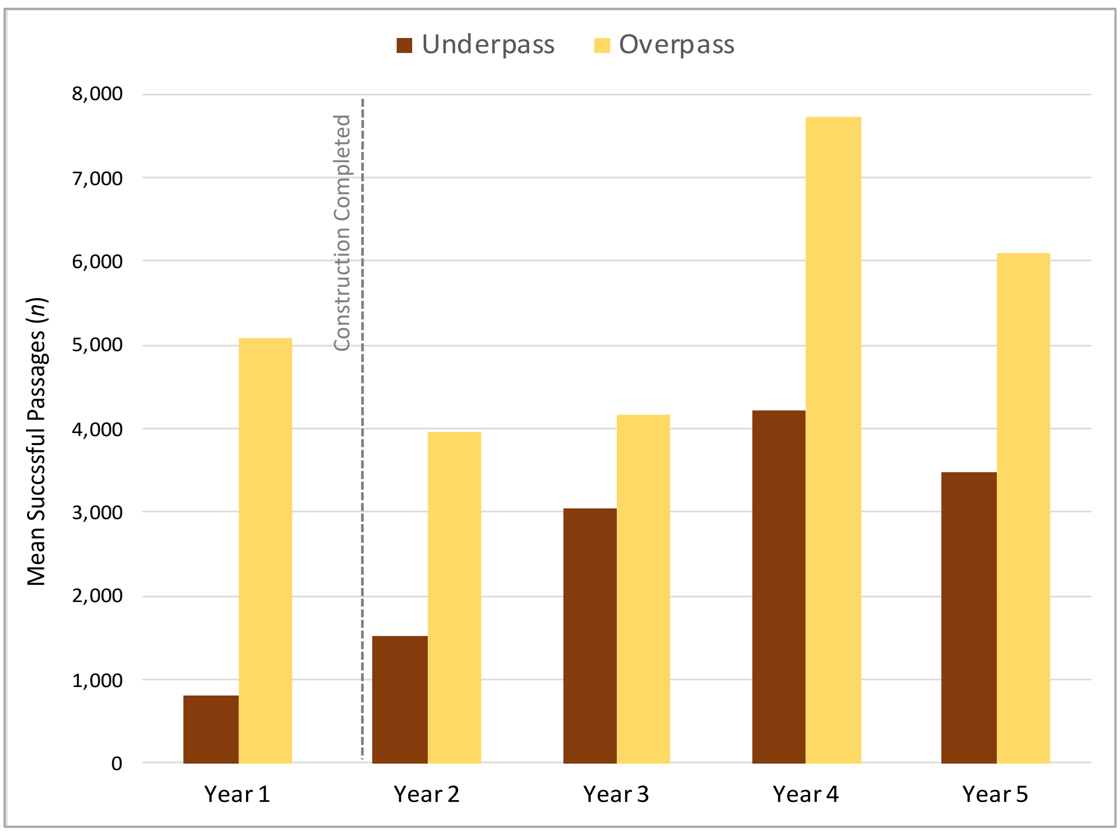

Figure 3-5. Annual number of mule deer successful passages standardized by the number of overpasses (*n*=2) and underpasses (*n*=5). Only one overpass and three underpasses were constructed and monitored in Year 1 through the end of Summer Year 2 when construction was completed.

Statistical investigations into the differences in success rates between overpasses and underpasses were conducted. An analysis of deviance (Type II Wald chi square tests) of the overall post construction mean success rate for overpasses (97%) was not shown to be different from the mean success rate of underpasses (96%; p=0.233; Fig. 3-6). A gender-based preference for overpasses or underpasses based on buck and doe success rates could not be determined, but in the final three years of the study, bucks and does used overpasses (55% and 65%, respectively) more than underpasses.

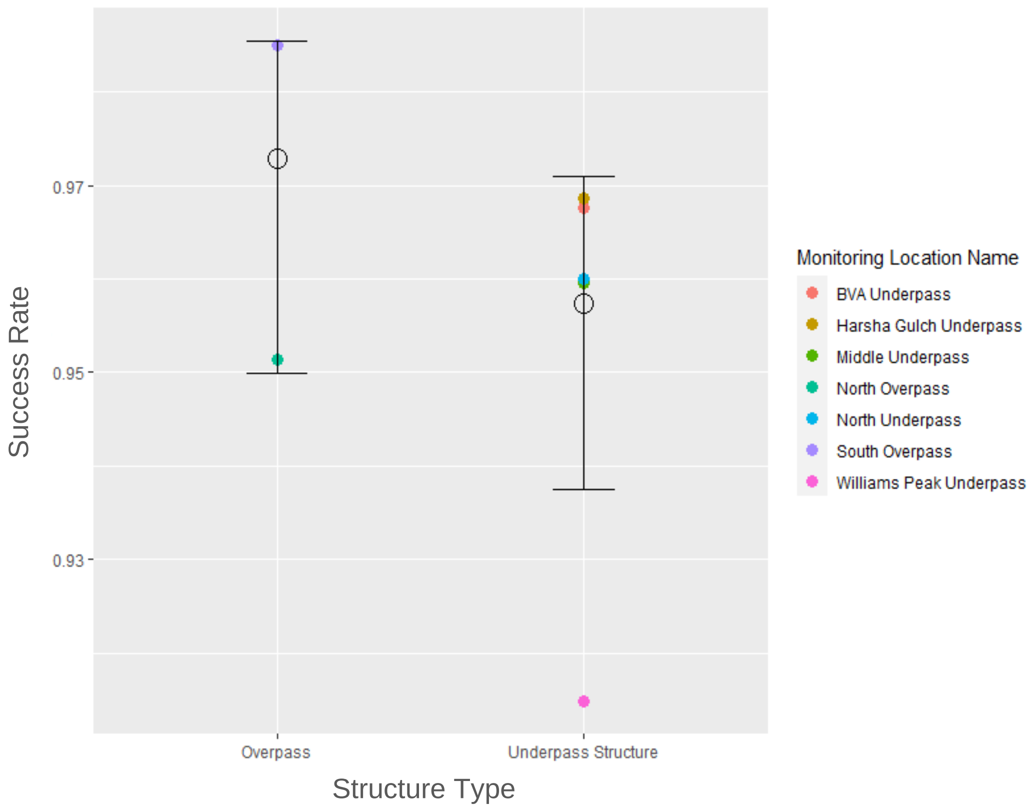

Figure 3-6. Mean mule deer success rate (open circle) and standard deviation by crossing structure type.

Analysis of Landscape and Structural Variables Influencing Mule Deer Abundance, Successful Passages, and Success Rates

Statistical analyses were performed to examine the relationship of structural and landscape variables on mule deer presence at the crossing structures (abundance), average successful passages per day, and success rates. Because all of the underpasses and the two overpasses each have the same dimensions, an analysis of the effect of structure dimensions was not performed.

The landscape variables that were measured included vegetation cover types adjacent to crossing structures (percent grass, brush, trees, bare), proximity to a drainage, and distance to human disturbance (e.g., homes, barns, other centers of human activity). The structure variables that were measured at underpasses included approach slope and the presence of a drainage trough. Structural variables at overpasses were not evaluated because of the small sample size (*n*=2).

Statistical analysis revealed that all but one of the explanatory variables that were evaluated had no or little influence on mule deer abundance at crossing structures or mule deer success rates (Table 3-3). It was plausible that abundance increased with brush cover, but this result was not significant (*p*=0.097). Tree cover was rare in this sagebrush dominated landscape and the potential effect of this variable on abundance or success rate could not be reliably determined. Bare ground was the only variable with a significant effect on mule success rate – success rate decreased as bare ground cover increased (*p*=0.051).

Table 3-3. Results of statistical analyses to determine the influence of explanatory variables on mule deer abundance and mule deer success rates at crossing structures. Because of the small number of overpass structures (*n*=2), analysis of structural variables (e.g., entrance ramp slope and length) could not be conducted. The results of estimated regressions for tree cover was questionable (*p*-values in parenthesis) because there was only one crossing structure location with a non-zero value.

Explanatory Variable	Test Type	Mule Deer Abundance	Mule Deer Success Rate
Landscape Variables			
Landcover: Bare Ground	Abundance: Linear regression with 95% confidence interval Success Rate: Linear regression (logit scale)	*p*=0.436	*p*=0.051
Landcover: Brush		p=0.097	*p*=0.845
Landcover: Trees		(*p*=0.490)	(*p*=0.869)
Landcover: Grass		*p*=0.870	*p*=0.456
Distance to Ephemeral Drainage	Abundance: ANOVA with 95% confidence intervals Success Rate: Type II Wald chi square	*p*=0.320	*p*=0.106
Distance to Disturbance		*p*=0.163	*p*=0.944

Explanatory Variable	Test Type	Mule Deer Abundance	Mule Deer Success Rate
Structural Variables			
Underpass Approach Slope	Linear regression (logit scale)	n/a	p=0.517
Underpass Drainage Trough Presence		n/a	p=0.374

These results also did not find a relationship between mule deer abundance at a structure or mule deer success rate and the structural variables that were measured. An interesting trend was that of success rate increasing with increasing distance from an ephemeral drainage. However, this may be attributed to the fact that the two overpasses, with their high success rates, are located the greatest distances from low-lying drainages.

Seasonal Use of Crossing Structures

Successful passages by mule deer at the wildlife crossing structures were plotted for each month from the onset of the camera monitoring in December 2015 through April 2020 (Fig. 3-7). Periods of peak mule deer use differed at each crossing structure location and varied from one year to the next. In general, mule deer numbers began increasing in October as migratory herds arrived on winter range and decreased in April as these herds moved out of the study area onto summer range. Mule deer activity generally peaked in February or March at all crossing structures, although the timing of these peaks varied from year to year and by location. Winter 2018-19 saw the greatest number of successful passages at all of the crossing structures except the Middle Underpass where the number of successful passages decreased slightly (-7%).

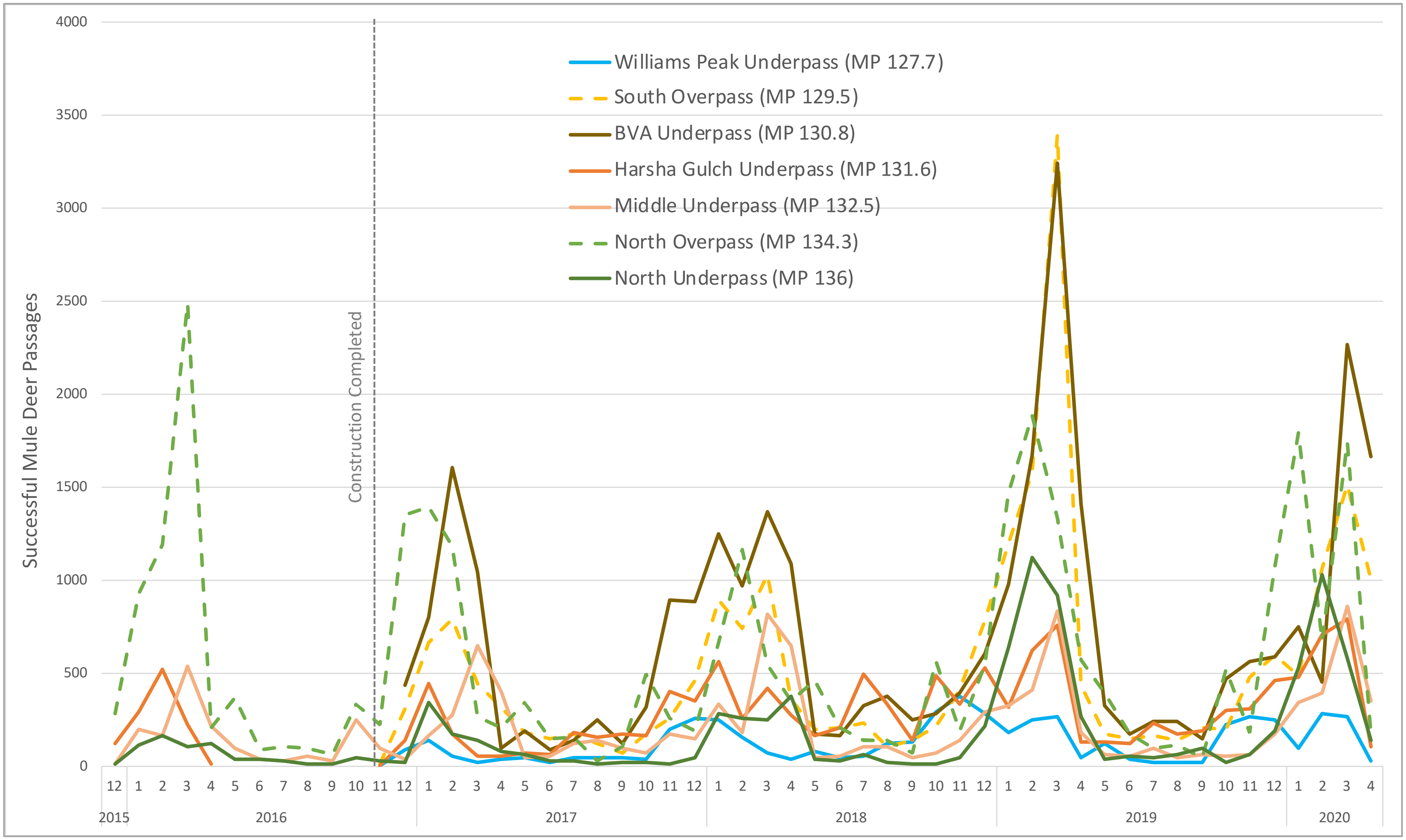

Figure 3-7. Mule deer successful passages by month and year at each of the wildlife crossing structures over the five-year study period.

Mule Deer Direction of Origin

Movements through or over the crossing structures originated from both east or west. In general, movements originating from either side of the highway were nearly equal (Fig. 3-8). The project area was located within mule deer winter range and many of the same animals were making regular movements through the structures to access the habitat and resources on either side of the highway. The greatest variations in the origin of movements were apparent during spring and fall migrations. In May, which corresponds with spring migration, 70% of mule deer passages were from the west to the east. This pattern reversed in October, which corresponds with fall migration, when 67% of mule deer passages were from the east to the west.

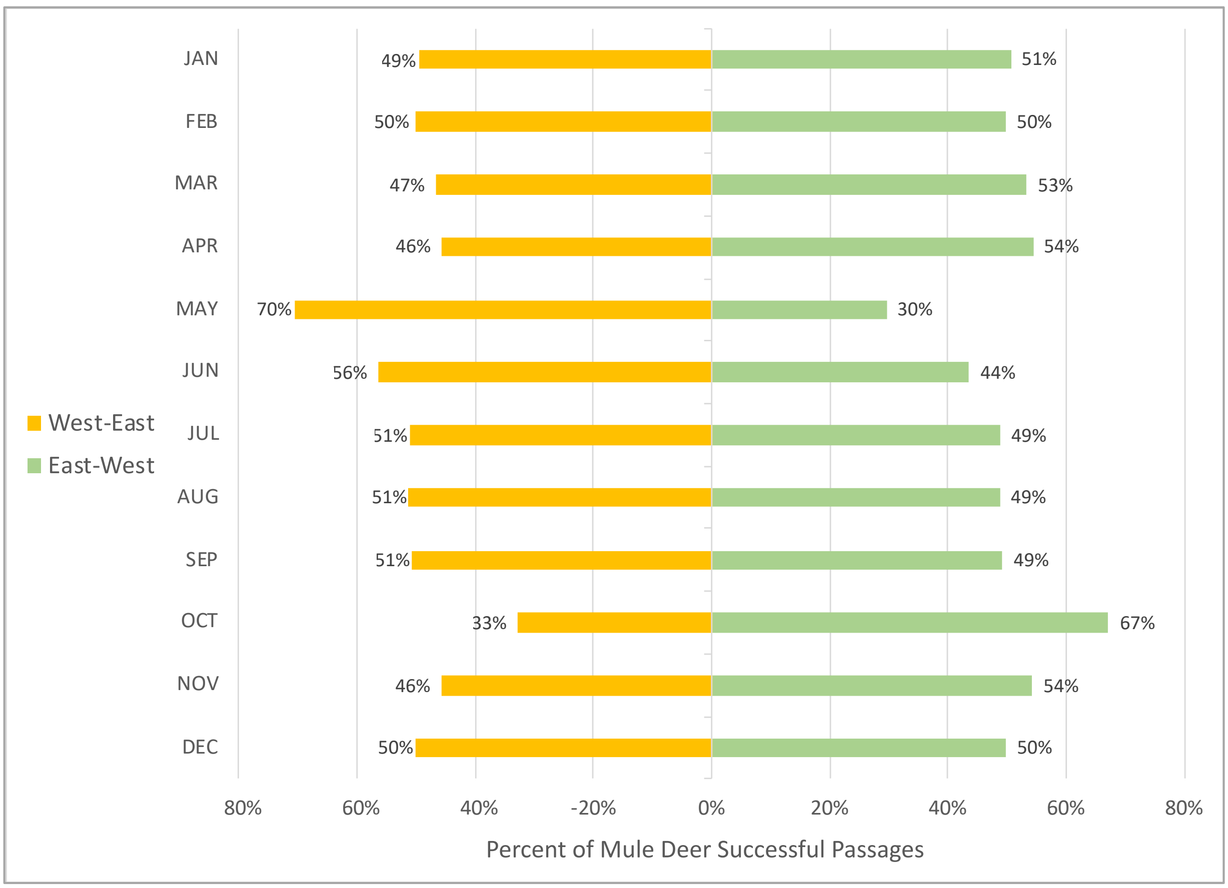

Figure 3-8. Direction of origin of mule deer successful passages by month of the year (Years 1-5).

Mule Deer Use of Crossing Structures by Time of Day

Over half of all mule deer successful passages at the crossing structures occurred during daylight hours (Fig. 3-9), although the research team noted that many daytime movements occurred early or late in the day.

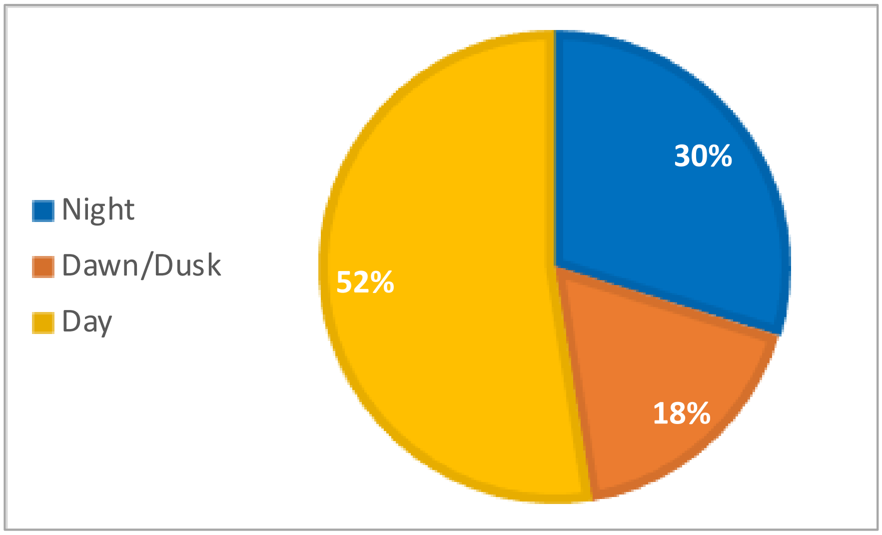

Figure 3-9. Mule deer successful passages at the crossing structures by time of day.

Demographics of Mule Deer Using Crossing Structures

In Years 3-5, from June through December, across all crossing structure locations, bucks represented 24% of successful passages, does 53%, and fawns 17% (Fig. 3-10), with the remainder recorded as unknown gender. Across structure locations, the proportion of buck successful passages ranged from 19% to 38%. When considering only those animals identified as male or female, in the final year of the study, 32% were bucks and 68% does.

Figure 3-10. Doe and two fawns crossing through the BVA Underpass.

Mule Deer Use of Small Culverts

Three small culverts (6-8' openings) were monitored for varying lengths of time. The small culverts were located between the crossing structures. The distance to the nearest crossing structure from the Culbreath Box, the BVR Pipe Culvert and the BVR Box Culvert was 0.8, 0.1, and 0.5 miles, respectively. Few mule deer approaches (*n*=369) were recorded at the small culverts compared to the large crossing structures. While mule deer were documented passing through each of the small culverts (total number of successful passages = 103), the average number of mule deer successful passages per monitoring day was 0.05, which equates to one successful passage for every 20 monitoring days across the three small culver locations. The highest number of successful passages was documented at the BVR Box Culvert (*n*=96; MP 133); fewer than five passages were recorded at each of the other two culvert locations (Fig. 3-11).

Figure 3-11. Mule deer repelling at the BVR Box Culvert.

The majority of mule deer approaches to the small culverts resulted in a repel (*n*=142) or parallel movement (*n*=124). The success rate for mule deer at small culverts was 28%, the repel rate was 39%, and the parallel rate was 34%. The highest mule deer repel rate at the small culverts was documented at the Culbreath Box Culvert (67.6%). This small culvert location was also the only one where domestic animals were documented, including cats (*n*=21) and dogs (*n*=9).

Predator Influences on Mule Deer Use of Crossing Structures

Mountain lions made 182 successful passages through the crossing structures with a 96% success rate. Lion activity was greatest during the winter months, when mule deer abundance was high. Figure 3-12 compares average mountain lion and mule deer successful passages per monitoring day at each of the crossing structures. The number of mule deer passages per monitoring day was greatest at the BVA Underpass (*n*=23.15), where only one mountain lion passage was documented, and the North Overpass (*n*=18.1), where a total of 7 mountain lion passages were documented. The number of mountain lion passages per day was greatest at the Williams Peak Underpass (*n*=0.12), which had the lowest number of mule deer passages per day (*n*=3.85), and the Middle Underpass (*n*=0.02). The statistical significance of mule deer negative correlations in usage at each structure location due to mountain lion presence could not be determined at a broad temporal scale. An analysis of the time between mule deer use of a crossing structure following a lion event found that the time lapse between these two events ranged from 42 minutes to 21 days, with an average time of 3:32 hours and a median time of 27:12 hours.

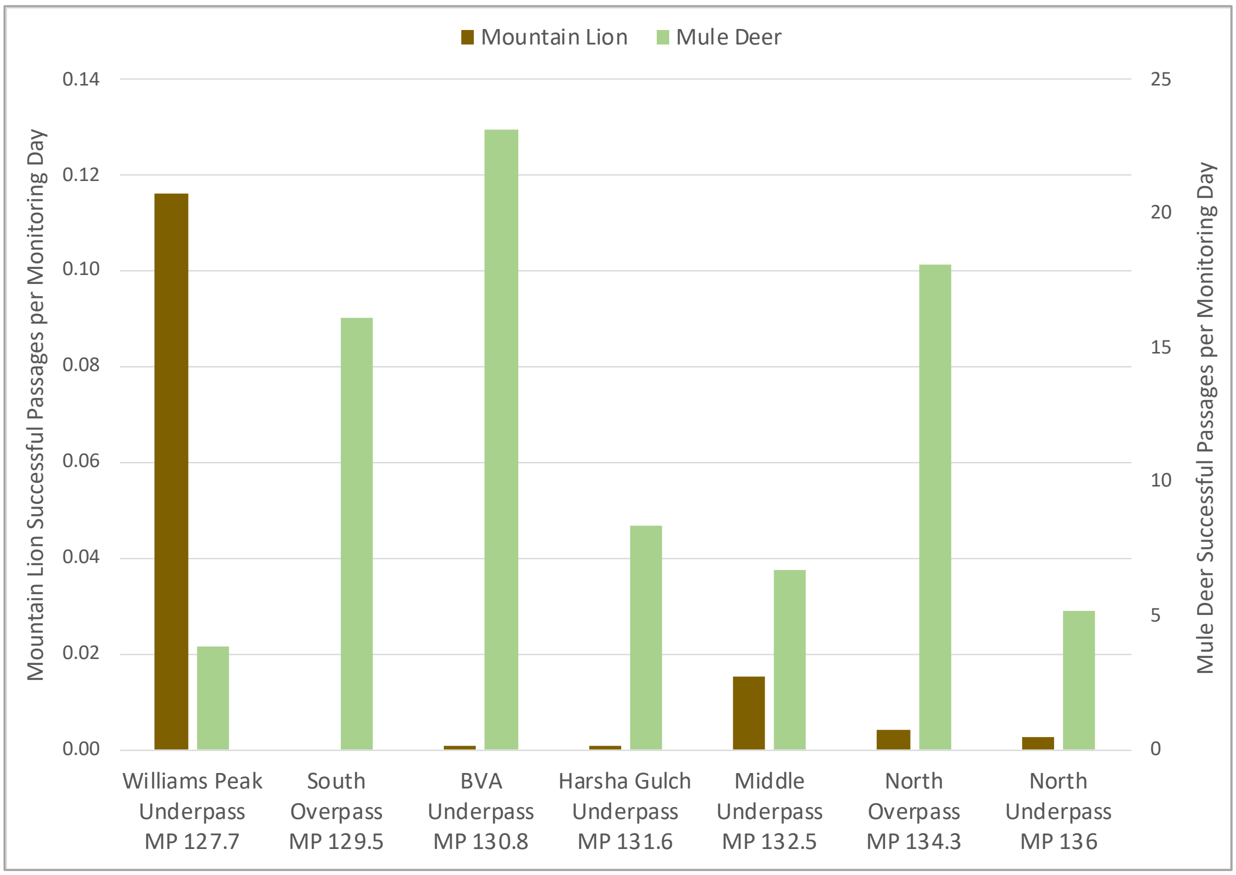

Figure 3-12. Mountain lion and mule deer successful passages per monitoring day at each crossing structure.

Human Influences on Mule Deer Use of Crossing Structures

The wildlife crossing structures were used by humans walking, riding horses, and in vehicles and may have affected mule deer and other wildlife use of the structures. Excluding Years 1-2 when construction was ongoing, human events (presence at the crossing structures regardless of the number involved) were most frequent at the Harsha Gulch Underpass (MP 131.6; *n*=287). Harsha Gulch Underpass was the only location where vehicle events were documented (tractor/ATV; *n*=27) and was used by BVR for ranch access on either side of the highway. When standardized by the number of monitoring days, human presence at crossing structures ranged from 0.01 human events per monitoring day at the Middle Underpass (MP 132.5) and the North Underpass (MP 136) to 0.26 humans per day at Harsha Gulch Underpass. Across all locations, there were 0.1 human events per day documented at the crossing structures, which equates to human presence at one of the crossing structures once every ten days.

Human events were overwhelmingly during daytime hours (95%) and a slight majority of mule deer successful passages (52%) was also during the daytime; however, there were substantially more mule deer passages (*n*=48,109) than human events (*n*=420). A statistical analysis was conducted to ascertain if human presence had an effect on mule deer daytime use of wildlife crossing structures. The relationship between the proportion of mule deer successful passages that occurred during the daytime and the number of human events at each structure was assessed using a generalized linear mixed model with a binomial distribution and a logit link. Number of human events was log transformed (base 2, with an additive increment of 1 to deal with zero counts). Monitoring location was included as a random effects factor to accommodate the clustering of monthly observations within location; and the covariance of the repeated measurements was modeled with a first-order autoregressive structure. The slope of the regression was significant at 0.116. This small p-value might suggest a relationship, but without strong support from the data from this study (Figure 3-13). The odds of a successful passage happening during day (rather than during dusk, night, or dawn) decrease 1.075 (= 1/[exp(-0.07245)]) times with each doubling of the number of human events.

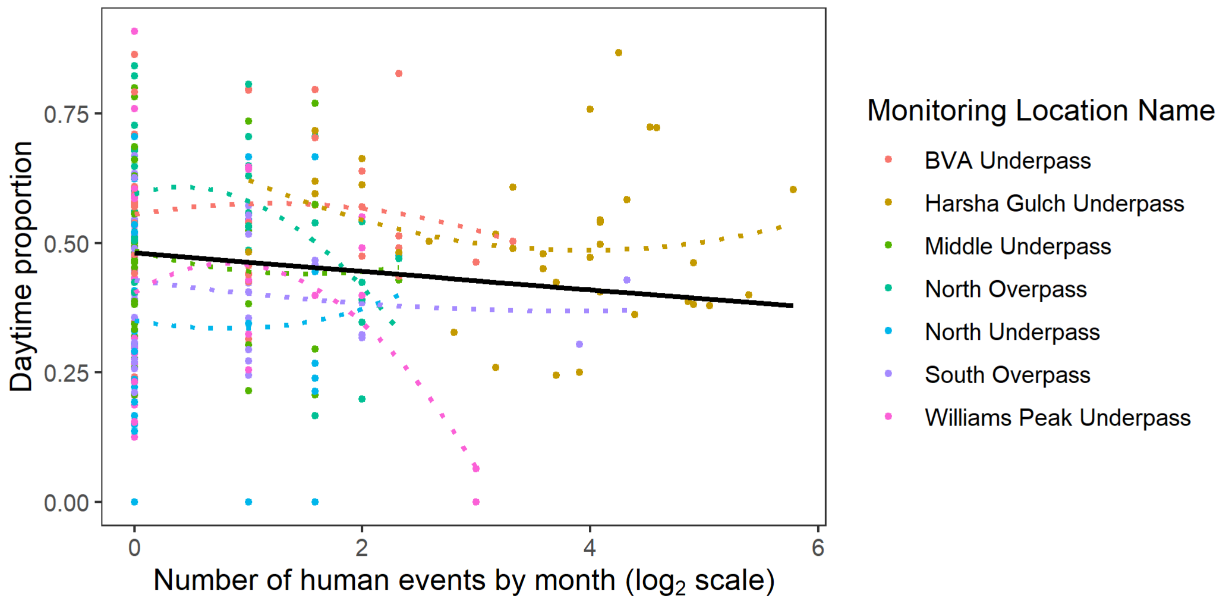

Figure 3-13. Proportion of mule deer successful passages occurring during the daytime relative to the number of human events at crossing structures. Each observation represents one month in the 3 post construction years (36 observations for each location). The dotted lines are smoothed curves fit to the data for each location, demonstrating location-specific relationships. The black line depicts the statistical regression of the number of successful passages during the day relative to the total number of successful passages on the number of human events.

Winter Snowpack and Mule Deer Movements at Crossing Structures

The number of mule deer successful passages per winter month was analyzed with respect to monthly winter severity to help illuminate if there was a relationship between mule deer successful passages and snow depth and temperatures. CPW's winter severity index was based on weekly measurements of temperature and snow depth at established transects (Birch 2020). The weekly indices were averaged by month for comparison to monthly winter mule deer passages at crossing structure (Fig. 3-14). A range of winter conditions were observed following the completion of construction activities, including two average winters (Winters 2016-2017 and 2018-2019), one mild winter (Winter 2017-2018), and one severe winter (Winter 2019-2020). In general, the month with the most severe winter conditions (January/February) was followed by the month with the highest number of mule deer passages. The number of mule deer passages (Fig. 3-15) peaked in Winter 2018-2019, while winter severity peaked in Winter 2019-2020, during which there was a relative decrease in the number of mule deer movements.

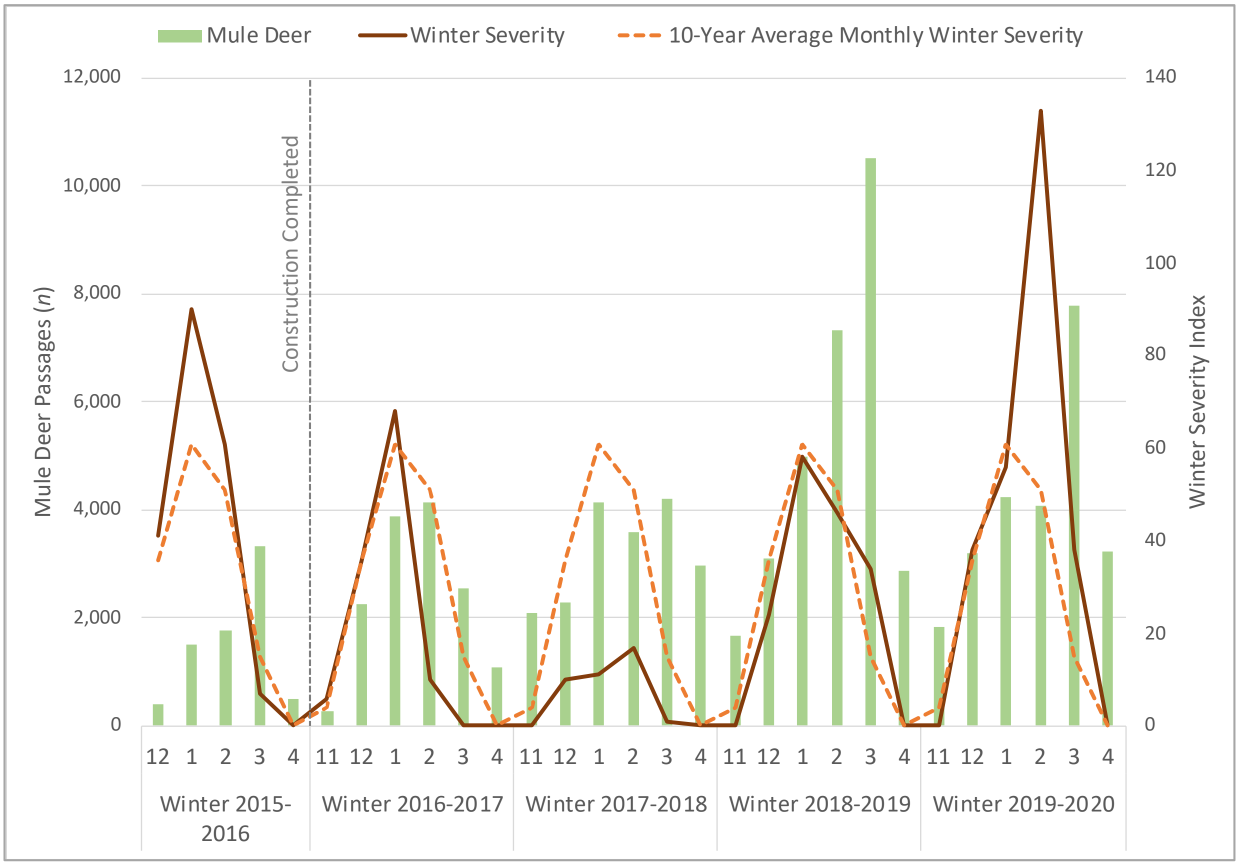

Figure 3-14. Comparison of mule deer successful passages, annual winter severity, and the ten-year average winter severity by winter month (November through April). Winter severity is an index based on weekly temperatures and snow depth.

Figure 3-15. Buck at the South Overpass navigating deep snow conditions in February 2020.

DISCUSSION

This research documented 112,678 mule deer successful passages across seven structures, providing a wealth of information on mule deer use of wildlife crossing structures. This high number of mule deer successful passages combined with high success rates at the crossing structures over five years establishes the SH 9 wildlife mitigation project as one of the most successful projects to date for mule deer in North America. The SH 9 study was unique from many other studies in that the structures were located in winter range rather than along a migration path, resulting in regular movements by many of the same animals throughout the winter months. This was an important result as it demonstrates the need to consider deer habitat use at local levels when choosing to prioritize conservation between winter range and migration paths. Recent emphasis in the western United States suggests that migration paths are of the highest priority in mule deer conservation. Monitoring research on SH 9 demonstrated that, in some places, facilitating movement within winter range may be of greater concern.

The number of mule deer successful passages and corresponding success rates at all crossing structure locations were high from the outset of this research, indicating that mule deer adapted quickly to the crossing structures and fencing. In the final three years of the study, there were an annual average of 29,873 mule deer successful passages with an average success rate of 96%. The number of times mule deer used the structures was also a striking result of this study. On average, there were 125 successful passages by mule deer over and through all seven crossing structures each day during the winter months, with respect to the number of monitoring days. This equates to an average of 17.5 successful passages per structure each winter day. A portion of these successful passages represent the number of potential WVC that were avoided had the mitigation project not been implemented. See Chapter 8 for the presentation of WVC crash and carcass reductions in the study area after mitigation.

The number of successful passages at the SH 9 crossing structures exceeds the number documented in other studies of mule deer use of crossing structures. Cramer and Hamlin (2019) recorded 78,610 mule deer success movements through seven structures over five years on US Highway 89 in southern Utah. Stewart (2015) recorded 35,369 successful passages by migratory mule deer at five wildlife crossings (two overpasses and three underpasses) over four monitoring years on US Highway 93 in Nevada. In southwest Wyoming, Sawyer and LeBeau (2011) reported over 49,000 success movements by migratory mule deer through seven wildlife underpasses over three years on US Highway 30. Each of these studies examined wildlife crossing structure use by migratory herds. The high number of passages documented by this research may be attributed to the location of these crossing structures near the river bottom within mule deer winter range.

This discussion summarizes the findings on mule deer successful passages and success rates by location, evaluates the study results relative to the performance measures, and provides insight into questions regarding mule deer use of crossing structures and the variables influencing successful passages and success rates.

Mule Deer Successful Passages by Location

While successful passages and success rates were high overall, the number of mule deer passages varied at each of wildlife crossing structure locations. Use of structures varied in large part relative to the locations of the structures in the landscape. After all construction activities were completed in late fall 2016, the highest number of mule deer success movements were at the BVA Underpass (*n*=28,677; MP130.8), the North Overpass (*n*=22,873; MP 134.3; Fig. 3-16), and the South Overpass (*n*=20,053; MP 129.5). These three structures accounted for 69% of all passages in Years 3-5. The BVA Underpass and the South Overpass are located within 1.3 miles of one another in the southern portion of the project area. This area had the highest number of wildlife carcasses collected annually preconstruction, with a peak in WVC around MP 130. Towards the north end of the project area, the North Overpass and

Figure 3-16. Mule deer crossing over the North Overpass.

North Underpass (MP 136) had the second and fourth highest number of successful passages, respectively. In the center of the study area, the Harsha Gulch (MP 131.6; Fig. 3-17) and the Middle (MP 132.5) Underpasses each had lower numbers of mule deer successful passages. The least amount of mule deer activity was documented at the Williams Peak Underpass (MP 127.7) at the very south end of the project, nearly two miles south of the next closest structure, the South Overpass. These underpass structures were all of the same dimensions, and the two overpass structures were also of the same dimension. Hence, the results of this study suggest that the differences in crossing structures use was likely due to structure location relative to subtle differences in the landscape along the 10.4-mile study area that influence mule deer distribution and movements. However, these variables were not evaluated in the present study.

Figure 3-17. Mule deer fawn nursing and other deer resting in the shade at the Harsha Gulch Underpass.

Performance Measures Evaluation

Mule deer use of the seven wildlife crossing structures exceeded the performance measures defined at the outset of the research (Table 3-4). However, there is some nuance in interpreting the observed results relative to the performance measure, as discussed below in the following subsections.

Table 3-4. Mule deer performance measures evaluation. Parentheses indicate that the performance measure was largely met.

Performance Measure	Met	Not Met
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	✔	
By the end of the study, the proportion of buck-doe mule deer successful passages through all crossing structures will be in the same proportion of bucks and does as estimated by CPW for the local population	✔	
Each year there will be an increase in the number of mule deer successful passages at wildlife crossing structures annually until an overall equilibrium/plateau is reached	(✔)	

Mule Deer Success Rate

Over the course of the study, the annual mule deer success rate at the crossing structures ranged from 95% to 96%, exceeding the minimum goal of 60% and the final year goal of 80%. This performance measure was also exceeded when considered on an individual structure basis. Each of the seven wildlife crossing structures had an average success rate greater than 90%.

Proportion of Bucks to Does

Buck and doe successful passages were drawn from December through June counts when antlers are most visible to accurately identify gender. Gender ratios at the crossing structures were compared to CPW post-hunt aerial survey population estimates. In the final year of the study, the proportion of bucks to does successfully using the crossing structures (32% bucks and 68% does) was roughly equivalent to CPW's observed 2019 post-hunt population ratio of 40.1 bucks per 100 does (Lamont 2020), or 29% bucks and 71% does for the Middle Park (D-9) population.

Variation in the proportional use of wildlife crossing structures by each gender may be expected for structures located in winter range (Fig. 3-18). Individuals whose winter home ranges are bisected by the highway make more frequent passes through the crossing structures, while individuals whose winter home ranges are farther from the highway encounter the structures less frequently, perhaps only during their biannual migrations. Consequently, the count of mule deer successful passages primarily reflected those individuals whose winter home ranges were adjacent to or bisected by the highway, regardless of the herd's gender composition as a whole. Regardless, these results demonstrated that buck use of the crossing structures closely resembled the population structure in the study area, as documented by CPW.

Figure 3-18. Mule deer buck crossing through the BVA Underpass in winter.

Increase in Mule Deer Successful Passages Over Time

Mule deer successful passages varied monthly, and annually. In general, monthly mule deer activity began increasing in October, marking the onset of migratory mule deer arriving on winter range, and began decreasing again in April as these mule deer moved to high elevation summer ranges. Peak activity occurred in February and March. Fluctuations in the onset of winter conditions on high elevation summer range and winter severity on winter range likely had a strong influence on annual variation in the arrival of deer on winter range and periods of peak activity.

The number of mule deer successful passages generally increased each year post construction. Following the completion of construction activities in Year 2, the total number of mule deer successful passages increased by 52% in Year 3 and by 55% in Year 4. During Year 5, a 19% decrease was observed. Given a mule deer population that was largely stable during the study period, annual variation in mule deer use of crossing structures in winter range may be the result of multiple factors, perhaps most importantly, the density of mule deer on winter range. The decrease in mule deer passages observed from Year 4 to Year 5 may, in part, be related to winter severity. The winter of Year 5 (2019-2020) was the most severe winter during the study timeframe, resulting in more restricted movements and fewer passages at the crossing structures by deer navigating deep snow conditions.

While impossible to confirm without additional years of monitoring, it was likely that the number of mule deer passages observed in Years 4 and 5 were both within the natural range of variability. In five years of monitoring in Banff, Canada, researchers similarly documented an increase in ungulate movements each year without ever leveling out (Clevenger and Waltho 2003). These results suggest that even where mule deer readily adapt to new wildlife crossing structures, as observed in this study, more than five years of monitoring may be required to establish whether a plateau in passage rates has been achieved.

Multiple studies have documented an increase in mule deer passage rates over time, suggesting an adaptation period to new crossing structures (Cramer and Hamlin 2020, Cramer and Hamlin 2019, Sawyer et al. 2012). The high initial and ongoing number of successful passages on SH 9 may be the result of multiple factors, including the location of the crossing structures in winter range where wintering animals encounter the structures with regularity through the winter months; the position of the crossing structures in the landscape relative to sight lines; and crossing structure dimensions. The SH 9 underpasses are wider, taller and, in some cases, shorter in length than many of the crossing structures evaluated in other studies.

Do the Wildlife Crossing Structures Provide Connectivity for Mule Deer Across SH 9?

The extent to which the wildlife crossing structures mitigation provided connectivity was assessed relative to functional connectivity. Functional connectivity is defined as the degree to which landscapes (including the transportation mitigation) increase movement of genetic, organism, and population flows through the landscape within a mosaic of habitat type and uses (Hilty et al. 2006, Taylor et al. 2006).

Genetic, individual, and population connectivity were present prior to the mitigation construction, as mule deer regularly moved back and forth across SH 9, though this created a high risk of WVC. Consequently, while safety was a major driver for the mitigation project and wildlife fencing alone may have been able to achieve a reduction in WVC, the need for continued mule deer movement across SH 9 to access habitat and resources and maintain connectivity necessitated the inclusion of wildlife crossing structures in this mitigation project.

The findings of this research demonstrate that the SH 9 wildlife crossings, in conjunction with fencing, successful preserved genetic, individual, and population-level connectivity for mule deer while improving driver safety. That the SH 9 wildlife crossings provide genetic connectivity was assumed based on the high number of mule deer successful passages at the crossing structures and the mixing of herds from different summer range areas on the Blue River valley winter range. Population level connectivity was achieved when individuals of both genders and all age groups were successfully using the crossing structures. The high number of mule deer successful passages documented by this research (112,678) including movements by bucks, does and juveniles, combined with a success rate of 96% across all of the wildlife crossing structures, indicated that the mitigation was highly effective in accommodating connectivity for mule deer across demographic groups. The findings of this study suggest that the wildlife crossings provided population level connectivity for both winter migrants and resident herds.

This study documented a dramatic decrease in WVC as a result of the mitigation (Chapter 8). This reduction in WVC combined with the number of successful passages substantiates the finding of ongoing mule deer population connectivity as a result of this comprehensive mitigation project. This finding of the preservation of long-term connectivity with crossings structure mitigation was corroborated by studies in other locations (e.g., Sawyer et al. 2016, Sawyer et al. 2012, Simpson et al. 2016).

Do Mule Deer Prefer Underpasses or Overpasses?

Despite a small number of crossing structures, this field study was well suited to examine the question of mule deer preference between overpasses and underpasses because structure dimensions were consistent among the two types of structures. Mule deer successful passages and success rates were high at all crossing structures. A comparison of the average number of successful passages per monitoring day per structure revealed that mule deer used the overpasses nearly five times more than the underpasses. Yet, the structure location with the highest total number of success movements was an underpass (BVA) rather than an overpass. Notably, the majority of preconstruction WVC carcasses were recorded around the location of the BVA underpass (Chapter 8), representing where mule deer were historically unsuccessful in attempting to cross the road. Statistical analyses of mule deer abundance and successful passages in relation to structure type could not detect a discernable preference for one structure type over the other and both underpasses and overpasses functioned well for mule deer (Fig. 3-19). These results likely reflected variations in mule deer winter range habitat use – that is, structures located in portions of the winter range with the greatest density of mule deer receive the most use, regardless of structure type.

Figure 3-19. Mule deer on the North Overpass (top) and at the Harsha Gulch Underpass (bottom).

These results contrast with other field studies in sagebrush habitats. Simpson et al. (2016) documented a higher repel rate for migratory deer at underpasses and found a distinct preference for overpasses. Only one overpass (160’ wide by 66’ long) and one underpass (26’ wide by 20’ high by 92' long cylindrical corrugated metal culverts) type and size were evaluated in this study, which may have influenced the findings. Elsewhere, Sawyer et al. (2016) reported a preference for underpasses by migratory mule deer. The underpasses in this study were approximately 65' wide by 13' high by 42' long span bridges. These examples illustrate that mule deer structure preference may be specific to the crossing structure types and sizes available in a given study area and their use by migratory versus wintering mule deer. A more robust analysis of species-specific structure preferences and the influences of structure type would require a meta-analysis across multiple study areas with a larger sampling of overpass and underpass dimensions, and more comprehensive analysis of other potential variables influencing wildlife densities and movement patterns.

What Factors Influence Mule Deer Use of Crossing Structures?

The statistical analyses conducted detected little or no significant effects of the landscape or structural variables measured on mule deer abundance or success rates. These included structure type (underpass vs overpass), the presence of a drainage trough through an underpass, the approach slope leading to an underpass (a proxy for structure visibility and sight lines), land cover type, distance to a drainage, and distance to human disturbance. The results of these analyses were likely also influenced by a small sample size and other confounding factors. Underpass type and size are known to affect mule deer passage rates (Clevenger and Barrueto 2014, Cramer 2012, Reed et al. 1975), but because structure type and dimensions were the same between the two overpasses and among the five underpasses, the effect of structure dimensions could not be assessed in this study.

These outcomes, combined with the finding of high success rates at all of the crossings structure locations but high variability in mule deer abundance across the study area, suggest that other variables may have a greater influence on mule deer abundance and success rates than the structural and landscape variables measured in the immediate vicinity of a crossing structure, provided that the structure is sufficiently sized and designed, such as those on SH 9. Similarly, Sawyer et al. (2012) suggested that differences in mule deer use of crossing structures of the same size may be related to the location of the underpasses relative to established migration routes. One such measure that may affect mule deer abundance on winter range is variability in mineral composition and forage quality (Peterson 2008); this study was not designed to evaluate these factors.

Do Predators Influence Mule Deer Use of Crossing Structures?

Mountain lion activity at the crossing structures was greatest during the winter months, which corresponded with the activity period for their prey, mule deer. Mule deer and mountain lions used the same structures, often within hours of one another. This study was not designed to capture mountain lion activity in the landscape around the crossing structures, so the level of mule deer avoidance of a crossing structure when mountain lions were nearby was unknown, though such temporary avoidance is highly plausible and has been documented elsewhere (Mata et al. 2020). Mule deer avoidance of the Williams Peak Underpass was documented for a four-day period during which 60 mountain lion passages were recorded by what appeared to be an adult with several cubs, including urine marking at the underpass. No mule deer or other wildlife activity was recorded at the underpass for three days following this event but resumed thereafter. The influence of mountain lions on mule deer use of the crossing structure was temporary with no long-term or sustained avoidance observed as reported in other studies (e.g., Caldwell and Klip 2019). When there was a gap of eight or more days between a mountain lion event and a mule deer returning to that structure, these events all occurred after March 27, when deer have begun dispersing on winter range at the onset of the spring migration and are represented in the landscape in lower concentrations. As documented elsewhere, on SH 9 there was no evidence of predation in or around the crossing structures (Ford and Clevenger 2010, Little et al. 2002) or an apparent reduction in deer use of the crossings due to predator activity (Andis et al. 2017; Plaschke et al. 2021).

Does Human Activity Influence Mule Deer Use of Crossing Structures?

The degree to which humans may affect mule deer presence and use of structures was difficult to determine in a setting such as SH 9 where the number of human events was low, particularly in comparison to mule deer successful passages. The wildlife crossing structures were intentionally sited in areas with low human disturbance. The influence of human activity on wildlife use of crossing structures in other studies was greatest at crossing structures located in high human density settings (Clevenger and Waltho 2005), while in areas with low human activity, at least half of all mule deer passages occur during daylight hours (Cramer 2012). Statistical analysis of the effect of human presence on mule deer successful passages during the daylight hours found a slight negative effect of human presence on mule deer successful passages. These results were presumably because human activity was low across the study area, despite ranch related activities at Harsha Gulch Underpass and recreational activity (hikers with or without dogs) primarily at the South Overpass and the BVA Underpass, both of which are in close proximity to Blue Valley Acres, a low-density residential development.

Mule Deer Use of Small Culverts

Unlike the large wildlife overpasses and underpasses, the small culverts were not designed for wildlife passage. Of the three monitored small culverts, the Culbreath Box Culvert was the shortest and had the largest opening (8' high by 7.5' wide by 99' long), but its location adjacent to a ranch with horses, dogs, and cats likely resulted in much higher repel (68%) and parallel rates (27%) than at the other small culvert locations where the average mule deer success rate was 33%. While in much of the study area mule deer behavioral adjustments to avoid human interactions appear to be minimal and temporary, perpetual disturbance at this location rendered this small culvert largely unsuitable for mule deer passage.

In Summary

The study was instrumental in demonstrating the success of the SH 9 wildlife crossing structures for mule deer based on success rates, numbers of successful passages, connectivity for all age and gender classes of the population and use of both underpass and overpass structures. These results will guide designs of future wildlife crossing structures to achieve maximum use and success. The fact that statistical analyses could find little influence of structural and landscape variables on mule deer successful passages at the structures is a testament to the value of the Blue River drainage as mule deer winter range and the ability of mule deer to adapt to various structure conditions. The high success rate also demonstrates that the crossing structures were adequately sized to accommodate mule deer passage. The wildlife mitigation system was a success for mule deer and if adaptively managed and maintained, should provide connectivity for wildlife while making SH 9 safer from WVC for motorists for decades to come.

Chapter 4. Other Species Use of Crossing Structures

RESULTS

Overview of Species Use of Crossing Structures

In addition to mule deer, sixteen wildlife species successfully used the crossing structures during the five-year study (Fig. 4-1). The suite of species captured in this research encompasses the full array of meso and large mammal species known to be present in this landscape.

This chapter presents and discusses the use of the crossing structures by these species. The objective of this chapter is to demonstrate the differences in abundance and success rates at the different structures for the different species in order to better understand potential species-specific preferences. Table 4-1 presents an overview of the species recorded at the crossing structures post construction, total approaches, successful passages, rates of success, repel and parallel movements, and the average number of monitoring days between successful passages for each species across all seven wildlife crossing structures.

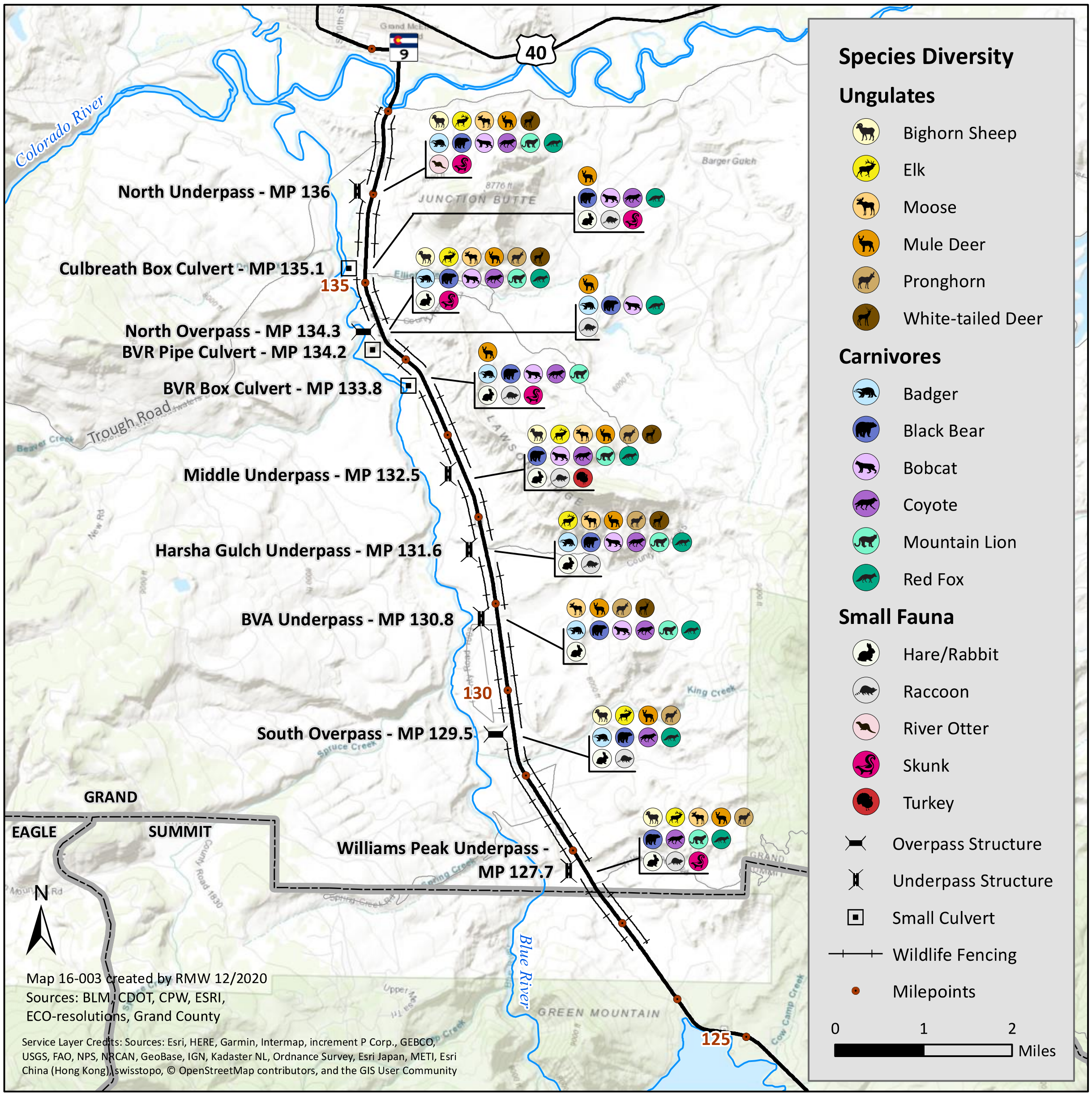

Figure 4-1. Diversity of species that made successful passages at each wildlife crossing structure and small culvert over the five-year study period.

Table 4-1. Total approaches and successful passages by species other than mule deer at the combined wildlife crossing structures, and corresponding success, repel, and parallel rates. Average number of monitoring days between successful passages is a frequency index for comparing successful passages among the different species.

Species	Total Approaches	Total Successful Passages	Success Rate	Repel Rate	Parallel Rate	Average Number of Monitoring Days between Successful Passages
Ungulates						
Bighorn Sheep	37	30	81%	19%	0%	287
Elk	540	489	91%	7%	2%	18
Moose	83	75	90%	5%	5%	115
Pronghorn	134	133	99%	1%	0%	65
White-tailed Deer	78	74	95%	4%	1%	116
Other Species						
Badger	12	9	75%	0%	25%	956
Black Bear	264	263	99.6%	0.4%	0%	33
Bobcat	148	132	89%	4%	7%	65
Coyote	2,971	2,875	96.8%	1.6%	1.6%	3
Mountain Lion	184	182	99%	0%	1%	47
Rabbit/Hare	641	589	92%	2%	6%	15
Raccoon	10	8	80%	0%	20%	1,076
Red Fox	367	310	85%	3%	12%	28
River Otter	2	2	100%	0%	0%	*
Skunk	4	4	100%	0%	0%	2,152
Turkey	6	6	100%	0%	0%	*

**Species documented using a crossing structure only on one occasion.*

Ungulates

Successful Passages and Success Rates at Crossing Structures

Five ungulate species other than mule deer were documented using the crossing structures: bighorn sheep, elk, moose, pronghorn, and white-tailed deer. Each of these ungulate species successfully used the crossing structures on multiple occasions, however, the number of successful passages and the success rates varied by species and over time. Elk made the most passages through or over the crossing structures. Successful passages by all other species were much less common. Table 4-2 presents the number of documented preconstruction movements and post construction total, successful, and repel movements and success rates for each species at each crossing structure, small culverts and the existing bridge over the Colorado River. The data are presented by crossing structure, beginning with crossing structures at the lower mileposts and moving northward.

Table 4-2. The number of preconstruction detections, post construction total approaches, successful passages, repel movements, and success rates for each ungulate species at the wildlife crossing structures, small culverts, and one existing bridge. Dark gray shaded rows are the overpasses; light gray are the underpasses. The BVR Box Culvert (MP 133.8) and the BVR Pipe Culvert (MP 134.2) were omitted from the table because there were no ungulate approaches at these locations.

Structure	Movements and Success Rate	Bighorn Sheep	Elk	Moose	Pronghorn	White-tailed Deer
Williams Peak Underpass MP 127.7	Preconstruction Detections	0	41	0	0	0
	Total Approaches	16	20	2	1	0
	Success Passages	10	11	2	1	-
	Repels	0	9	0	0	-
	Success Rate	63%	55%	100%	100%	-
South Overpass MP 129.5	Preconstruction Detections	0	25	0	1	0
	Total Approaches	10	30	0	19	0
	Success Passages	10	27	-	19	-
	Repels	0	2	-	0	-
	Success Rate	100%	90%	-	100%	-

Structure	Movements and Success Rate	Bighorn Sheep	Elk	Moose	Pronghorn	White-tailed Deer
BVA Underpass MP 130.8	Preconstruction Detections	0	0	1	0	0
	Total Approaches	0	1	6	82	16
	Success Passages	-	0	6	82	16
	Repels	-	1	0	0	0
	Success Rate	-	0%	100%	100%	100%
Harsha Gulch Underpass MP 131.6	Preconstruction Detections	0	0	0	0	0
	Total Approaches	1	25	10	17	13
	Success Passages	0	21	9	16	12
	Repels	1	4	0	1	0
	Success Rate	0 %	84%	90%	94%	92%
Middle Underpass MP 132.5	Preconstruction Detections	0	0	0	0	0
	Total Approaches	1	37	22	9	12
	Success Passages	1	29	19	9	11
	Repels	0	8	2	0	1
	Success Rate	100%	78 %	86%	100%	92%
North Overpass MP 134.3	Preconstruction Detections	0	0	0	0	0
	Total Approaches	8	84	15	6	4
	Success Passages	8	62	13	6	4
	Repels	0	13	0	0	0
	Success Rate	100%	74%	87%	100%	100%
Culbreath Box Culvert MP 135.1	Total Approaches	0	0	0	0	3
	Success Passages	-	-	-	-	0
	Repels	-	-	-	-	0
	Success Rate	-	-	-	-	0

Structure	Movements and Success Rate	Bighorn Sheep	Elk	Moose	Pronghorn	White-tailed Deer
North Underpass MP 136	Preconstruction Detections	0	1	0	0	0
	Total Approaches	1	343	28	0	33
	Success Passages	1	339	26	-	31
	Repels	0	3	2	-	2
	Success Rate	100%	99%	93%	-	94%
Colorado River Bridge MP 137	Total Approaches	0	0	3	0	1
	Success Passages	-	-	2	-	1
	Repels	-	-	1	-	0
	Success Rate	-	-	67 %	-	100 %
Total Successful Passages		**30**	**489**	**77**	**133**	**75**
Overall Success Rate		**81%**	**91%**	**90%**	**99%**	**91%**

Preconstruction detections of these ungulate species were generally low, in part because of their small population numbers in this landscape, but also because preconstruction camera monitoring can only capture a small snapshot of the wildlife activity in the vicinity of a future wildlife crossing. At a minimum, ungulate species made successful passages at each of the crossing locations where they were detected preconstruction. Notably, the greatest number of elk preconstruction detections were in the southern portion of the project area (Williams Peak Underpass and the South Overpass) while, post construction, the greatest number of elk passages were at the North Underpass.

The number of successful passages by each ungulate species across the seven wildlife crossing structures and the Colorado River Bridge is presented in Figure 4-2. Ungulate use of the three small culverts was scant and the numbers are not plotted for these structures. Elk successful passages were most common in the north end of the study area at the North Underpass (MP 136, *n*=339) and the North Overpass (MP 134.3, *n*=62). Pronghorn successful passages occurred most often at the adjacent BVA Underpass and South Overpass. Moose passages occurred at all of the large structures except the South Overpass. White-tailed deer used structures in the central and northern portions of the study area. The average number of monitoring days at each of the wildlife crossing structures averaged a total of 1,408 monitoring days each, except the Colorado River Bridge, which was only monitored in Year 3.

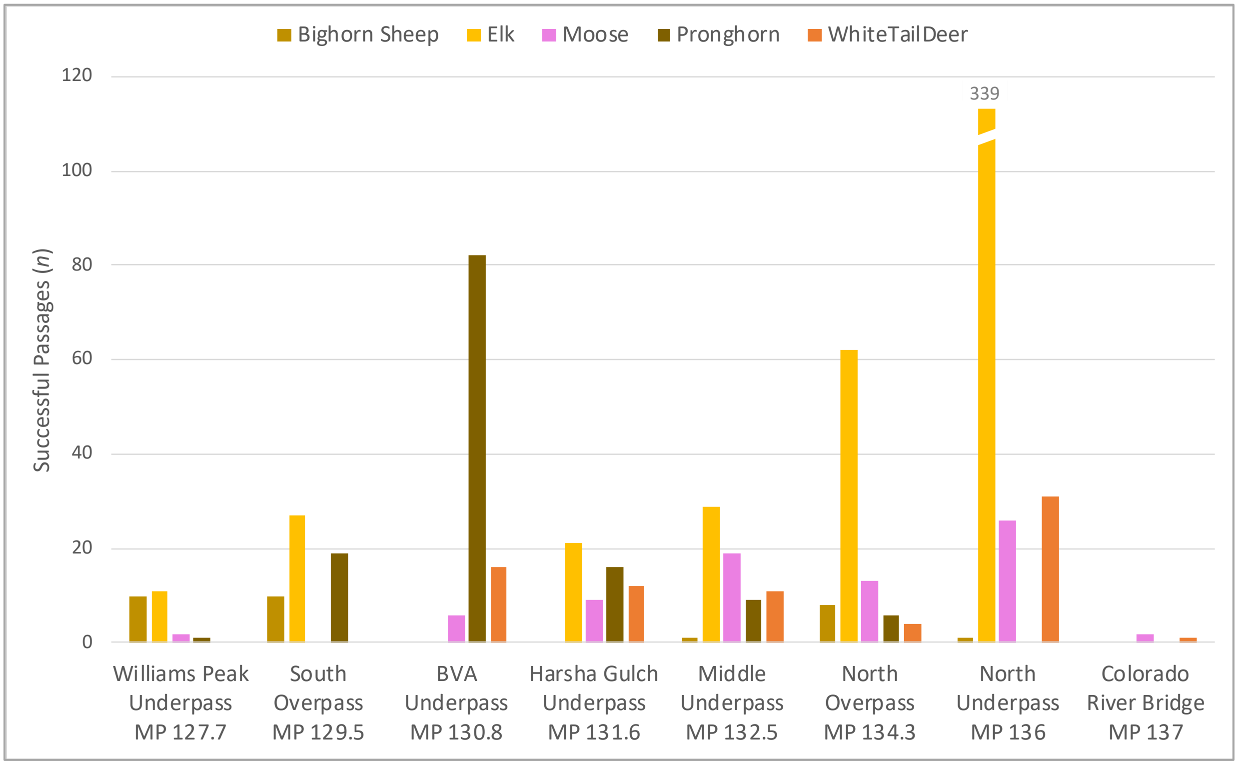

Figure 4-2. Successful passages at each wildlife crossing structure location and existing bridge for bighorn sheep, elk, moose, pronghorn, and white-tailed deer during the five-year study. The number of monitoring days at the Colorado River Bridge was one-fourth that of the other locations.

Wildlife movements at habitat cameras relative to movements at crossing structures for ungulates other than mule deer are reported in Table 4-3. In general, species that were captured at a habitat camera were also captured at the associated crossing structure, although species captured at both locations were not necessarily the same individuals. In two instances a species (elk and moose) captured at the habitat camera was not documented at the crossing structure (BVA Underpass and South Overpass, respectively). While these isolated events at discrete locations were not representative of the species use of the crossing structures as a whole, these events identify locations where a species was present in the landscape but did not approach a crossing structure.

Table 4-3. Comparison of ungulate species successful passages at wildlife crossing structures and presence at habitat camera locations adjacent to wildlife crossing structures. Presence at habitat cameras does not imply that animals were moving to or from a crossing structure. Bolded numbers indicate where a given species was detected by the habitat camera but was not detected at the crossing structure.

Species	Monitoring Location	Williams Peak UP	South OP	BVA UP	Harsha UP	Middle UP	North OP	North UP
Bighorn Sheep	Structure	10	10	0	0	1	8	1
	Habitat	8	1	0	0	0	0	0
Elk	Structure	11	27	0	21	29	62	339
	Habitat	1	51	**13**	23	25	129	228
Moose	Structure	2	0	6	9	19	13	26
	Habitat	2	**1**	1	10	19	3	17
Pronghorn	Structure	1	19	82	16	9	6	0
	Habitat	0	15	61	0	2	5	0
White-tailed Deer	Structure	0	0	16	12	11	4	31
	Habitat	0	0	0	1	28	4	19

The number of elk documented successfully using the crossing structures relative to the number of elk captured at habitat cameras generally increased each year post construction. By Year 5, the number of elk using the crossing structures was twice the number seen at the habitat cameras. However, this activity was not distributed evenly across the study area and there were two locations (BVA Underpass and Harsha Gulch Underpass) where the number of elk at the habitat cameras surpassed the number of passages at the crossing structures.

Table 4-4 lists the total number of successful passages by each ungulate species with respect to structure type (overpasses and underpasses). In addition, to account for the unequal number of overpasses (*n*=2) versus underpasses (*n*=5), this table also presents a comparison of the average number of successful passages per day at the combined underpasses versus the combined overpasses. In general, these ungulate species used the underpass structures more frequently than the overpass structures, except bighorn sheep, which used the overpasses nearly four times more than underpasses on an average per unit basis (*n*=30 successful passages). Moose, elk, and pronghorn all used underpasses approximately two times more than the overpasses, relative to their availability in the landscape. However, for elk, a second analysis was conducted recognizing that the analysis of elk use of underpasses versus overpasses was skewed by the increasing habituation to the North Underpass by a herd in this portion of the study area in the final years of the study. In the revised analysis omitting Year 5 data, elk were nearly four times more likely to use an overpass than an underpass (an annual average of 5.2 passages at the combined overpasses versus 1.4 passages at the combined underpasses). White-tailed deer were seven times more likely to use an underpass than an overpass.

Table 4-4. Successful passages by ungulates other than mule deer at overpasses versus underpasses. The annual average number of successful passages was standardized by the number of active camera monitoring days at the two overpasses and five underpasses. For elk, the annual average number of successful passages by structure type was also calculated for Years 1-4 to eliminate the influence of increasing habituation that occurred in Year 5 (in parenthesis).

	Bighorn Sheep	**Elk**	**Moose**	**Pronghorn**	**White-tailed Deer**
Total Successful Passages					
Overpasses (*n*=2)	18	89	13	25	4
Underpasses (*n*=5)	12	400	64	198	71
Success Rates					
Overpass Success Rate	100%	78%	87%	100%	100%
Underpass Success	63%	94%	90%	99%	95%
Annual Average Number of Successful Passages by Structure Type					
Overpass	2.3	11.4 (5.2)	1.7	3.2	0.5
Underpass	0.6	20.8 (1.4)	3.3	5.6	3.7

Successful Passages and Success Rates Over Time

In addition to spatial variation in the distribution of ungulate use of crossing structures, the number of successful passages and success rates varied over time (Fig. 4-3). The number of successful passages generally increased for each species year-over-year, although for several species (bighorn sheep, moose and white-tailed deer), the total number of approaches decreased from Year 4 to Year 5. Despite these trends in the total number of approaches and successful passages, success rates for each species remained high each year post construction, with the exception of bighorn sheep. Because of the small number of bighorn sheep each year (annual average of 9.3 approaches post construction), small changes in the number of repel movements had a large impact on success rates. Annual success rates for bighorn sheep ranged from 50% in Year 5 (n=2 approaches) to 100% in Years 2 and 3 (n=2 and n=11 approaches, respectively). Other species with similarly small numbers of total approaches each year, such as moose and white-tailed deer, maintained high success rates (≥83%) each year post construction. Pronghorn success rates were at least 98% each year of the study.

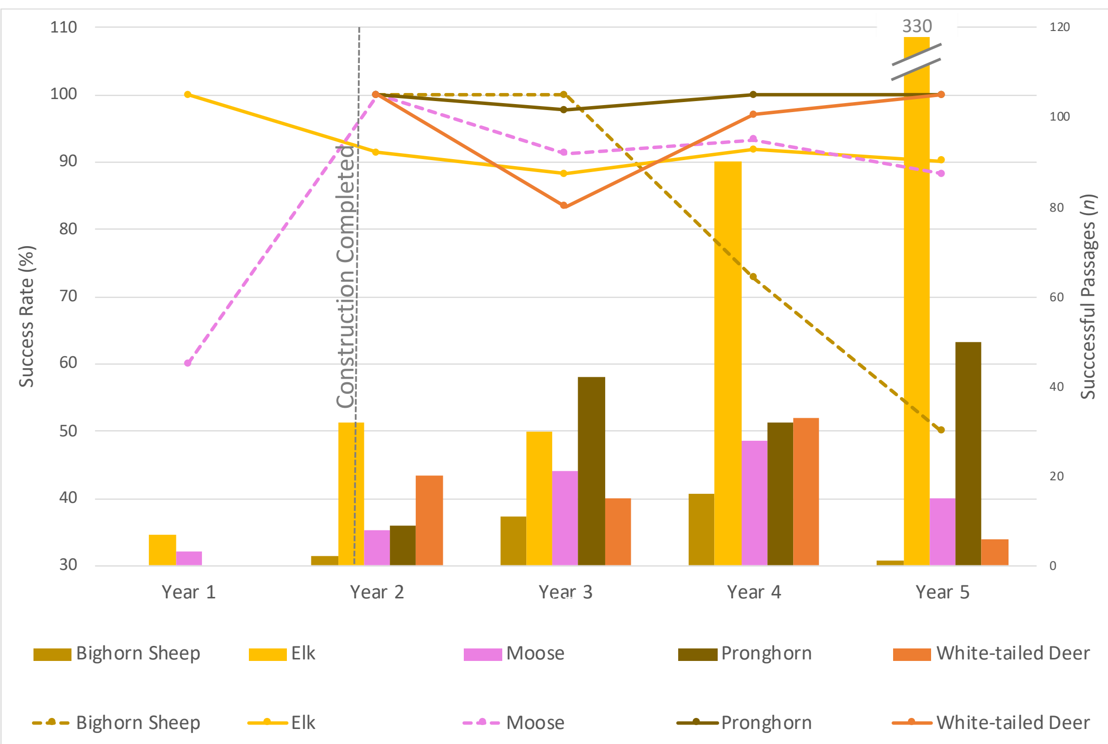

Figure 4-3. Number of successful passages by ungulate species other than mule deer and species success rates at the combined crossing structures each year of the study. Monitoring Year 1 only included the winter season (November – April). Monitoring during the summer months of Year 2 was limited due to ongoing construction at crossing locations in both Phase 1 and Phase 2.

Each ungulate species used both overpasses and underpasses over the course of the study in varying proportions (Fig. 4-4). Elk and moose were the only ungulate species other than mule deer to use the crossing structures in Year 1, which did not include a summer season. In Year 2, following the completion of construction, each ungulate species was observed at both underpasses and overpasses, except pronghorn and white-tailed deer, which were not documented at an overpass until Year 4. Many of these movements by the different ungulate species were by individual animals, pairs, or small family groups. The exception to this was elk in Years 4 and 5, which were increasingly documented in small herds at the North Underpass.

Elk passages at underpasses was greater than at overpasses but this was driven exclusively by movements at the North Underpass by what was presumed to be the same herd making more regular passages. Moose were also more commonly observed at underpasses but movements at both underpasses and overpasses were documented each year of the study, including during the construction phase (Year 1). The majority of pronghorn passages were males (79%) making solo movements or in pairs at underpass structures. Bighorn sheep passages at overpasses were consistently higher than at underpasses, with a 100% success rate at overpasses versus 63% at underpasses, but the total number of sheep passages was small (n=30). White-tailed deer visited the underpasses more than the overpasses and were not observed at all at the two southernmost structures in the study area (Williams Peak Underpass and the South Overpass).

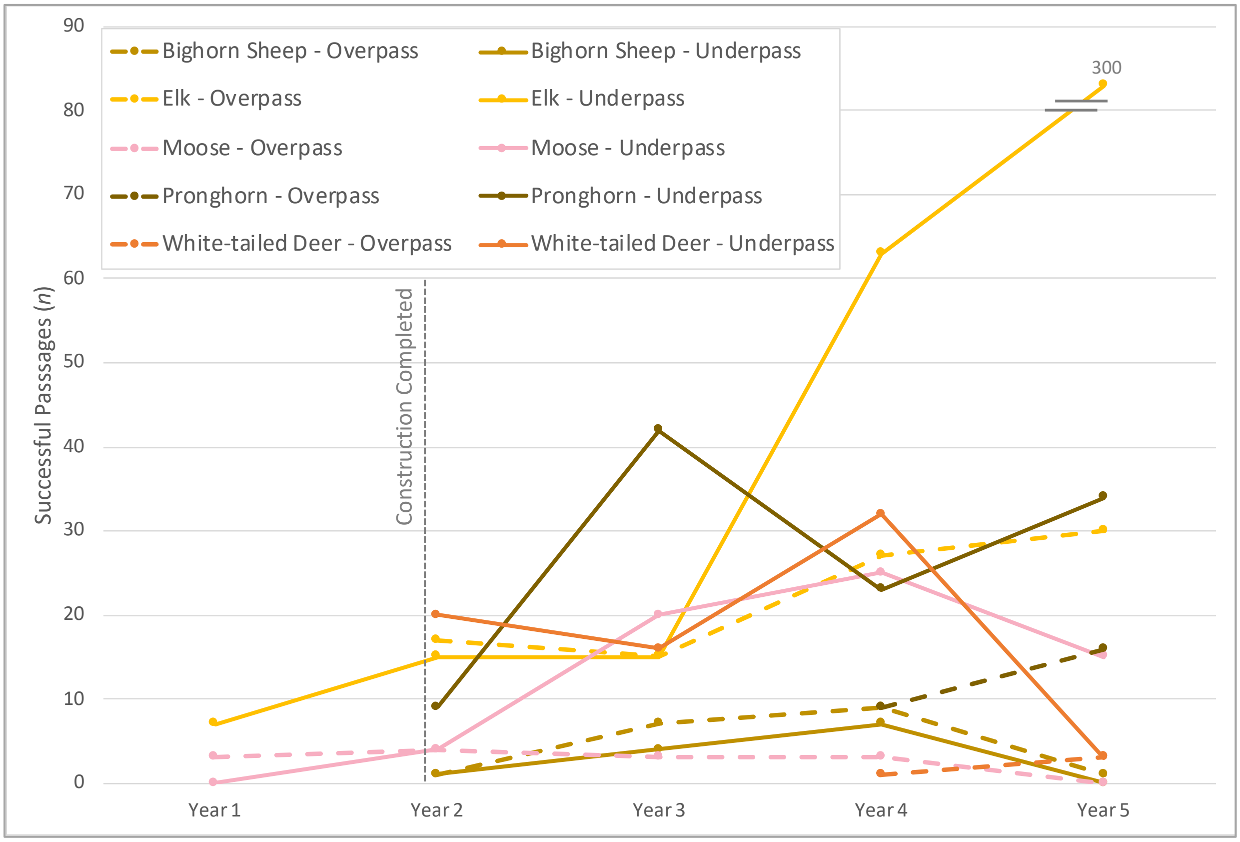

Figure 4-4. Ungulate use of overpasses and underpasses each year of the study.

Crossing Structures Use by Species

Elk

In total, there were 489 successful passages by elk through the crossing structures over the course of the study. The annual number of successful passages by elk were generally low during the first three years of the study and then increased in Years 4 and 5 (Fig. 4-5). In Year 1 there were only 12 successful passages at the crossing structures. By Year 5 there were 330 elk successful passages. The elk success rate increased over time resulting in an average success rate of 91% and a repel rate of 7%. The elk success rate at the combined overpasses was 78% and 94% at the combined underpasses. The majority of elk passages were during the winter months (83%), particularly in the month of February, except in Winter Year 3 when no elk were documented approaching the crossing structures. Elk passages during the summer months remained generally consistent each year of the study (*n*=22-35).

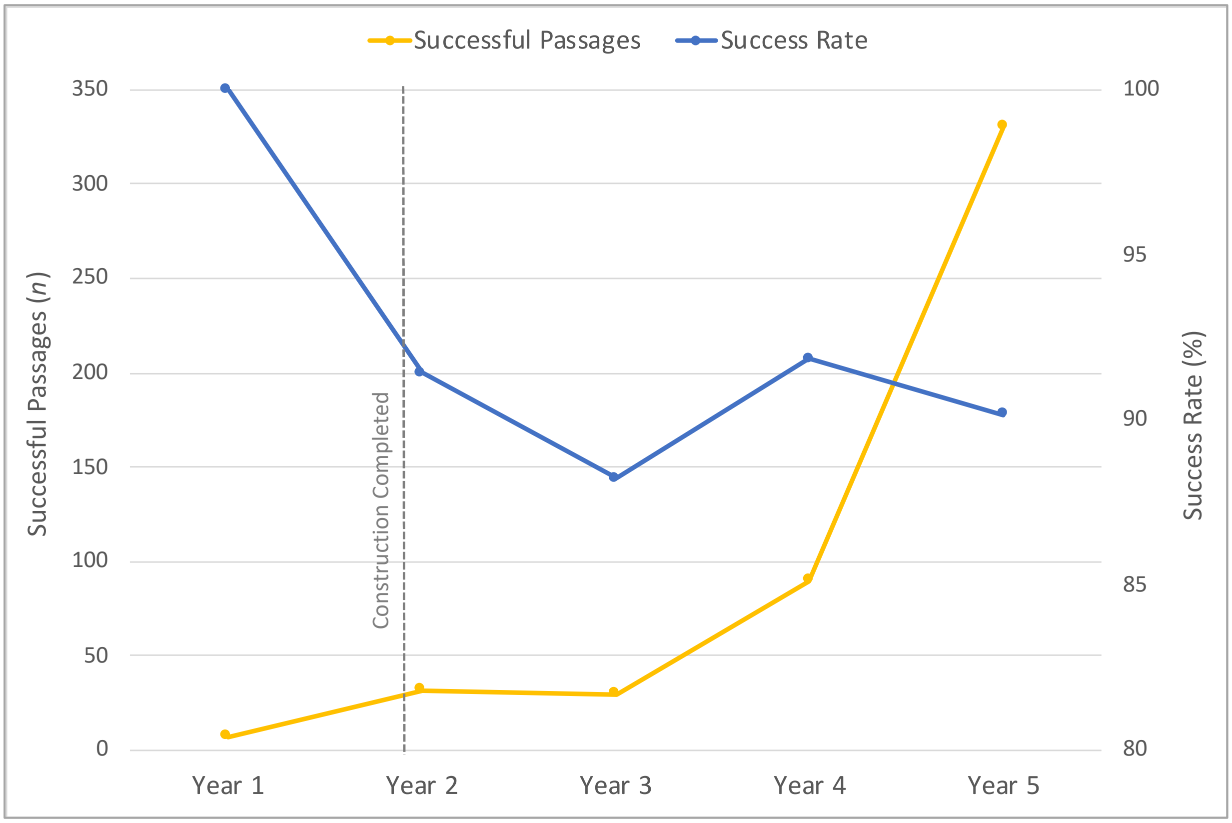

Figure 4-5. Number of successful elk passages and elk success rate at the combined crossing structures each year of the study. Monitoring Year 1 only included the winter season (November – April). Monitoring during the summer months of Year 2 was limited due to ongoing construction at crossing locations in both Phase 1 and Phase 2.

Elk were documented approaching each of the crossing structures but made only one approach to the BVA Underpass and no successful passages at this location. Successful passages occurred at all of the other crossing structures (Fig. 4-6). Success rates at these crossing structures ranged from 55% at the Williams Peak Underpass (*n*=20), where the first elk passage wasn't documented until Year 4, to 99% at the North Underpass (*n*=343). The high number of elk movements at the North Underpass were primarily the result of small herds (likely the same animals) that began increasingly using the underpass in Years 4 and 5. Fifty-seven percent of all successful passages by elk were at the North Underpass in Year 5 (*n*=280). Most elk passages were by cows (*n*=374; 73%) at underpasses and overpasses. Bulls comprised 12% of all elk passages and calves 7%. Eighty-three percent of elk successful passages were at night, dawn, or dusk.

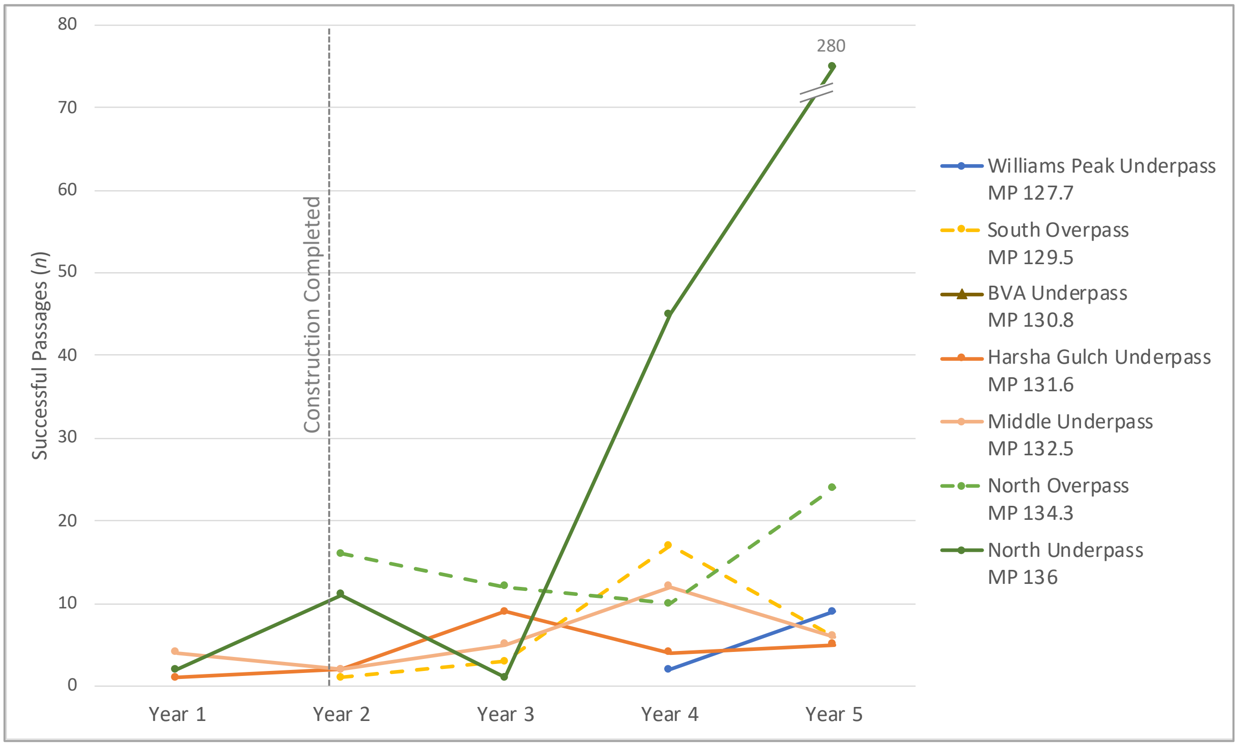

Figure 4-6. Number of successful passages by elk at each crossing structure location over the five-year study period.

Figure 4-7. Deer leading elk through the North Underpass.

Through Year 3, the largest groups of elk to successfully use a crossing structure was five animals. The majority of the 69 successful elk passage during this timeframe were made by solitary animals and pairs. These successful passages were made exclusively by cows and bulls. Year 4 marked the first passages by groups larger than five animals. Initially these herd movements were characterized by multiple crossing attempts over five to ten minutes before all animals finally crossed through the structure successfully. On several occasions, elk and deer movements were intermixed, with some elk only making a successful passage by following the deer through the structure (Fig. 4-7).

Bighorn Sheep

Bighorn sheep made a total of 30 successful passages at the crossing structures with an average success rate of 81%. The success rate for bighorn sheep at overpasses was 100% (*n*=18 approaches) and 63% at underpasses (*n*=19). Bighorn sheep were nearly four times more likely to use an overpass than an underpass, relative to their availability in the landscape. Three locations had success rates of 100% (Middle Underpass, North Overpass, and North Underpass) but these locations also had a small number of total approaches (*n*=1-8). Most bighorn sheep approaches occurred at the southern end of the study area, at the Williams Peak Underpass (*n*=16) and the South Overpass (*n*=10), which had success rates of 63% and 100%, respectively. No bighorn sheep approaches were documented at the BVA Underpass, and only one at the Harsh Gulch Underpass, which resulted in a repel movement.

Figure 4-8. Bighorn sheep band on the North Overpass.

Five of the 16 bighorn events (31%) involved solitary ewes or rams. Seven of the 16 events (44%) involved three or more sheep. Almost all of these small group events included at least one male and one female and, on one occasion, a young lamb (Fig 4-8). Bighorn sheep were equally represented in winter and summer, but the majority of sheep passages occurred during the month of April. All bighorn sheep passages were during the daylight hours.

Moose

Moose approached the crossing structures 83 times, resulting in 75 successful passages and an overall success rate of 90%. Moose were documented using all of the crossing structures except the South Overpass, with success rates ranging from 86% at the Middle Underpass (*n*=22 approaches) to 100% at the Williams Peak Underpass (*n*=2) and the BVA Underpass (*n*=6). The success rate for moose was 87% at overpasses and 90% at underpasses. More successful passages were made at underpasses (*n*=64) than at overpasses (*n*=13). Moose activity was greatest in the northern portions of the study area (Fig 4-9) with the highest number of moose passages at the North Underpass (*n*=26). Moose activity at this location was dominated by cows, often with their young; only one bull moose was recorded here. Successful passages by moose occurred throughout the year but were most common during the summer months, with the majority of successful passages at night, dawn, or dusk (65%).

Figure 4-9. Cow with calf at the North Underpass (left) and bull moose on the North Overpass (right).

Pronghorn

Pronghorn made 133 successful passages out of 134 approaches to the crossing structures. The sole repel movement was recorded at the Harsha Gulch Underpass. The overall success rate for pronghorn was 99%. Pronghorn activity was greatest in the middle to southern portions of the study area, from the South Overpass (MP 129.5) to Harsha Gulch Underpass (MP 131.6). The BVA underpass was by far the most used structure, with 82 successful pronghorn passages. The only crossing structure pronghorn did not approach was the North Underpass. Overall, pronghorn were 1.75 times more likely to use an underpass than an overpass, relative to their availability in the landscape.

Pronghorn used the crossing structures as either solitary animals or in pairs. Seventy-nine percent of all successful passages were made by solitary bucks (Fig. 4-10). No young of the year were recorded using the structures. Pronghorn successful passages occurred only during the months of May through December. Eighty percent of all successful passages by pronghorn were during the daylight hours.

Figure 4-10. Solitary pronghorn buck at the Middle Underpass.

White-tailed Deer

There were 74 successful passages by white-tailed deer out of 78 total approaches to the crossing structures, resulting in a success rate of 95%. White-tailed deer use of the crossing structures was only in the middle and northern portions of the study area. White-tailed deer did not approach the two southernmost crossing locations; nor were they detected in these areas at the habitat cameras or during preconstruction monitoring. The North Underpass had the greatest number of white-tailed deer successful passages (*n*=31). While white-tailed deer tend to prefer riparian areas, only one approach and successful passage was recorded at the existing Colorado River Bridge. A limited number of monitoring days, human activity, or other factors may have influenced the results at this location.

Success rates ranged from 92% at the Harsha Gulch Underpass (*n*=13 approaches) and the Middle Underpass (*n*=12) to 100% at the BVA Underpass (*n*=16) and the North Overpass (*n*=4). The North Overpass was the only overpass structure used by white-tailed deer. The majority of all white-tailed deer passages were at the underpass structures (95%; Fig 4-11). The total number of bucks and does recorded was nearly equal (33 bucks and 32 does) but the vast majority of bucks were documented at the North Underpass. Does were more evenly distributed across the structure locations with the greatest number of does at the BVA Underpass (*n*=11) and Middle Underpass (*n*=9). Most white-tailed deer movements at the crossing structures were by solitary animals or pairs. On several occasions, groups of up to four – and on one occasion a group of 11 animals – were observed crossing through the North Underpass. White-tailed deer successful passages occurred only in May through December. Eighty-nine percent of white-tailed deer successful passages were during the daylight hours.

Figure 4-11. White-tailed deer at the BVA Underpass.

Carnivores and Other Species

Successful Passages and Success Rates by Species

In addition to ungulates, ten large and medium-bodied mammals were documented using the crossing structures, as well as one avian species (wild turkey). Each of these species successfully used the crossing structures on multiple occasions; however, the number of successful passages and the success rates varied by species and among the different crossing structures. Coyote made the greatest number of successful passages at the crossing structures (*n*=3,028). Successful passages by all other species were less numerous, but most species used all or most of the crossing structures, including black bear, bobcat, hare/rabbit (not identified to the species level), mountain lion and raccoon. The number of documented approaches, successful passages, and repel movements for each species and success rate at each crossing structure, small culverts and the Colorado River bridge are presented in Table 4-5. The data are presented by crossing structure, beginning with crossing structures at the lower mileposts and moving northward. Two species were documented using a crossing structure only once: in Year 4, two river otters successfully passed through the North Underpass and a group of six turkeys used the Middle Underpass.

Table 4-5. The number of preconstruction detections, post construction total approaches, successful passages, repel movements, and success rates for non-ungulate species at the wildlife crossing structures, small culverts, and one existing bridge. Dark gray shaded rows are the overpasses; light gray are the underpasses. Preconstruction monitoring was not conducted at the small culverts or the existing bridge.

Structure	Movements and Success Rate	Badger	Black Bear	Bobcat	Coyote	Hare/ Rabbit	Mountain Lion	Raccoon	Red Fox	Skunk
Williams Peak Underpass 127.7	Preconstruction	0	0	0	8	3	0	0	1	0
	Total Approaches	0	2	1	82	4	147	1	32	1
	Success Passages	-	2	0	74	3	145	1	27	1
	Repels	-	0	0	4	0	0	0	1	0
	Success Rate	-	100%	0%	90%	75%	99%	100%	84%	100%
South Overpass MP 129.5	Preconstruction	0	0	1	50	9	0	0	0	0
	Total Approaches	3	1	0	1,133	564	0	3	173	0
	Success Passages	2	1	-	1,108	541	-	2	144	-
	Repels	0	0	-	5	7	-	0	7	-
	Success Rate	67%	100%	-	98%	96%	-	67%	83%	-
BVA Underpass MP 130.8	Preconstruction	0	0	1	8	0	2	0	0	0
	Total Approaches	2	2	16	186	32	1	0	80	0
	Success Passages	1	2	14	179	25	1	-	71	-
	Repels	0	0	0	4	2	0	-	0	-
	Success Rate	100%	100%	88%	96%	78%	100%	-	89%	-
Harsha Gulch Underpass MP 131.6	Preconstruction	1	0	0	3	0	0	1	0	0
	Total Approaches	1	77	62	523	3	1	4	24	0
	Success Passages	1	77	61	512	3	1	4	19	-
	Repels	0	0	0	8	0	0	0	1	-
	Success Rate	100%	100%	98%	98%	100 %	100%	100%	79%	-

Structure	Movements and Success Rate	Badger	Black Bear	Bobcat	Coyote	Hare/ Rabbit	Mountain Lion	Raccoon	Red Fox	Skunk
Middle Underpass MP 132.5	Preconstruction	0	0	0	0	0	0	0	0	0
	Total Approaches	0	163	35	251	11	24	1	26	0
	Success Passages	-	162	30	246	4	24	1	25	-
	Repels	-	1	3	4	0	0	0	0	-
	Success Rate	-	99%	86%	98%	36%	100%	100%	96%	-
BVR Box Culvert MP 133	Total Approaches	1	123	80	159	4	8	1	0	1
	Success Passages	1	117	74	136	1	6	1	-	1
	Repels	0	3	1	12	0	0	0	-	0
	Success Rate	100%	95%	93%	86%	25%	75%	100%	-	100%
BVR Pipe Culvert MP 134.2	Total Approaches	2	9	6	0	0	0	1	9	0
	Success Passages	1	7	6	-	-	-	1	8	-
	Repels	1	1	0	-	-	-	0	0	-
	Success Rate	50%	78%	100%	-	-	-	100%	89%	-
North Overpass MP 134.3	Preconstruction	0	0	0	0	1	0	0	0	0
	Total Approaches	5	3	8	546	25	7	1	25	2
	Success Passages	4	3	3	495	13	7	0	18	2
	Repels	0	0	3	16	5	0	0	2	0
	Success Rate	80%	100%	38%	94%	52%	100%	0%	72%	100%
Culbreath Box Culvert MP 135.1	Total Approaches	0	36	28	22	7	0	3	6	4
	Success Passages	-	35	28	17	1	-	3	6	4
	Repels	-	1	0	0	0	-	0	0	0
	Success Rate	-	96%	100%	77%	14%	-	100%	100%	100%

Structure	Movements and Success Rate	Badger	Black Bear	Bobcat	Coyote	Hare/ Rabbit	Mountain Lion	Raccoon	Red Fox	Skunk
North Underpass MP 136	Preconstruction	0	0	26	10	2	0	0	0	0
	Total Approaches	1	16	26	270	2	4	0	7	1
	Success Passages	1	16	24	261	0	4	-	6	1
	Repels	0	0	0	6	0	0	-	0	0
	Success Rate	100%	100%	92%	97%	0%	100%	-	86%	100%
Colorado River Bridge MP 137	Total Approaches	0	0	9	0	0	2	7	2	2
	Success Passages	-	-	8	-	-	1	7	2	1
	Repels	-	-	1	-	-	1	0	0	0
	Success Rate	-	-	89%	-	-	50%	100%	100%	50%
Total Successful Passages		11	422	248	3,028	591	189	20	326	10
Overall Success Rate		73%	98%	92%	96%	91%	97%	91%	85%	91%

Preconstruction detections of these species were generally low, in part because of their dispersed populations in this landscape, but also because of the limitations of preconstruction camera monitoring, which captured only a small portion of the wildlife activity in the vicinity of the future wildlife crossings. Six non-ungulate species were recorded during preconstruction at the crossing structure locations. At least one individual of every species made a successful passage at each of the crossing locations where they were detected preconstruction, with the exception of bobcat at the South Overpass. Generally, preconstruction monitoring reflected post construction activity at the crossing structures. During preconstruction monitoring, coyote was primarily documented at the South Overpass location, which corresponds with the high number of coyote passages at this location post construction. While bobcat was primarily documented at the North Underpass during preconstruction, this location represented less than 10% of all bobcat passages post construction. Black bear was not documented during preconstruction monitoring.

Success rates were generally high for all of these species. Black bear, bobcat, coyote, hare/rabbit, mountain lion, raccoon, and skunk had average success rates higher than 90%. River otter and turkey both had 100% success rates; however, both species were represented by a small number of individuals, each in a single event. Badger and red fox had the highest parallel rates (20% and 12%, respectively), meaning they didn't always attempt a passage when in the vicinity of a crossing structure. Repel rates for every species were less than 7%.

The magnitude of use varied substantially by species and crossing structure location (Fig. 4-12). While coyote was documented at all of the crossing structures, successful passages by coyote were most common at the South Overpass (MP 129.5), Harsha Gulch Underpass (MP 131.6), and the North Overpass (MP 134.3). Black bear and bobcat passages were most numerous at the Middle Underpass (MP 132.5), the BVR Box Culvert (MP 133.8), and the Harsha Gulch Underpass. Mountain lion passages occurred primarily at the Williams Peak Underpass (MP 127.7), which accounted for 93% of all successful passages by mountain lion.

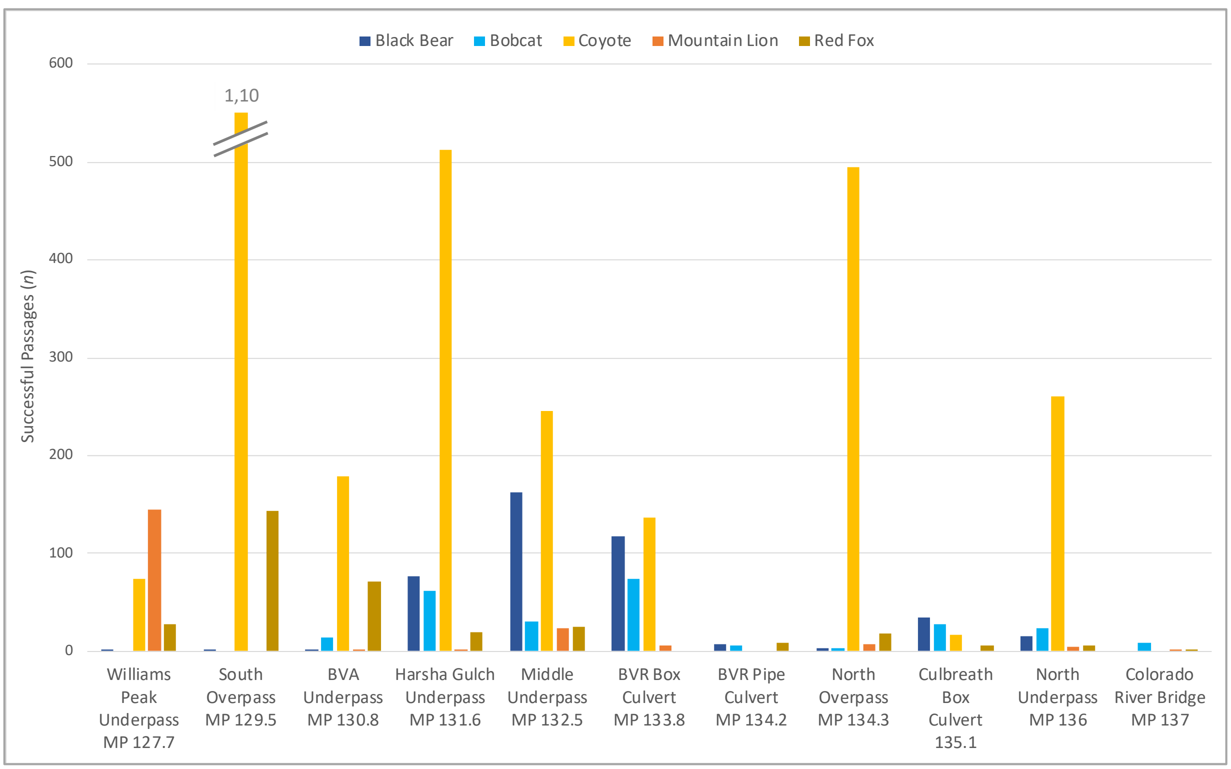

Figure 4-12. Successful passages by black bear, canids, and felids at wildlife crossing structures, small culverts, and the Colorado River Bridge.

Post construction wildlife activity at the habitat cameras generally reflected species' successful passages at each wildlife crossing structure, although species captured by structure and habitat cameras were not necessarily the same individuals. Table 4-6 provides an overview of movement by ten large and medium-bodied species captured at habitat cameras relative to successful passages at the corresponding crossing structure. In only a few instances was a species captured at a habitat camera that was not also documented making a successful passage at the crossing structure. However, these events occurred in low numbers. In general, species passages at the crossing structures were more comprehensively and more frequently documented than species presence at the habitat cameras.

Table 4-6. Comparison of large and medium-bodied mammal species successful passages at wildlife crossing structures and presence at adjacent habitat camera locations. Presence at habitat cameras does not imply that animals were moving to or from a crossing structure. Bolded numbers indicate where a given species was detected by the habitat camera but was not detected at the crossing structure.

Species	Monitoring Location	Williams Peak UP	South OP	BVA UP	Harsha UP	Middle UP	North OP	North UP
Badger	Structure	0	2	1	1	0	4	1
	Habitat	0	0	0	0	**2**	15	0
Black Bear	Structure	2	1	2	77	162	3	16
	Habitat	0	1	0	0	118	7	7
Bobcat	Structure	0	0	14	61	30	3	24
	Habitat	**1**	**1**	0	0	97	7	2
Coyote	Structure	74	1,108	179	512	246	495	261
	Habitat	55	284	42	34	842	872	19
Hare/Rabbit	Structure	3	541	25	3	4	13	0
	Habitat	4	100	0	0	239	22	0
Mountain Lion	Structure	145	0	1	1	24	7	4
	Habitat	21	1	0	0	2	2	1
Raccoon	Structure	1	2	0	4	1	0	0
	Habitat	0	1	0	0	1	0	0

Species	Monitoring Location	Williams Peak UP	South OP	BVA UP	Harsha UP	Middle UP	North OP	North UP
Red Fox	Structure	27	144	71	19	25	18	6
	Habitat	25	45	9	1	6	46	2
Skunk	Structure	1	0	0	0	0	2	1
	Habitat	0	0	0	0	**1**	1	0
Turkey	Structure	0	0	0	0	6	0	0
	Habitat	0	0	0	0	2	0	0

Successful Passages and Success Rates by Structure Type

All of the non-ungulate species, with the exception of those that were documented in only one event, were recorded successfully using the overpass and underpass structures as well as the small culverts. Table 4-7 lists the total number of successful passages by black bear, canids, and felids with respect to structure type (overpass, underpass, or small culvert). In addition, to account for the unequal number of overpasses (*n*=2), underpasses (*n*=5), and small culverts (*n*=3) and the unequal monitoring effort at different locations, this table also presents a comparison of the annual average number of successful passages per day at the three structure types for each species standardized by the number of monitoring days. Black bear and bobcat both used the small culverts most frequently, whereas coyote and red fox were more likely to use an overpass than an underpass structure or a small culvert. Mountain lions were at least nine times more likely to use an underpass than an overpass or a small culvert. Figure 4-13 displays the total number of successful passages by each of these species at the three structure types.

Table 4-7. Successful passages by black bear, canids, and felids at each structure type. The annual average number of successful passages was standardized by the number of active camera monitoring days at the two overpasses and five underpasses.

	Black Bear	**Bobcat**	**Coyote**	**Mountain Lion**	**Red Fox**
Total Successful Passages					
Overpasses (*n*=2)	4	3	1,603	7	162
Underpasses (*n*=5)	259	137	1,272	176	150
Small Culvert (*n*=3)	159	108	153	6	14
Success Rate					
Overpasses	100%	38%	97%	100%	82%
Underpasses	100%	92%	97%	98%	88%
Small Culvert	95%	95%	85%	75%	93%
Annual Average Number of Successful Passages by Structure Type					
Overpass	0.5	0.4	205.7	0.9	20.8
Underpass	13.5	7.1	66.2	9.2	7.8
Small Culvert	25.5	17.3	24.6	1.0	2.2

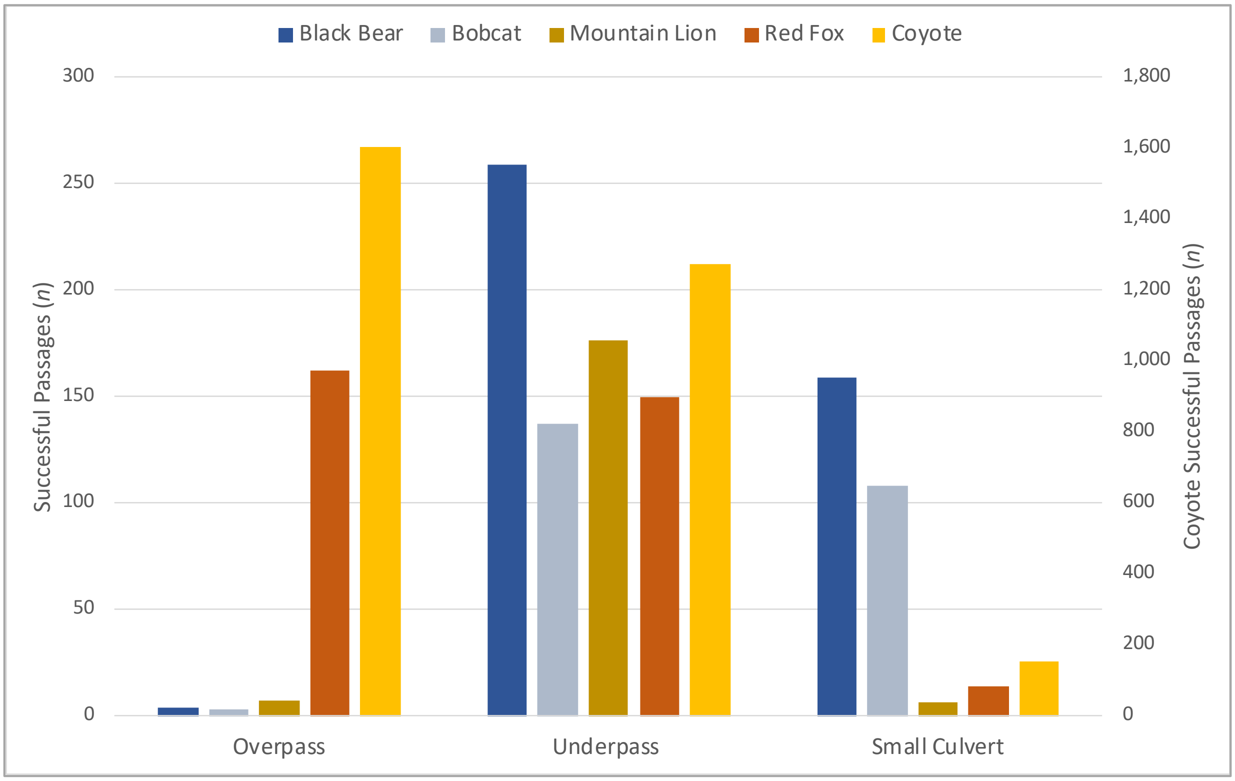

Figure 4-13. Total number of successful passages at overpasses, underpasses, and small culverts by black bear, bobcat, mountain lion, red fox, and coyote. Coyote was plotted on a secondary axis due to the large number of coyote passages.

Successful Passages Over Time

Figure 4-14 presents crossing structure use by different species over time. For most species, crossing structures use generally increased each year with some annual variation. Badger, raccoon, and skunk use of the crossing structures was more sporadic and remained low throughout the study. The number of successful passages by other species, including coyote (not shown), mountain lion, and red fox varied from one year to the next, although coyote use of the crossing structures was high all years post construction. Monitoring cameras were optimized to record movements by larger fauna, and it was likely that movements by small fauna were often missed. Regardless, successful passages by rabbits and hares increased over the study period, particularly at the overpass structures. Two species (river otter and turkey) were only documented in Year 4. Rabbit/Hare passages increased markedly in Years 4 and 5. Much of this activity was at the South Overpass and corresponded with increasing vegetation growth on the overpass.

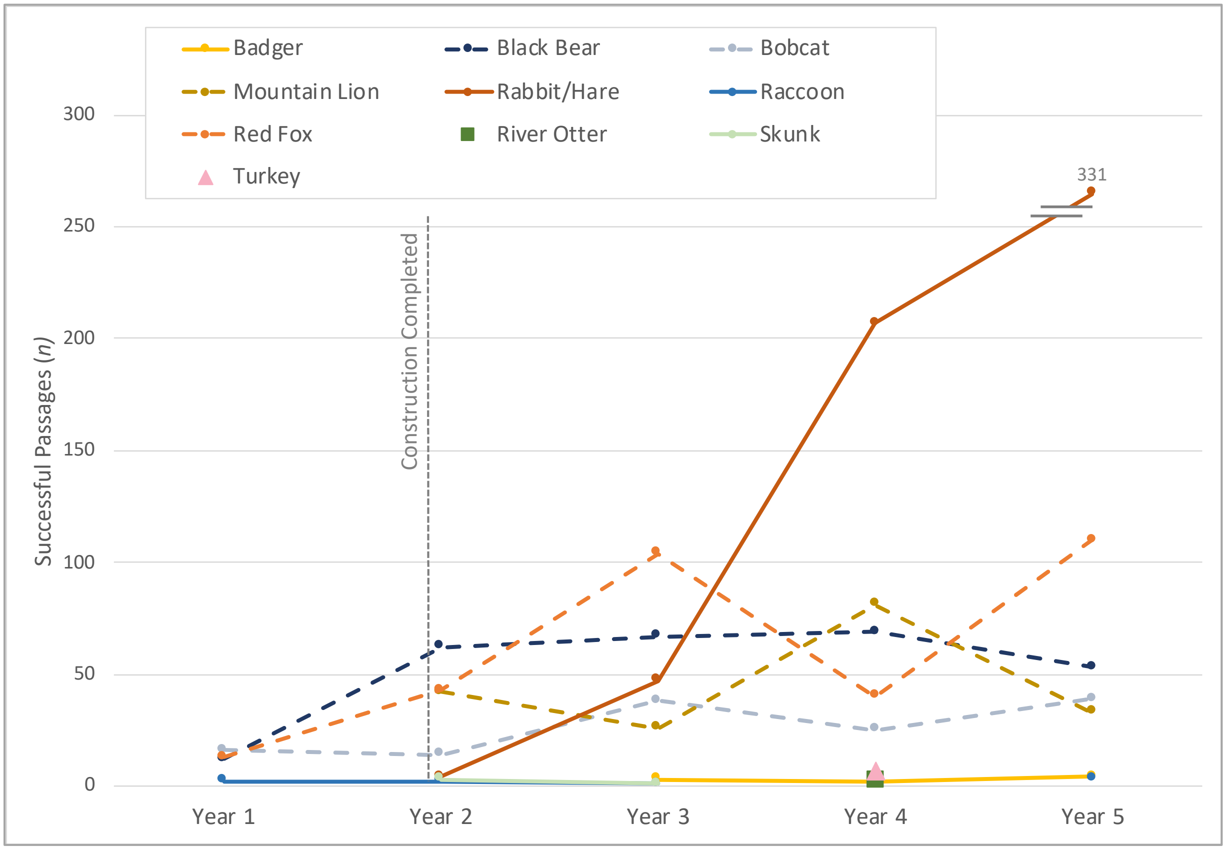

Figure 4-14. Number of successful passages by bears, canids, felids and small fauna at the combined crossing structures, small culverts and the Colorado River Bridge each year of the study. Coyote was excluded from the graph due to the large number of coyotes each year of the study. Monitoring Year 1 only included the winter season (November – April). Monitoring during the summer months of Year 2 was limited due to ongoing construction at crossing locations in both Phase 1 and Phase 2.

Seasonal and diurnal variations in species use of the crossing structures were also evaluated. Black bear, raccoon, and badger were recorded passing under or over SH 9 primarily during the summer months, while mountain lion was almost exclusively recorded during the winter months. Bobcat, coyote, rabbit/hare, and red fox were documented in nearly equal numbers year-round. All of these species, with the exception of river otter and turkey which were only documented on one occasion each, were observed using the crossing structures primarily and, in some cases, almost exclusively during the nighttime hours. Ninety percent or more of all passage events were during nighttime for mountain lion, rabbit/hare, raccoon, and skunk. Black bear passages were nearly evenly distributed between nighttime and daytime, with a small portion occurring during the crepuscular hours.

Factors Influencing Species Diversity at Crossing Structures

The diversity of species at the wildlife crossing structures was calculated based on the data from the last three years of the study (Years 3-5). Species diversity as measured by the Shannon diversity index was highest at the South Overpass (MP 129.5) and the North Underpass (MP 136), and lowest at the BVA Underpass (MP 130.8) and North Overpass (MP 134.3).

The linear regression demonstrated little to no effect between most of the land cover variables (proportion of bare ground [p=0.611], grass [p=0.885], brush [p=0.235], or trees [p>0.999]) and the species diversity at the structure locations. The ANOVA demonstrated there did not appear to be an effect of distance to ephemeral drainage (p=0.982) or an effect of distance to human disturbance on the species diversity (p=0.390).

Linear regression of the effect of the slope at the underpass approaches indicated there was some influence on species diversity (p=0.070). However, results were influenced by the BVA underpass' small approach value which had high leverage on the analysis. The pattern cannot be construed as compelling evidence of a relationship between approach slope and species diversity. The presence of a drainage trough did not influence species diversity (p=0.165).

Analysis of variance on the effect of structure type on species diversity found the means were not different from one another (p=0.901) and there was no evidence of a relationship between structure type and species diversity. The diversity index values were varied within the overpass and underpass categories. The North Overpass was one of the structures with the highest species diversity, while the South Overpass had the lowest species diversity. No strong trend could be determined between the two structure types.

Species diversity at the seven wildlife crossing structures was varied, but not varied enough or with consistent trends to detect how the diversity may have been affected by landscape or structural variables. The number of structures limited the ability of statistical modeling to discern clear distinctions as to the causes of the differences in diversity at the seven locations.

DISCUSSION

This discussion addresses three topics: 1) the evaluation of how well the wildlife mitigation met the performance measures for ungulates other than mule deer and for carnivores; 2) patterns observed in elk use of the crossing structures; and 3) the effectiveness of the crossing structures for other ungulates and meso to large carnivores.

Performance Measures Evaluation

Sixteen species other than mule deer were documented using the crossing structures. Most of the performance measures defined at the outset of the research for elk and other species were met or exceeded (Table 4-8). One performance measure was not met. The following subsections discuss the nuance in interpreting these results relative to each performance measures.

Table 4-8. Performance measures evaluation for other ungulates and carnivores. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
Elk success rates at each structure will be a minimum of 60% and have a goal of 75% success during the final year of the study.	✔	
Success rates for all meso to large mammal species (other than deer and elk) detected at 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.	✔	
By the end of the study, bull and cow elk passages through all crossing structures will be in the same proportion of bulls and cows estimated for the local population.		(✔)

Performance Measure	Met	Not Met
By the end of the study, the number of successful elk passages at all structures annually, will be at least 50% of the number of elk movements captured at associated habitat cameras (animals documented in the vicinity of the structures, but not necessarily using structures), irrespective of season.	✔	
Each year there will be an increase in the number of successful elk passages at wildlife crossing structures annually until an overall equilibrium/plateau is reached.	(✔)	
Each year, there will be at least one to several successful passages at the 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, mountain lion, black bear, bobcat, and other species.	✔	

Elk Success Rate

The annual post construction success rate for elk ranged between 88% to 92% with an average success rate of 91%, exceeding the goal of a 75% success rate by the final year of the study. These success rates are higher than what has been documented in other studies (e.g., Cramer 2012, Gagnon et al. 2011).

Success rates for Meso to Large Mammal Species other than Mule Deer and Elk

Success rates for all meso to large mammal species other than mule deer and elk were greater than the minimum goal of 60% and, for all species except badger, were greater than the goal of 80%. Among ungulate species, bighorn sheep had the lowest success rate at 81%; all other ungulates had success rates greater than 90%. Among non-ungulate species, success rates ranged from 73% for badger (*n*=11 successful passages) to 98% for black bear (*n*=422).

Proportion of Bull to Cow Elk

Bull and cow successful passages were drawn from February counts to compare bulls' use of the crossing structure to the gender ratio of the CPW post-hunt population, which is estimated around the end January and beginning of February. In February of the final year of the study, the proportion of bulls successfully using the crossing structures relative to cows was 5%. All of the bulls recorded during this timeframe were young bulls travelling in cow and calf groups. The proportion of bulls documented at the crossing structures was much lower than the estimated proportion of bulls in the 2019 post-hunt population (41.4 bulls per 100 cows; 29% bulls and 77% cows; B. Lamont, personal communication).

This performance measure may not have been an achievable goal for this study. Elk are known to show strong segregation between genders during this time of year. Whereas cows, calves, and young bulls tend to travel together in large groups, mature bulls often form bachelor groups that often reside in isolated, mid-elevation zones and move very little during winter months. Thus, the relative infrequent use of crossing structures by mature bull elk during winter was not surprising. Few bull elk were observed at the habitat cameras adjacent to the crossing structures, and very few mature bulls were observed in this study. In addition, the lack of preconstruction elk movements across SH 9 was evidenced by the small number of elk WVC in the preconstruction data, lending further evidence that most elk movements are not east-west across the highway. In Year 5, young bulls were increasingly included in herd level movements at the North Underpass.

Proportion of Elk at Habitat Cameras Relative to Successful Passages

By the final year of the study, there were nearly two times more successful elk passages at the crossing structures than were documented by the habitat cameras, but this activity was not evenly distributed across all of the crossing structure locations. At five of the crossing structures the number of successful elk passages was at least 75% that of the activity observed at the habitat cameras. But at two locations (BVA Underpass and Harsha Gulch Underpass), the number of elk at the habitat cameras surpassed the number of passages at the crossing structures. In Year 5, elk approached the BVA Underpass on only one occasion and no successful passages were made. Elk were documented in small numbers (*n*=1-7) at the adjacent habitat camera, indicating some elk presence in the vicinity of the structure. Elk approached the Harsha Gulch Underpass seven times in Year 5 with a success rate of 71% but were documented at the habitat cameras 16 times. The low number of approaches and the absence of elk from preconstruction monitoring at these two locations suggests that, in general, elk were not attempting to use these crossing structures and elk activity at the habitat cameras may have been the result of north-south movements parallel to the highway.

Increase in Elk Passages

Following the completion of construction, the number of elk passages was fairly constant in Years 2 and 3 (*n*=32 and *n*=30, respectively). During this timeframe, elk passages were made by solitary animals, pairs, or groups of up to five animals. These patterns began to shift in Year 4, when larger groups began to attempt crossing at the North Underpass. These herd movements involved multiple crossing attempts over five to ten minutes but, ultimately, resulted in all of the animals making a successful passage. This initial reluctance decreased in Year 5, as hesitation behavior decreased, and the total number of successful passages increased from 45 in Year 4 to 280 in Year 5. These movements were likely made by the same herd in the northern portion of the study area and reflected increasing habituation to the crossing structure. A plateau in elk passages at this location or other crossing structure locations was not observed during the timeframe of this study. Considering the longer adaptation periods required for elk use of crossing structures (Gagnon et al. 2011), it may be several more years before a plateau is reached; or, due to the distribution of elk in the study area relative to the crossing structures, a plateau may never be reached.

Annual increases in the number of elk passages were also observed at the North Overpass, where a total of 24 successful passages were documented in Year 5. Elsewhere, elk activity remained low in Year 5 with less than ten passages at each of the other crossing structures, although some annual variation was observed from Year 4 to Year 5.

Annual Passages by Other Ungulates and Carnivores

The purpose of the habitat cameras was to ensure that the crossing structures were successful in facilitating cross-highway movements by the species documented in the vicinity of the structures. In almost all cases, ungulate (bighorn sheep, moose, pronghorn, and white-tailed deer) and carnivore (black bear, bobcat, coyote, mountain lion, and red fox) presence documented by habitat cameras was also reflected in successful passages by these species at the associated crossing structure. Given that the habitat cameras are only able to capture a portion of the wildlife activity occurring in the vicinity of a structure, the annual capture rates at the habitat cameras were not always reflected at the crossing structures and vice versa. The only species documented at a habitat camera that were not recorded using the corresponding crossing structure were moose at the South Overpass and bobcat at the Williams Peak Underpass and the South Overpass. In each case, the species was recorded only once at the habitat cameras. In only one case was a species (bobcat) also documented approaching the crossing structure (Williams Peak), though this approach was a parallel movement. Notably, movements documented by the habitat cameras may be by individuals moving parallel to the highway (north-south) as well as by individuals approaching or coming from the highway (east-west).

What Patterns Were Observed in Elk Use of Crossing Structures?

Limited data precluded statistical analysis of structural and landscape variables that may have influenced elk use of crossing structures. The discussion of factors influencing elk use of crossing structures is based on comparative analyses and a general understanding of elk movements in the study area. Wintering elk in the Blue River Valley appear to make fewer cross-highway movements than mule deer, primarily remaining on one side of the highway or the other, particularly among mature bull elk.

Elk activity was unevenly distributed throughout the study area. Elk successful passages were most common in the northern portions of the study area (North Overpass and North Underpass) each year post construction. Only one elk approach and no elk passages were recorded at the BVA Underpass, although the crossing structures to the north (Harsha Gulch Underpass) and south (South Overpass) both had 20 or more elk passages post construction with success rates of 84 and 90%, respectively. Elk passages were also documented at the Middle Underpass but no passages were recorded at the Williams Peak Underpass until Year 4. Elk success rates also varied across the crossing structure locations, ranging from 55% at the Williams Peak Underpass to 99% at the North Underpass.

In contrast to these post construction findings, preconstruction data revealed that most elk activity was around the Williams Peak Underpass (*n*=41) and the South Overpass (*n*=25). Much of this activity appeared to be by elk on the east side of SH 9 that foraged near the highway but did not appear to attempt crossing. The only other preconstruction detection was a single elk at the North Underpass. In addition to the inherent limitations of preconstruction camera monitoring, the lack of preconstruction detections may also reflect road avoidance behavior (Frair et al. 2008). However, the question remains with regards to the lack of post construction movements of elk detected in the vicinity of the Williams Peak Underpass (*n*=20) compared to higher preconstruction numbers. Elk in this portion of the study area may have moved farther from the roadway and are only beginning to learn to use the crossing structure (*n*=2 in Year 4; *n*=9 in Year 5). It is also possible that these animals moved farther south towards the fence end, where elk were documented on the east side of the highway on multiple occasions attempting to cross the highway at-grade or entering into the fenced right-of-way (Chapter 7).

In the northern portion of the study area, elk activity at the North Underpass jumped from 46 approaches in Year 4 to 282 approaches in Year 5. Although sometimes multiple attempts were required before the passages were completed, almost all of these approaches resulted in successful passages. In several events, elk were observed successfully following mule deer through the underpass after several failed attempts. These interspecies interactions with mule deer leading other, more wary ungulates through a crossing structure has also been documented in Utah (Cramer 2014) and Wyoming (Seidler et al. 2018). This increase in elk passages at the North Underpass in the final Year of the study indicates a growing familiarity with the crossing structure by elk in this portion of the study area. In February 2020, a small herd was observed making several back and forth passages through the underpass, sometimes multiple passages in a day. No elk passages were documented at the nearby Colorado River Bridge, an existing bridge located one mile to the north. While camera monitoring occurred only in Year 3, there was also frequent human recreational activity at this location.

Elk used both the overpasses and underpass successfully, although the success rate at underpasses was higher (94%) than at the overpasses (78%). Analysis of elk use of underpasses versus overpasses was skewed by the increasing habituation to the North Underpass by a herd in this portion of the study area. In a revised analysis omitting Year 5 data to eliminate the influence of habituation on elk use of the two crossing structures type, elk were nearly four times more likely to use an overpass than an underpass (an annual average of 5.2 passages at overpasses versus 1.4 passages at underpasses). A preference by elk for overpasses or large span bridges has been documented in other studies (e.g., Gagnon et al. 2011, Huijser et al. 2016). However, the observed habituation to the North Underpass in Year 5 suggests that these initial preferences may be overcome in time through increased familiarization.

This research could not evaluate the importance of structural versus landscape characteristics on elk use of crossing structures, and it is likely that both are influential (Clevenger and Waltho 2005, Gagnon et al. 2011). Both crossing structure types on SH 9 appear to be suitable for successful elk passages, although the underpasses may require a longer period for animals to adjust to the structures. Landscape variables that influence the distribution of elk on winter range also appear to affect elk use of the crossing structures. Seventeen years of monitoring in Banff, Canada found that a preference by elk for structures with greater openness (overpasses and large span underpasses) decreased slightly over time (Clevenger and Barrueto 2014).

Other Species Use of Crossing Structures

Road ecology research documents a number of species-specific preferences regarding the design of wildlife crossing structures and structure type preferences, but many gaps remain in the knowledgebase. While limited data for less common species in the SH 9 study area precluded statistical analysis of structural and landscape variables that may have influenced other species use of crossing structures, comparative analyses and a general understanding of these species' distributions in the study area helped to elucidate species-specific preferences for the overpasses versus the underpasses on SH 9.

Ungulates

Bighorn Sheep

Bighorn sheep were nearly four times more likely to use an overpass than an underpass, relative to their availability in the landscape. A preference for overpasses was further substantiated by the 100% success rate at overpasses, compared to 63% at underpasses, and the use of the overpasses by small bands including both rams and ewes and, in one event, a lamb. These results are consistent with research on US 93 in northern Arizona investigating wildlife crossing structure use by desert bighorn sheep (Gagnon et al. 2017). Unlike the small bighorn sheep population in the SH 9 study area, this portion of US 93 bisects one of Arizona's largest bighorn sheep populations and monitoring documented over 6,000 approaches to the crossing structures. Ninety percent of all bighorn sheep successful passages were at overpass structures (50' and 100' wide) with a success rate of 90%.

Moose

Moose used the underpasses nearly twice as much as the overpasses, relative to their availability in the landscape, and was not recorded using the South Overpass at all. In Montana, moose were more likely to use an overpass than bridges or large culverts (Huijser et al. 2016); however, it's uncertain whether this was due to structure type or other landscape variables influencing the distribution of moose in that study area. In Banff, Clevenger and Barrueto (2014) reported that moose had high fidelity to a few crossing structures in proximity to favored habitat.

Pronghorn

Pronghorn successfully used both overpasses (*n*=25; 100% success rate) and underpasses (*n*=198; 99%) in this study. Only one pronghorn repel movement was documented (Harsha Gulch Underpass, Year 3). Overall, pronghorn were 1.75 times more likely to use an underpass than an overpass. These patterns in pronghorn use of overpasses versus underpasses differ from what has been reported elsewhere. In Arizona, Theimer et al. (2012) concluded that pronghorn was hesitant to use anything but the most open bridge underpasses or overpasses. Research in Wyoming documented a strong-species specific preference for overpasses by migratory pronghorn (Sawyer et al. 2016) and a reluctance to use underpasses (Sawyer and Rudd 2005, Sawyer et al. 2016). Yet, pronghorn use of underpasses is not entirely unprecedented. In southwest Wyoming wintering pronghorn were documented using an underpass without hesitation with a success rate of 79% (*n*=89; Plumb et al. 2003). This study documented movements by individuals and groups up to 57 animals, although the authors noted that pronghorn use of the underpass was small relative to the local population size.

Collectively, these findings suggest differences in individual and population level tolerances for different crossing structure types. Crossing structure design considerations may vary depending on the location of the mitigation project (e.g., along a migratory route or within a seasonal home range) and the urgency of the need for cross-highway connectivity. Successful use of the crossing structures on SH 9 to date indicate incidental or opportunistic use of both overpasses and underpasses primarily by bucks in summer range. Over a longer period of time, these tolerances could grow, such that small herds or does with their young may also begin to use the crossing structures (e.g., Seidler et al. 2018).

White-tailed Deer

Bucks and does used the crossing structures in nearly equal numbers (*n*=33 buck successful passages; *n*=32 does). However, buck and doe use of the crossing structures was not evenly distributed. At the North Underpass, almost all successful passages were by bucks (81%), but at all other structures used by this species, does (65%) outnumbered bucks. Overall, white-tailed deer used the underpasses seven times more than the overpasses, relative to their availability in the landscape.

Carnivores

Black Bear

Black bear was one of the only species documented making successful passages at all of the crossing structures and all of the small culverts. The majority of black bear successful passages were at the Middle Underpass (*n*=162), which was the only crossing structure location with riparian cover (trees and shrubs) immediately adjacent to both structure entrances. While associations with vegetation cover were not borne out through statistical analysis, the presence of riparian cover in this sagebrush dominated landscape was a likely factor in the high number of bear approaches and successful passages observed at this location.

Black bear was most likely to use a small culvert or an underpass (Fig. 4-15), with few approaches and successful passages documented at either of the overpasses. These findings are corroborated by research in other locations, which have documented black bear use of a variety of underpass types (Huijser et al. 2016) with a preference for more constricted crossing structures (Clevenger and Waltho 2005, Clevenger and Barrueto 2014). While grizzly bear was also present in these other study areas, even with the absence of this competitor in the SH 9 study area, black bear demonstrated strong preference for the more constricted culverts (7.5-8 foot wide and high).

Figure 4-15. Black bear at the Middle Underpass (top) and the BVR Box Culvert (bottom).

Several studies have documented a learning curve for black bear, in which crossing structure use increases after five or more years (Huijser et al. 2016, Clevenger and Barrueto 2014). Since the completion of construction on SH 9, bear successful passages have remained fairly stable each year of the study (range=53-69). It is possible that bear movements may remain steady or they may grow over a longer timeframe, as has been observed elsewhere.

Bobcat

Figure 4-16. Bobcat entering the BVR box culvert.

Bobcat used five of the seven wildlife crossing structures, all three small culverts, and the Colorado River Bridge. Bobcat passages were most numerous at the BVR Box Culvert (MP 133; Fig. 4-16) and the Harsha Gulch Underpass (MP 131.6). Other monitoring studies have also documented bobcat using a variety of structure types (Cramer 2014, Huijser 2016). On SH 9, bobcat was infrequently observed using an overpass (*n*=3) and was twice as likely to use a small culvert over an underpass. Elsewhere in Colorado, Singer et al. (2011) documented bobcat crossing through drainage culverts, including ones that were partially filled with sediment.

Coyote

Figure 4-17. Coyote on the South Overpass.

Coyote was the most frequent visitor to the crossing structures other than mule deer, averaging a successful passage every three days. Much of this activity was at the South Overpass (MP 129.5; Fig. 4-17). At all of the crossing structure locations, it appeared that regular passages were made by the same individuals who had incorporated the crossing structure into their home ranges, although this could not be confirmed. Coyote passages increased each year of the study, peaking in Year 4, and decreasing again slightly in Year 5. While habituation and frequent passages by the same individuals was a likely contributor to the increase in coyote passages over time, it is unknown why the number of passages decreased in Year 5. Coyote was documented at all three structure types but were most commonly documented at the overpass structures. In Banff, Clevenger and Barrueto (2014) did not find a preference for overpasses or underpasses in either their shorter term (2 and 4 year) models or the long-term model (16 years).

Mountain Lion

Mountain lions used the underpasses ten times more than the overpasses and nine times more than the small culverts relative their availability in the landscape and the number of monitoring days at each structure type (Fig. 4-18). This finding was inevitably influenced by the high number of passages at the Williams Peak Underpass relative to all other crossing structure and small culvert locations. Other research has reported a preference by mountain lions for more constricted crossing structures (Clevenger and Waltho 2005). Other variables, such as proximity to cover (Clevenger and Waltho 2005) was an unlikely factor influencing mountain lion use of the Williams Peak Underpass, as this structure was surrounded by sagebrush habitat with little other cover nearby. Unsurprisingly, mountain lion activity at the crossing structures was greatest during the winter months, which was also the period of greatest mule deer abundance.

Figure 4-18. Mountain lion at the Middle Underpass.

Red Fox

Red fox made successful passages at all of the crossing structures and most of the small culverts but was more than twice as likely to use an overpass than an underpass, and nine times more likely to use an overpass than a small culvert (Fig. 4-19). The factors influencing red fox use of the crossing structures could not be determined in this study. Research in other locations has documented red fox using a variety of structure types and sizes with good visibility including bridges (Singer et al. 2011) and culverts (Cramer et al. 2014) and were not dissuaded by longer culverts (Sparks and Gates 2012).

Figure 4-19. Red fox with prey at the BVA Underpass

How Effective Were the Crossing Structures in Providing Connectivity for Other Ungulates and Meso to Large Carnivores?

The extent to which the wildlife crossing structures mitigation provides connectivity for the diversity of species documented was assessed relative to functional connectivity. Functional connectivity is defined as the degree to which landscapes (including the transportation mitigation) increase the movement of genetic, organism, or population flows through the landscape within a mosaic of habitat type and uses (Hilty et al. 2006, Taylor et al. 2006). The purpose of highway mitigation is to support movements by all individuals in a population and to preserve genetic connectivity between populations.

Preconstruction photos of wildlife in the vicinity of the roadway at the future crossing structure locations can help in identifying the species that may be impacted by habitat fragmentation and the barrier effect of the highway, and their distribution across the study area. These data can then be compared with post construction data to determine whether the animals present preconstruction successfully used the structures at those locations. Preconstruction data on species other than mule deer was minimal relative to the post construction data at the crossing structures for each of these species. Preconstruction camera monitoring documented a variety of species movements close to the highway, but it was impossible to determine the frequency of cross-highway movements. Nor are these species reflected in preconstruction wildlife-vehicle collision data, with the exception of a limited number of elk (Chapter 8). It is reasonable to assume that these species did occasionally cross SH 9 prior to mitigation construction but were not involved in collisions because of small population sizes and, potentially, more cautious road crossing behavior (Frair et al. 2008, Montgomery et al. 2012). Overall, the ungulate and meso to large mammal species detected at each preconstruction crossing structure location were also documented making successful passages at the crossing structure locations where they had been documented preconstruction with few exceptions.

Post construction, all of the ungulate (bighorn sheep, elk, moose, pronghorn, and white-tailed deer) and meso to large carnivore species (black bear, bobcat, coyote, mountain lion, and red fox) present in the study area used the crossing structures each year of the study. All of these species were documented successfully using the crossing structures each year post construction with success rates of at least 80% for bighorn sheep and red fox, and greater than 90% for all other ungulate and carnivore species. While the number of passages by these species was much lower than mule deer (Chapter 3), less frequent passages are to be expected given smaller population sizes and less defined need for cross-highway movements when compared to wintering mule deer in the Blue River valley. The consistent nature of these species' successful passages through the crossing structures over the course of the study, combined with high success rates each year of the study, suggests that the mitigation provided, at a minimum, a base level of genetic connectivity for all of the species documented pre- and post construction.

The effectiveness of the crossing structures in providing population level connectivity varied by species in this study. These findings are discussed below for each of the ungulate and meso and large carnivore species in the context of this study area and compared to findings in other areas.

Ungulates

Bighorn Sheep

Bighorn sheep was the most infrequently documented of the ungulate species, yet both rams (n=10) and ewes (n=18) successfully used the crossing structures. In one event, a band composed of a ram, an ewe, a yearling, and a lamb successfully passed over the North Overpass. Successful passages at underpasses were exclusively by lone individuals; at overpasses, both individuals and groups made successful passages.

The mitigation provided some population connectivity with a mix of rams and ewes successfully using the crossing structures, but only one lamb. The overall low number of bighorn sheep successful passages are a reflection of limited bighorn sheep habitat and the small overall bighorn sheep population in the Blue River Valley.

Elk

Bulls, cows and calves were all documented making successful passages at the crossing structures. As described previously, much of the elk movement in the study area was at a distance from the highway rather than across SH 9. Still, elk successful passages at the crossing structures increased over time, particularly in Years 4-5. Both bulls and cows were documented making successful passages, although bulls were in much smaller numbers (8% across all years) and appeared to be younger bulls rather than mature adults. These results indicate that the crossing structures provided some population level connectivity for elk, with the potential for greater connectivity as elk continue to adapt to the crossing structures. Full population-level connectivity may be unrealistic if mature bulls do not use this portion of the landscape.

Moose

Moose are sparsely distributed in this landscape with most movements by solo bulls or cows or cows with calves. These patterns are typical of moose populations in the wild, in which bulls are solitary and cows are either in pairs or with their calves. Similar patterns were observed at the crossing structures, where bulls, cows and calves were documented using the structures. These results indicate that the mitigation provides population connectivity for moose in this landscape.

Pronghorn

Pronghorn successful passages were limited to individual animals or pairs of adult animals. Both the underpasses and overpasses worked well for solitary bucks and a small number of doe pronghorn (99% success rate). But because 79% of all successful passages were made by solitary bucks, this high success rate should be taken with caution, as these numbers did not represent genders and ages of the entire population. Based on information from CPW, pronghorn populations in the Blue River valley are primarily west of SH 9, which may explain the small number of does that used the crossing structures and a complete lack of use by fawns during the study timeframe.

White-tailed Deer

Most white-tailed deer movements were by solitary animals or pairs, with occasional movements by groups of up to five animals. These results corroborate local knowledge that the distribution of white-tailed deer in the study area is concentrated in river bottoms such as the Colorado River and the Blue River. As such, the lack of use of the southernmost crossing structures by white-tailed deer was likely driven by the lack of white-tailed deer habitat in those areas, as opposed to avoidance of the crossing structures themselves.

Carnivores

For carnivores, visually differentiating between males and females is difficult if not impossible from camera data, except where a female was documented with her young. Demographic connectivity for these species cannot be ascertained through camera monitoring though it may be assumed that the wildlife crossing provided some population connectivity for those species who were documented with their young (black bear, coyote, and mountain lion).

In Summary

The focus of the SH 9 mitigation project was to provide connectivity for wintering mule deer across SH 9 and to reduce WVC, yet this study also demonstrated the value of the mitigation for a number of other species, including year-round and seasonal animals (Fig. 4-20). While the total number of successful passages by these other species was much lower than for mule deer, success rates were high (80% or greater) for nearly every species documented, and all species showed stable or increasing crossing structure use during the five-year study period. The multispecies benefits of the mitigation were revealed through comprehensive year-round monitoring over multiple years. Monitoring research in other locations emphasizes the need for long-term studies to fully capture different species adaptation rates to wildlife crossings (Clevenger and Barrueto 2014, Gagnon et al. 2011). Ongoing variability and increasing passage rates by many species in this study suggests that wildlife was still adapting to the mitigation and patterns in wildlife use of the crossing structures may continue to evolve over time.

Figure 4-20. Two river otters (left) crossing through the North Underpass and five of six turkeys (right) crossing through the Middle Underpass.

Chapter 5. Wildlife Guards

RESULTS

Cameras recorded a total of 1,866 approaches at the 12 monitored wildlife guard locations. Five locations were round bar guards (two of which replaced flat bar guards after Year 1), five were flat bar guards, and two were flat bar guards with a pedestrian grate (Fig. 5-1). Cameras also documented parallel movements by individuals that walked in front of but ignored the guards, although these movements were likely underrepresented as the camera positions were optimized to capture breach and repel movements.

Figure 5-1. Mule deer approaching a flat bar guard (top left), a round bar guard (top right), and a flat bar guard with a pedestrian grate (bottom left).

Overall, the wildlife guards deterred animals with hooved feet (ungulates) 81% of the time (*n*=1,135 repels). Animals with padded feet, bears, canids, and felids, were deterred 15% of the time (*n*=69 repels). The vast majority of approaches to the wildlife guards were made by mule deer. Other species that approached the guards in order of frequency included red fox, coyote, elk, moose, bobcat, white-tailed deer, black bear, bighorn sheep, pronghorn, and mountain lion.

Activity by Species and Location

Mule deer were the only species to visit all of the deer guards and made the greatest number of approaches to the guards (Table 5-1). Elk, while less frequent visitors to the guards, approached all of the guards except the Shaw guard. Of the carnivore species, red fox was the most common visitor to the guards. All other species made infrequent approaches to a more limited number of guards.

Table 5-1. Total number of approaches to the wildlife guards by large mammals

Wildlife Guard Name	Bighorn Sheep	Black Bear	Bobcat	Coyote	Elk	Moose	Mule Deer	Pronghorn	Red Fox	White-tailed Deer
Spring Creek MP 128.5 (flat bar)				2	1		98		2	2
Triangle Road MP 128.5 (round bar)	1			2	3	1	76		5	
Badger Road MP 129 (round bar)					3		94			1
County Road 1000 MP 129.7 (flat bar)	1			3	3		131		19	
Shaw MP 130.1 (flat bar with pedestrian grate)			1				135	1	4	
County Road 1002 MP 130.8 (round bar)		5	7	8	3	3	122	1	58	7

Wildlife Guard Name	Bighorn Sheep	Black Bear	Bobcat	Coyote	Elk	Moose	Mule Deer	Pronghorn	Red Fox	White-tailed Deer
Culbreath MP 135.1 (round bar)					1	2	47			
Trough Road MP 136.6 (flat bar)					23	5	71		3	
County Road 33 MP 136.9 (flat bar)			15	9	1		19		66	
Thompson MP 136.9 (round bar)		1	3	1	5	2	60		3	3
Total	**2**	**6**	**26**	**25**	**43**	**13**	**853**	**2**	**160**	**13**

From Year 3 through Year 5, ungulate approaches were highest at the guards located in the middle of the project area (County Road 1000, MP 129.7, *n*=135; Shaw, MP 130.1, *n*=136; and County Road 1002, MP 130.8, *n*=136). Despite a similar number of ungulate approaches to each of these three guards, over half of all breach events in the study area occurred at the Shaw guard (52%). Thirteen percent of all ungulate breaches occurred at the County Road 1000 guard, and 8% at the County Road 1002 guard. The Trough Road guard (MP 136.6) accounted for 10% all ungulate breach events, with the remaining guard locations accounting for 1-6% of all breaches.

The guard with the highest breach rate (62%) was the Shaw guard, a flat bar guard with a pedestrian grate (Table 5-2). On average, there were eight days between breach events at this location. The average number of monitoring days between ungulate breaches at other guard locations ranged from 52 to 264, except at the County Road 33 and Thompson guards at the far northern end of the study area, which each recorded only one ungulate breach during the final three years of the study. The ungulate breach rate at the Badger Road wildlife guard (9%) was similar to the other round bar guards, even though the wildlife fencing runs only along half the length of the guard at this location.

Table 5-2. Total number of approaches to the wildlife guards by ungulates and bear/canids/felids, and corresponding breach rates for each species groups (Years 3-5). For ungulates, the average number of monitoring days between ungulate breaches was also calculated.

Wildlife Guard Name (Guard Type)	Ungulate Approaches	Ungulate Breach Rate	Bear, Canid, Felid Approaches	Bear, Canid, Felid Breach Rate	Monitoring Days	Average # of Monitoring Days between Ungulate Breaches
Spring Creek MP 128.5 (flat)	101	4%	4	50%	1,057	264
Triangle Road MP 128.5 (round)	81	10%	7	71%	1,088	136
Badger Road MP 129 (round)	98	9%	0	-	925	103
County Road 1000 MP 129.7 (flat)	135	16%	22	73%	1,096	52
Shaw MP 130.1 (flat with grate)	136	62%	5	80%	640	8
County Road 1002 MP 130.8 (round)	136	10%	78	85%	1,075	83
Culbreath MP 135.1 (round)*	50	8%	0	-	400	100
Trough Road MP 136.6 (flat)	99	16%	3	67%	976	61
County Road 33 MP 136.9 (flat)	20	5%	90	87%	1,096	1,096
Thompson MP 136.9 (round)*	70	1%	8	88%	1,096	1,096

**These two guard locations were originally a flat bar guard (Thompson) and a flat bar guard with a pedestrian grate (Culbreath) in Year 1 but were replaced with round bar guards in Year 2. This table only presents data from Years 3-5, when both guards were round bars.*

Approaches to the wildlife guards by other large mammals (bears, canids, and felids) were greatest at the County Road 33 guard (MP 136.9, *n*=90) and County Road 1002 guard (MP 130.8, *n*=78). For these species, the percentage of breach events at each guard location corresponded directly with the number of approaches to the guard; that is, the more approaches to a guard, the greater the number of breaches at that guard. The breach rate for bears, canids, and felids was relatively high at all guard locations. The lowest breach rates were documented at the Spring Creek (50%; MP 128.5) and Trough Road guards (67%; MP 136.6).

Species Responses to Guard Type

Table 5-3 lists the total number of approaches, breach rates, repel rates, and the number of parallel movements by species at each of the three different guard types. For mule deer, the round bar guards were 91% effective in preventing breaches (*n*=508 repel movements) and the flat bar guards were 84% effective (*n*=482 repel movements). The round guards were also more effective in preventing elk breaches (81%) than the flat bar guards (75%), although the total number of elk movements at wildlife guards was fairly low (*n*=56). Moose, white-tailed deer, bighorn sheep, and pronghorn were infrequent visitors to the wildlife guards. Moose and white-tailed deer had a higher repel rate at round bar guards (100% and 82%, respectively) than at flat bar guards (70% and 67%, respectively). All approaches by bighorn sheep and pronghorn resulted in the individuals repelling from the guards. The flat bar guards with a pedestrian grate deterred ungulates 42% of the time (*n*=73 repels) and was the least effective guard type in preventing ungulate breaches.

Bears, canids, and felids were less frequent visitors to the guards but were much more likely to breach the guards than ungulates. Breach rates for these species ranged from 88-100% at all guard types, with the exception of coyote, which had a breach rate of 70% at flat bar guards and 41% at round bar guards. In general, these carnivores made few parallel movements at the guards.

Table 5-3. Total number of approaches, breach rates, repel rates, and the number of parallel movements by species at each guard type.

Species	Guard Type*	Total Approaches	Breach Rate	Repel Rate	Parallel Movements
Mule Deer	Flat Bar	572	16%	84%	160
	Flat Bar with Grate	171	58%	42%	0
	Round Bar	560	9%	91%	58
Bighorn Sheep	Flat Bar	1	0%	100%	0
	Round Bar	1	0%	100%	0
Elk	Flat Bar	40	25%	75%	4
	Round Bar	16	19%	81%	1
Moose	Flat Bar	10	30%	70%	0
	Round Bar	9	0%	100%	0
Pronghorn	Flat Bar with Grate	1	0%	100%	0
	Round Bar	1	0%	100%	0
White-tailed Deer	Flat Bar	3	33%	67%	0
	Round Bar	11	18%	82%	0
Black Bear	Flat Bar	3	100%	0%	0
	Round Bar	6	100%	0%	0
Bobcat	Flat Bar	19	89%	11%	8
	Flat Bar with Grate	2	100%	0%	0
	Round Bar	10	100%	0%	0
Coyote	Flat Bar	82	70%	30%	4
	Round Bar	17	41%	59%	0
Mountain Lion	Flat Bar	1	100%	0%	0
Red Fox	Flat Bar	233	91%	9%	15
	Flat Bar with Grate	8	88%	13%	0
	Round Bar	89	89%	11%	4

*Flat bar guards n=6; Flat bar guards with pedestrian grate n=3; Round bar guards n=5

Wildlife Guard Effectiveness in Preventing Ungulate Breaches

Ungulate repel rates were highest at the round bar guards, followed by the flat bar guards. Flat bar guards with a pedestrian grate had the lowest repel rates, with 58% of ungulate approaches resulting in a breach movement. The total number of ungulate breaches was greatest at the flat bar guards but, when standardized by the number of monitoring days, breaches were most common at the flat bar guards with a pedestrian grate (Table 5-4). On average, ungulate breach events were documented approximately six to ten times more frequently at the flat bar guards with a pedestrian grate than the flat bar guards or the round bar guards. Breach events by ungulates were 1.6 times more common at flat bar guards than at round bar guards.

Table 5-4. Total number of ungulate approaches, breach rate, monitoring days, and the average number of monitoring days between ungulate breach events for each guard type.

Guard Type*	Total Approaches	Breach Rate	Monitoring Days	Average Number of Monitoring Days between Breach Events
Flat Bar	626	17%	6,075	58.4
Flat Bar with Grate	172	58%	937	9.4
Round Bar	598	10%	5,489	96.3

*Flat bar guards n=6; Flat bar guards with pedestrian grate n=3; Round bar guards n=5

Activity at Wildlife Guards Over Time

The total number of approaches and breaches by ungulates and the corresponding breach rate generally decreased post construction. The one exception was in Year 4, when a small uptick in the breach rate was observed, most notably due to packed snow in one or more guards that allowed animals to walk over the guard (Figs. 5-2 & 5-3). Parallel movements also decreased

Figure 5-2. Mule deer breaching a wildlife guard by walking on snow packed in between the bars.

from a high in Year 2 and remained relatively stable each year thereafter, with a small decrease recorded in Year 5.

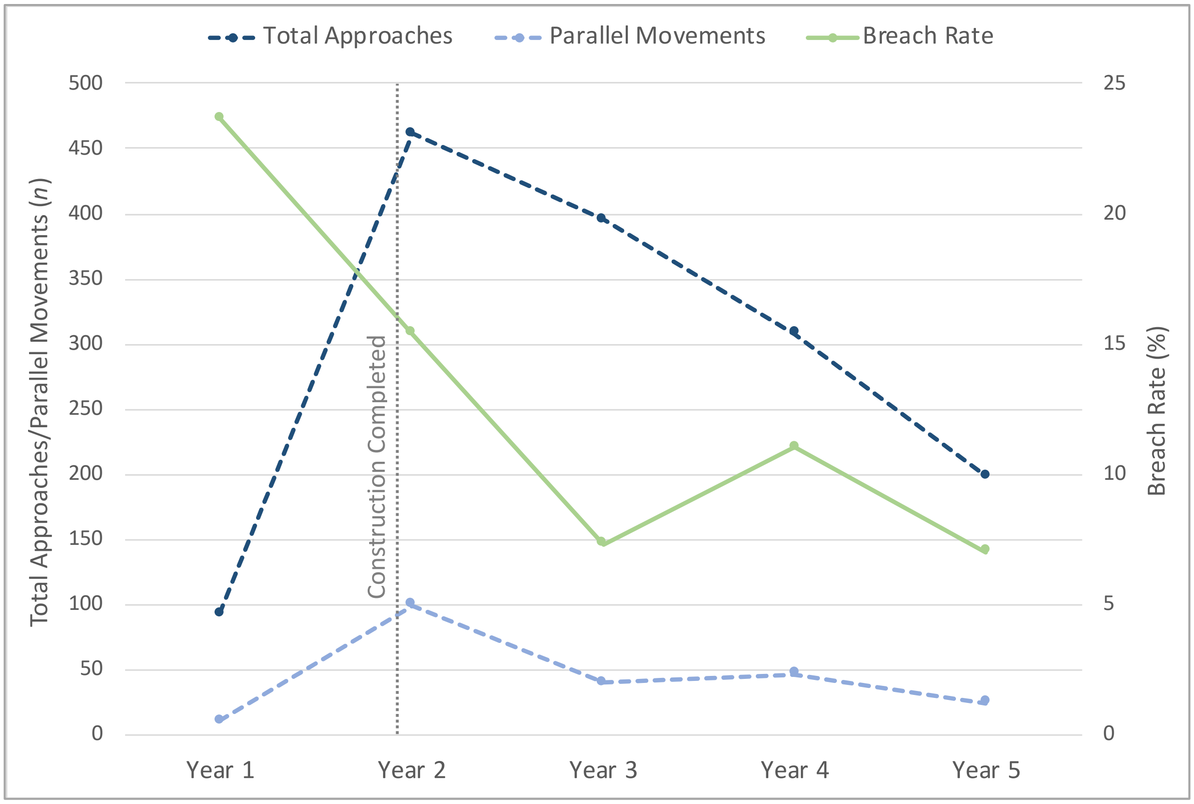

Figure 5-3. Total number of ungulate approaches, parallel movements and breach rate each year of the study.

Changes in Guard Efficacy Over Time

Figure 5-4 provides a standardized comparison of the changes in breach rates over time for each guard type by calculating the average number of breaches per monitoring day. The average number of breaches decreased at round bar guards each year, whereas at flat bar guards the average number of breaches per monitoring day varied from year to year. However, by Year 5, the average number of breaches per monitoring day was only slightly higher at flat bar guards (n=0.006) than at round bar guards (n=0.004). During the final three years of the study, flat bar guards with a pedestrian grate were represented by just one location (Shaw Guard, MP 130.1). At this location, the average number of breaches per day was seven to thirty-five times higher than at the flat bar or round bar guards and increased from Year 4 to Year 5.

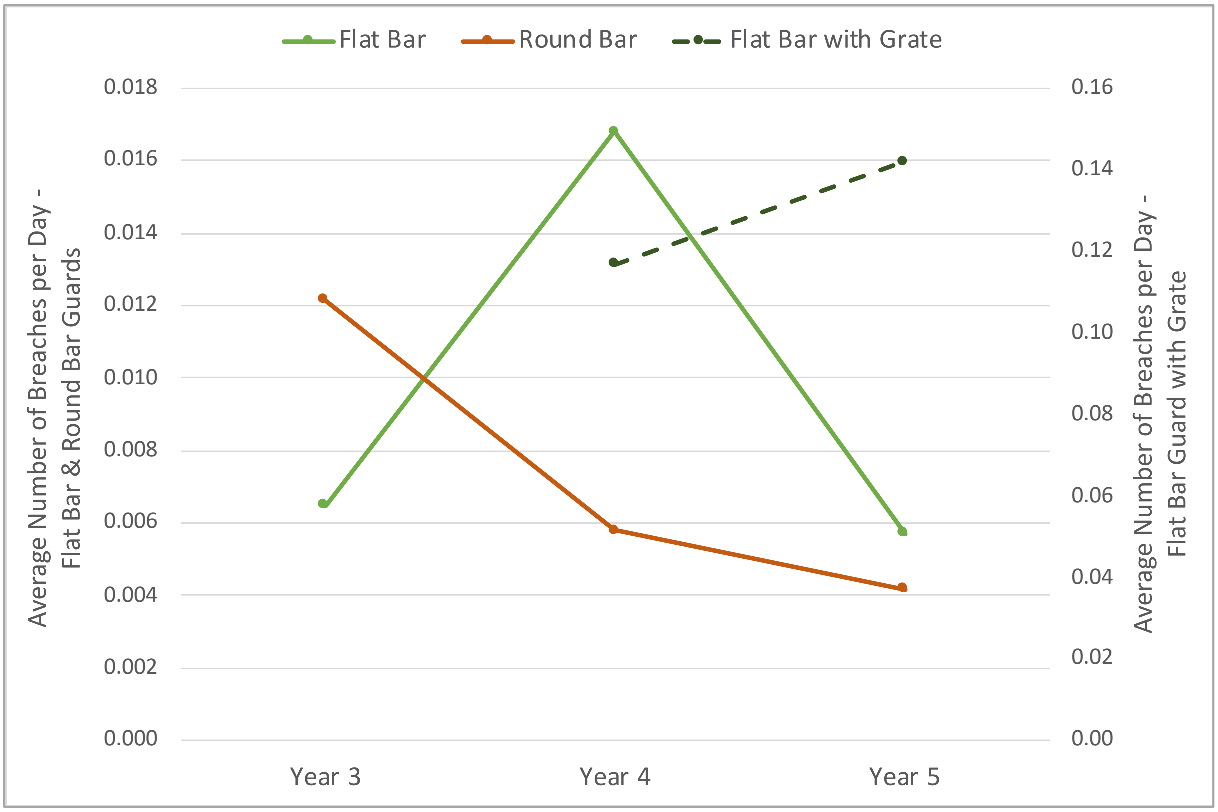

Figure 5-4. Average number of breaches per monitoring day by guard type Years 3-5. During this timeframe, six flat bar guards were monitored, five round bar guards, and one flat bar guard with a pedestrian grate.

Habitat Side versus Right-of-Way Side Breaches

Most ungulate breaches were made from the habitat side into the fenced right-of-way (83%), although, on occasion, mule deer or elk trapped inside the fencing breached the guards to return to the habitat side of the fencing. Mule deer were documented breaching a guard from the right-of-way side to the habitat side 40 times (17% of all mule deer breaches) and elk on three occasions (23% of all elk breaches). No other ungulate species were recorded escaping from the road right-of-way by breaching the guards. Bears (Fig. 5-5), canids, and felids were more likely to breach the guards in both directions, with 33% of breaches originating from the right-of-way side back to the habitat side of the fencing (*n*=132).

Figure 5-5. Black bear breaching a wildlife guard from the ROW side to the habitat side.

Breach Types

Wildlife breached the guards by walking on top of the bars, walking on the support beams, walking on the pedestrian grate (present on three of the monitored guards), walking on snow packed in between the bars, or by jumping the guard. For ungulates, breach type varied depending on guard type and, to some extent, species. Bears, canids, and felids breached all guards almost exclusively by walking on top of the bars (95% of 400 total approaches).

Mule deer was the only species that breached the guards in all different manners, though the frequency of each breach type varied by guard type (Table 5-5). The most common mule deer breach type was jumping, which was documented at all three guard types. Breaches by jumping a guard was the most common breach type at round bar guards (61.5%). Although the pedestrian grates were present at only two flat bar guard locations in Year 1 and one location in Years 4-5, walking on top of the grate was the second most common breach type across all years and all guard types. At flat bar guards with no pedestrian grate, the most common mule deer breach type was walking on snow packed in between the bars (42%) or by walking on top of the bars (31%). Mule deer walked on the support beams at the round bar guards (11.5%) more than at the flat bar guards (4%), despite the presence of angle iron on the support beams at the round guards.

Table 5-5. Mule deer breach types by guard type. After Year 1, two wildlife guards (one flat bar and one flat bar with a pedestrian grate) were replaced with round bar guards. Because monitoring data from all years and all guard types are presented here, the total number of guards of each type (14) is greater than the number of monitoring locations (12).

Guard Type	Total Breaches	Walk on Top	Walk on Support Beams	Walk on Grate	Walk on Packed Snow	Jump
Flat Bar (*n*=6)	99	31%	4%	0%	42%	22%
Flat Bar with Grate (*n*=3)	82	12%	1%	68%	11%	7%
Round Bar (*n*=5)	52	21 %	11%	0%	6%	62%

Breach types by other ungulate species varied according to guard type and species. Elk primarily breached guards by walking on top of the flat bar guards (*n*=10) and, on two occasions, at the round bar guards. One elk breach recorded at a round bar guard was by jumping the guard. White-tailed deer jumped the round bar guards on two occasions and walked on top of the flat bar guards once. Moose also made a limited number of breaches (*n*=3) by walking on top of the flat bar guards. No breaches by moose were documented at round bar guards despite a similar number of approaches at each guard type (flat bar *n*=10; round bar *n*=9).

Paired Guards Analysis

Six wildlife guard monitoring locations were included in three paired analyses of ungulate movements from Years 3-5 at flat bar and round bar guards that were in close proximity (Table 5-6). This analysis helped to control for different motivation levels to breach wildlife guards across the study area due to confounding factors such as the presence of wildlife crossing structures, landscape variables, habitat types, traditional movement pathways over the highway, and wildlife abundance in different portions of the study area. For the Thompson/County Road 33 guard pair and the County Road 1002/1000 guard pair, repel rates were higher at the round bar guards (99% and 90% respectively) than at the flat bar guards (95% and 84%, respectively). However, for the third guard pair, the repel rate was higher at the flat bar guard (Spring Creek, 96%) than the round bar guard (Triangle Road, 90%). The average number of breaches per year varied for each pair (the same, higher, or lower at the round bar guards), but the highest number of breaches per year was at County Road 1000, a flat bar guard.

Table 5-6. Ungulate breach and repel movements at wildlife guards included in the paired analysis (Years 3-5). Each pair is listed and shaded together.

Milepost	Monitoring Location	Total Approaches	Breach Rate	Repel Rate	Average Number of Breaches per Year	Parallel Movements
136.9	Thompson (round bar)	70	1%	99%	0.3	22
136.9	County Road 33 (flat bar)	20	5%	95%	0.3	5
130.8	County Road 1002 (round bar)	136	10%	90%	4.0	0
129.7	County Road 1000 (flat bar)	135	16%	84%	6.9	3
128.5	Triangle Road (round bar)	81	10%	90%	2.7	3
128.5	Spring Creek Road (flat bar)	101	4%	96%	1.4	35

Analysis of Factors Influencing Ungulate Breaches

Statistical analyses assessed the influence of guard characteristics (guard type and width) and landscape variables (distance to the nearest wildlife crossing structure and distance to disturbance) on breach, repel, and parallel rates of mule deer and ungulates. The Shaw location is the only flat bar guard with a pedestrian grate that was monitored during the analysis timeframe. Relative to the other guards, the Shaw guard had a high breach rate, and consequently low repel and parallel rates. Because of the high number of mule deer approaches and breaches at this location, the Shaw data are highly influential statistically and were omitted from these analyses.

Statistical analysis results were dominated by mule deer, which was the most common species at the wildlife guards. Consequently, models with all ungulates combined found the same results as models with mule deer only. Distance to the nearest crossing structure may have had an effect on breach and repel rates. Model results showed a decrease in both breach rates ($p<0.001$) and repel rates ($p=0.014$) with increasing distance to nearest crossing structure, while parallel rates increased with increasing distance to a crossing structure ($p=0.015$). However, model results failed to converge, and results could not be adjusted for overdispersion, thus the model parameters that were necessary for this analysis were not met and there is uncertainty in these results. No relationships were found between breach or repel rates and guard type ($p = 0.974$ and $p=0.122$, respectively); guard width ($p=0.399$ and $p=0.359$, respectively); or distance to nearest building ($p = 0.563$ and $p=0.411$, respectively).

DISCUSSION

Performance Measures

Over the full monitoring period, the wildlife guards successfully deterred ungulates 81% of the time out of a total 1,396 approaches to the wildlife guards. In the final year of the study, the repel rate across all three guard types was 75%; however, the vast majority of breach events occurred at a single guard location (79%, $n=52$), the Shaw guard, a flat bar guard with a pedestrian grate. With a breach rate of 55%, this guard type was ineffective at deterring ungulate breaches. Mule deer learned to walk across the pedestrian grate without hesitation, especially during the winter months when mule deer abundance is greatest, and snow often became packed into the grate creating an even more stable walking surface. Outside of this location, the repel rate at round bar guards was 94% and at flat bar guards 90% in the final year of the study. For the majority of wildlife guards in the study area the goal of an 80% repel rate was met (Table 5-7).

Table 5-7. Wildlife guards performance measures evaluation.

Performance Measure	Met	Not Met
By the end of the study, at least 80% of the individual mule deer, elk and other ungulate approaches to each wildlife guard will be deterred from entering the road right-of-way.	✔	

Are Round Bar Guards More Effective than Flat Bar Guards in Preventing Ungulate Breaches?

Statistical analyses did not detect a difference in ungulate breach rates at round bar guards versus flat bar guards. However, these analyses were limited by a small sample size and other confounding factors. Despite these inconclusive results, the wildlife guards were found to function as designed, with the round bar guards repelling mule deer (91%) and elk (81%) more than the flat bar guards (84% repel rate for mule deer; 75% for elk) across all study years. Moose and white-tailed deer also repelled at a higher rate from the round bar guards (100% and 82%, respectively) than at flat bar guards (70% and 67%, respectively), although the total number of approaches by these species was low (n=19 and n=14, respectively). Round bar guards have been implemented in only a few mitigation projects to date, with this research study offering the first comparative evaluation of their effectiveness. Additional research studies may be needed to further elucidate the effectiveness of this design.

All approaches by bighorn sheep and pronghorn resulted in the individuals being deterred from the guards. Despite the small number of bighorn sheep approaches to the guards, this reluctance by bighorn sheep to breach a wildlife guard is corroborated by similar findings of a 100% repel rate at double cattle guards in Arizona (Gagnon et al. 2020). In addition to differences in breach rates by species, breach rates may also be influenced by gender and age (Gagnon et al. 2020).

Flat bar guards with a pedestrian grate repelled ungulates only 42% of the time and are not recommended designs for future mitigation projects, particularly given the much higher repel rates of the other two guard types. Other alternatives for accommodating pedestrian access at wildlife guards include installing pedestrian access points through the fencing adjacent to the guards, although these, too, must be carefully designed to avoid wildlife breaches into the fenced right-of-way (Chapter 7).

Ungulate Activity at Wildlife Guards Over Time

Where wildlife crossing structures are effective in allowing successful passages under or over a highway, a decrease in ungulate approaches to the wildlife guards over time is anticipated as animals learn the locations of the crossing structures. On SH 9, there was a 52% decrease in ungulate approaches to the flat bar and round bar guards from Year 2 (*n*=361), following the completion of construction activities, to Year 5 (*n*=174). Other studies have documented similar decreases in approaches to wildlife guards over time (e.g., Cramer and Flower 2017), although the magnitude of these decreases may vary depending on the effectiveness and proximity of the crossing structures (Allen et al. 2013) and the difficulty involved in breaching wildlife guards with different designs, such as the Shaw guard with the pedestrian grate. Yet, as the total number of approaches to the wildlife guards decreases over time, differences in the effectiveness of each guard type may become less significant, and parallel movements are likely to increase. Post construction, the number of breaches at round bar guards decreased from Year 2 to Year 5 and fluctuated at flat bar guards from one year to the next. By the final year of the study, the average number of breach movements per monitoring day at flat bar guards (0.006) was nearly the same as at round bar guards (0.004). Additional monitoring would be required to determine whether these rates have stabilized.

What are the Most Important Factors Influencing Ungulate Breach Rates?

Mitigation projects across western states have employed a number of different wildlife guard designs, ranging from double cattle guards (e.g., Cramer and Flower 2017, Gagnon et al. 2020) to wildlife guards with a grid pattern (e.g., Allen et al. 2013, Cramer and Flower 2017, Peterson et al. 2003). Regardless of guard type, the SH 9 mitigation project incorporated several important design features based on lessons learned from other states. These features include a guard length (the distance animals must traverse to breach a guard) of at least 16 feet (Gagnon et al. 2020); and the absence of a concrete ledge framing the outside of a guard vault and the elimination of a center concrete strip supporting the two halves of the guard, both of which wildlife have quickly learned to exploit to breach a guard (Cramer and Flower 2017, Gagnon et al. 2020, Huijser et al. 2016). In addition, following observations of ungulates breaching the guards by walking on the support beams in Year 1, angle iron was added to the support beams of all the new guards constructed in Phase 2 to discourage these types of breaches. The angle iron discouraged some breaches, but mule deer still breached round bar guards with the angle iron by walking on the support beams on six occasions. To prevent possible injuries to ungulates that may fall in between the bars of a wildlife guard, Gagnon et al. (2020) experimented with placing welded black plates inside the guards to mimic the appearance of a cattle guard but found that they quickly became ineffective. While there was no evidence of wildlife injuries as a result of animals falling between the bars on SH 9, the potential for this type of injury remains a concern (Fig. 5-6). At one guard across a private driveway, a domestic horse became trapped in a flat bar guard and had to be euthanized.

Figure 5-6. Mule deer that fell between the bars of a wildlife guard.

Statistical analyses did not definitively discern an effect of the structural and landscape variables measured on ungulate breach, repel or parallel rates. Curious results with respect to distance to the nearest crossing structure found both decreasing breach and repel rates and increasing parallel rates as the distance to a crossing structure increased. These results are partly due to small sample sizes and the failure of the data to meet the model assumptions. They may also indicate that guards farther from a crossing structure were more commonly bypassed than those situated closer to one of the wildlife crossings.

Nevertheless, there are several factors likely to influence breach rates that were not measured by this study. Principal among these factors is motivation to cross a highway (Gagnon et al. 2020). Access to resources such as high-quality forage or water sources are likely motivators, particularly when the forage inside of the fenced right-of-way is more attractive than the accessible forage on the habitat side of the fence. Thus, the location of a wildlife guard with respect to these motivating factors is an important consideration. On SH 9, the two locations with the highest number of ungulate approaches to the guards were the County Road 1002 guard (MP 130.8) and the Shaw guard (MP 130.1). Both guards are situated between the BVA Underpass and the South Overpass, two of the crossing structure locations with the greatest mule deer abundance in the study area (Chapter 3) and the greatest concentration of preconstruction wildlife carcasses (Chapter 8). Assuming mule deer abundance is a proxy for forage quality on winter range, the location of these two guards in prime winter range and the fact that animals traditionally attempted to cross SH 9 in this area are likely factors in the high number of approaches at these two guard locations.

While location and motivation are factors influencing the number of approaches to the guards, breach rates are also directly influenced by the design of the guard and the ease (or difficulty) of crossing it. These differences in guard characteristics are exemplified by County Road 1002 and Shaw guards. Despite the nearly equal number of ungulate approaches at each location, the former is a round guard with a breach rate of 10%; the latter is a flat bar guard with a pedestrian grate with a breach rate of 62%. While the Shaw guard was the only guard with a pedestrian grate monitored during post construction, the analysis of other pairs of different guard types in close proximity generally substantiated these findings. In two out of three pairs (the

Thompson/County Road 33 pair and the County Road 1002/1000 pair), mule deer repel rates were highest at the round bar guards.

In summary, the round bar guard design was the most effective in deterring ungulate breaches, followed by the flat bar guard design. While the overall effectiveness of each guard type in repelling ungulates was different (90% repel rate at round bar guards; 83% repel rate at flat bar guards), these differences were not statistically significant. These two designs are recommended for keeping hooved wildlife out of the road right of way, with a preference for the round bar design. Other guard designs will be required to deter carnivores and other wildlife from entering the highway right-of-way.

Chapter 6. Escape Ramps

RESULTS

The goal of monitoring at escape ramps was to assess how well ungulates that became trapped in the fenced right-of-way (ROW) were able to use the escape ramps to exit the ROW and return back to the habitat side of the fence. Several different ramp designs were monitored to evaluate which features best encouraged ungulates to use the ramps to successfully escape the ROW. Escape ramps were constructed with a 2:1 or 3:1 slope, and with or without perpendicular rail fence. One jump down was constructed near the Harsha Gulch Underpass (Fig. 6-1).

Figure 6-1. Escape ramp with 2:1 slope and perpendicular rail fence (top left), 3:1 slope ramp with rail fence (top right) and jump down (bottom left).

Cameras recorded a total of 1,341 approaches by mule deer in the ROW at the 13 monitored escape ramps, and 261 approaches by elk. Other ungulates including bighorn sheep, moose, and white-tailed deer were recorded at escape ramps less than 15 times each. Pronghorn were not recorded at the escape ramps. Bears, felids, and canids were also documented. When an individual animal encountered an escape ramp inside the ROW, they either walked around the ramp (ignored) or ascended it. The intercept rate is the proportion of approach movements that resulted in an animal ascending the ramp. The escape rate is the number of intercept movements that resulted in a successful escape (jump down) back to the habitat side of the fencing. Across all locations and ramp types, mule deer had an intercept rate of 51% and an escape rate of 10%, and elk had an intercept rate of 57% and an escape rate of 23%

Spatial and Temporal Distribution of Mule Deer and Elk Activity at Escape Ramps

Trends in mule deer and elk activity at the escape ramps varied over time and with respect to locations on the landscape. Mule deer and elk activity at the escape ramps was detected immediately following the completion of construction activities in Year 2 (Fig. 6-2). Both mule deer and elk approaches increased slightly in the final two years of the study. Escape rates for mule deer and elk remained low throughout the study (10% and 23%, respectively). Mule deer approached all of the monitored ramp locations, with the majority of mule deer approaches at the two ramps adjacent to the south fence end (42%). Across all years, elk were documented at seven of the 13 locations, but 93% of elk approaches were at the East Fence End Escape Ramp, adjacent to the south fence end. Three percent of elk approaches were at the West Fence End Escape Ramp on the opposite side of the highway.

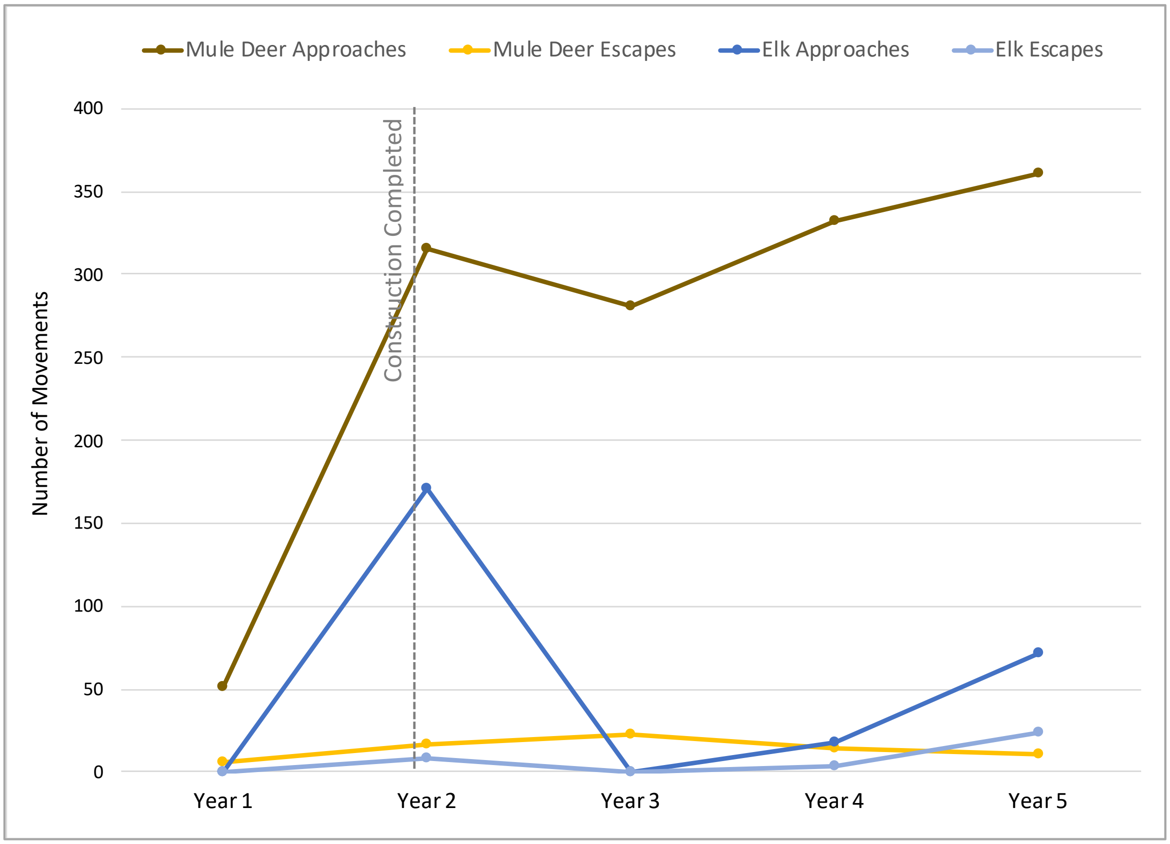

Figure 6-2. Elk and mule deer total approaches and successful escapes (jump downs) each year of the study.

Intercept and Escape Rates by Ramp Type

Intercept rates for mule deer were highest at the jump down ramp (76%; *n*=25), 2:1 slope ramps without rail fence (72%; *n*=81), and 3:1 slope ramps without rail fence (65%; *n*=459; Table 6-1). Escape rates for mule deer were highest at 2:1 slope ramps without rail fence (17%; *n*=14) and 3:1 slope ramps with rail fence (16%; *n*=15). Despite the high intercept rate at the jump down ramp, only three mule deer escaped off the ramp (12%). The 3:1 slope ramps without rail fence had the most mule deer escape movements (*n*=37), followed by the 3:1 slope ramps with rail fence (*n*=15) and the 2:1 slope ramps without rail fence (*n*=14). For elk, the highest intercept rate was at 3:1 slope ramps without rail fence (59%; *n*=146) with a resulting escape rate of 23% (*n*=33).

Table 6-1. Mule deer and elk total approaches, intercept rates and escape rates by ramp type.

Species	Escape Ramp Type	Total Approaches	Intercept Rate	Escape Rate
Mule Deer	2:1 slope with rail fence (*n*=4)	94	32%	3%
	2:1 slope without rail fence (*n*=1)	113	72%	17%
	3:1 slope with rail fence (*n*=2)	395	23%	16%
	3:1 slope without rail fence (*n*=5)	706	65%	8%
	Jump down (*n*=1)	33	76%	12%
Elk	2:1 slope with rail fence (*n*=4)	3	33%	100%
	2:1 slope without rail fence (*n*=1)	0	n/a	n/a
	3:1 slope with rail fence (*n*=2)	8	38%	33%
	3:1 slope without rail fence (*n*=5)	248	59%	23%
	Jump down (*n*=1)	2	0%	0%

Bighorn sheep were only recorded at the South Spring Creek Escape Ramp (3:1 slope with rail fence) where they had a 100% intercept rate (*n*=3) but no individuals successfully escaped. Moose were documented inside the ROW at the ramps seven times but the only successful documented escape by moose was at the Culbreath 3:1 Escape Ramp without rail. However, another successful escape was observed by one of the researchers at the Spring Creek Escape Ramp (3:1 slope without rail). White-tailed deer were recorded 16 times at 2:1 slope ramps with rail fence and 3:1 slope ramps without rail fencing. The individuals ignored (*n*=4) or intercepted (*n*=13) the ramps but did not escape off the ramps to the habitat side. The only successful escape by white-tailed deer was at the sole 2:1 slope ramp without rail fence (North Overpass Escape Ramp).

Bears, canids, and felids were also observed inside the ROW at escape ramps. Black bear escaped the ROW via a ramp on four occasions at 3:1 slope ramps (with and without rail fence) and at the jump down ramp, and ignored a 2:1 slope ramp without rail fence on one occasion.

Bobcat (*n*=20), coyote (*n*=57), and red fox (*n*=113) were most likely to ascend a ramp and turn around (intercept rates = 90%, 78%, and 74%, respectively). Bobcat had an escape rate of 33%, while neither coyote nor red fox had any successful escapes.

Both mule deer (*n*=4,488) and elk (*n*=370) were documented moving parallel along the fence line on the habitat side of the ramps. On a few occasions, elk were recorded looking up at the fence opening at the top of the ramp, but no mule deer or elk attempted to jump up from the habitat side of a ramp into the fenced ROW. The only species documented jumping or climbing up from the backside of the ramp to enter into the ROW were bobcat (*n*=5) and bear (*n*=1; Fig. 6-3).

Figure 6-3. Black bear climbing up the back side of an escape ramp to enter into the ROW.

Factors that Influence Intercept and Escape Rates

Statistical modeling examined potential associations between the overall ungulate intercept rate or escape rate over the five years of the study and the structural characteristic of the escape ramps (ramp height, ramp slope, presence of a guide fence, ramp position with respect to the road) and the corresponding landscape variables (distance to nearest crossing structure, and distance from road; Table 6-2). Although statistical modeling revealed relationships between intercept or escape rates and structural and landscape variables, it also revealed that the sample size was too small and often the variability among locations was too great to make strong inferences of these relationships.

The strongest relationship between intercept rates and the measured variables was that of the presence of guide fences on the ramps. Ungulates were more likely to intercept ramps without perpendicular rail fence (64%) than ramps with perpendicular rail fence (26%; $p < 0.001$).

Ramps positioned below the road grade were also more likely to be intercepted (62%) than those located above the road grade (32%; p=0.037). Other associations were observed, but were not statistically significant, including increasing intercept rates with decreasing distance from a crossing structure (p=0.173); increasing intercept rates with increasing distance to the road (p=0.550); and decreasing intercept rates with increasing ramp height (p=0.661). There was no difference in intercept rates relative to ramp slope (p=0.396), and intercept rates were nearly equal at ramps with 2:1 (54%) and 3:1 slopes (52%)

Escape rates increased with decreasing ramp height, but the results were not statistically significant (p=0.484). The greatest number of successful escapes occurred at ramps 72 inches (6') or shorter (n=70) and at ramps between 72 and 78 inches (6'-6'6"; n=34). Only 3 successful escapes were documented at ramps taller than 78 inches. The modeling did not show a relationship between escape rates and ramp slope (p=0.742); presence of guide fence (p=0.827); ramp position relative to the roadway (p=0.401); distance to road (p=0.773); or distance to crossing structure (p=0.985).

Table 6-2. Total approaches by ungulates, intercept rates and escape rates by ramp location. Ramp type, height, landscape position relative to the roadway, and distance from pavement are listed for each location. Gray highlighted rows indicate paired ramps at adjacent locations with different specifications.

Monitoring Location	**Ramp Type**	**Ramp Height (inches)**	**Position**	**Distance from Road (feet)**	**Total Approaches**	**Intercept Rate**	**Escape Rate**
Thompson MP 136.8	2:1 slope with rail fence	78	Below Grade	90	1	100%	0%
Trough Road 3:1 MP 136.6	3:1 slope without rail fence	72	Below Grade	105	61	69%	12%
Trough Road 2:1 MP 136.6	2:1 slope with rail fence	76.5	Above Grade	95	53	38%	10%
SWA MP 135.9	2:1 slope with rail fence	88	At Grade	65	5	0%	-

Monitoring Location	Ramp Type	Ramp Height (inches)	Position	Distance from Road (feet)	Total Approaches	Intercept Rate	Escape Rate
Culbreath 2:1 MP 135.1	2:1 slope with rail fence	77.5	Above Grade	90	47	32%	0%
Culbreath 3:1 MP 135.1	3:1 slope without rail fence	75.5	Below Grade	75	146	94%	7%
North Overpass MP 134.3	2:1 slope without rail fence	73.5	Above Grade	95	114	72%	18%
Harsha MP 131.6	Jump down without rail fence	80.5	Below Grade	160	35	71%	12%
Badger Road MP 129.1	3:1 slope without rail fence	70	Below Grade	85	132	45%	23%
Spring Creek MP 128.5	3:1 slope without rail fence	71	Below Grade	105	92	55%	10%
South Spring Creek MP 128.4	3:1 slope with rail fence	70	Below Grade	115	130	45%	17%
East Fence End MP 126.7	3:1 slope without rail fence	65	Below Grade	180	525	61%	11%
West Fence End MP 126.7	3:1 slope with rail fence	69	Above Grade	95	288	16%	16%

Ramps at adjacent locations with differing designs (2:1 vs 3:1 slope; presence/absence of perpendicular rail fence) were grouped into two pairs for a simple comparative analysis. Because the ramps in a pair are in close proximity, theoretically, animals trapped in the ROW have roughly equal access to both ramps and similar motivation to remain in the ROW or escape via the ramp due to the similar landscape and roadway situation at both ramps in a pair. In each pair, the 3:1 slope ramp without rail fence had an intercept rate higher than the 2:1 slope ramp with rail fence. In each pair, the ramp with the lowest ramp height had the highest escape rate, although the number of successful escapes was low at all of the paired ramps. Further analysis was compounded by multiple design variables and a small sample size and could not be completed for these pairs.

DISCUSSION

Performance Measures

In the final year of the study, the number of mule deer approaches to an escape ramp was at its highest (*n*=361), yet the mule deer escape rate was at its lowest (5%). The overall escape rate for mule deer was 10% but it varied from year to year. This performance measure for mule deer was not met (Table 6-3). Elk intercept and escape rates generally increased over time. In the final year of the study, the elk intercept rate was 69% and the escape rate was 48%, just below the performance measure goal of a 50% escape rate. The goal of no mule deer or elk jumping up from the habitat side of a ramp into the ROW was met.

Table 6-3. Escape ramps performance measures evaluation.

Performance Measure	Met	Not Met
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.		✔

How Successful were the Escape Ramps in Allowing Ungulates and Other Wildlife to Escape out of the Fenced Right-of-way?

The objective of a wildlife crossings system with continuous fencing and wildlife guards is to prevent wildlife from entering into the fenced ROW. Nevertheless, no mitigation system is perfectly tight at all times and escape ramps are an important component, allowing animals that do become trapped in the ROW a means of escaping back to the habitat side of the fencing (Gagnon et al. 2020, van der Ree et al. 2015). On SH 9, the escape ramps were more successful in allowing elk to escape the ROW (23%) than mule deer (10%; Fig. 6-4).

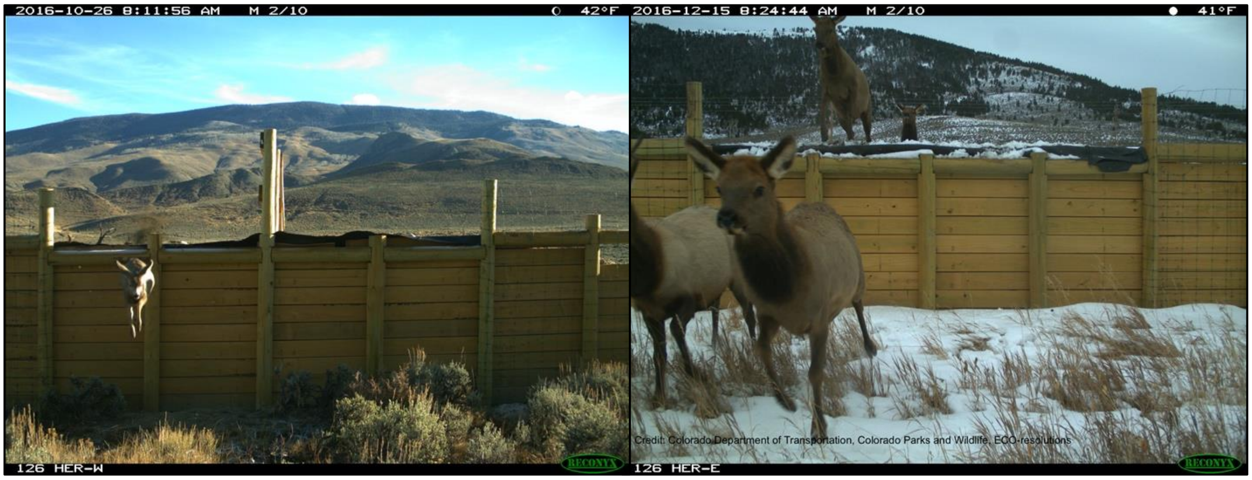

Figure 6-4. Deer (left) and elk (right) making successful escapes off the escape ramps.

Escape rates for mule deer and elk were lower than what has been documented in other studies. On US 550 in southeast Colorado, Siemers et al. (2015) document an escape rate of nearly 50% for mule deer; however, escape rates ranged from 8% to 70% across the 11 ramps, which ranged in height from 4.5’ with a perpendicular rail to 6.5’. Gagnon et al. (2020) detected a 13% escape rate for mule deer across three study sites in Arizona. Escape rates for elk were higher, ranging from 25-37% depending on ramp height. In Utah, there was an overall escape rate of 70% for mule deer at four 5-feet high escape ramps with no perpendicular fence on top (Cramer and Hamlin 2020), although shorter ramp heights may be more susceptible to jump backs into the ROW (Gagnon et al. 2020).

While escape mechanisms such as escape ramps are generally thought to be most critical in the period immediately following construction, when fencing and other infrastructure is new and unfamiliar to wildlife, mule deer activity in the ROW remained high over time on SH 9. This research was not able to definitively determine the source of mule deer activity in the ROW, although a portion may be attributed to mule deer and elk breaches into the fenced right-of-way at the south fence end (Chapter 7) and mule deer breaches at the Shaw Wildlife Guard, which had a high breach rate particularly during the winter when snow packed in between the guard bars (Chapter 5). High mule deer counts in the ROW may also reflect multiple movements by the same individuals that were trapped in the ROW over a longer period of time.

What Were the Most Important Factors Influencing Ungulate Intercept and Escape Rates?

The SH 9 project included five ramp designs, allowing for comparative analysis among ramp types within the study area. Most field studies of mitigation projects only evaluate one ramp design (Huijser et al. 2015), except where comparative analyses have been conducted across multiple study sites (e.g., Gagnon et al. 2020). While small sample sizes for each ramp type limited the strength of conclusions, the patterns that emerged are discussed below.

Most mule deer (42%) and elk (95%) approaches to escape ramps were at the two ramps adjacent to the south fence end, supporting the idea that ramp location near the fence end was the greatest factor influencing the number of approaches to an escape ramp. Other potential points of entry into the ROW included breached wildlife guards and temporary gaps in the fencing. Because only 12 elk approaches (out of a total of 261) were documented at escape ramps elsewhere in the study area, the influence of other variables on elk intercept and escape rates could not be determined. The remainder of this section focuses on factors influencing mule deer intercept and escape rates.

The strongest relationship detected in the statistical analyses was the difference in intercept rates in relation to the presence of guide fence on the ramps. The purpose of the fence is to guide approaching animals to ascend the ramp. Yet, mule deer intercept rates were higher at ramps without perpendicular rail fence (69%) than those with perpendicular fence (38%). Ramps without rail fence may be more attractive to ascend because they offer a clearer view of the fence gap at the top of the ramp. While Siemers at al. (2015) reported a positive correlation between mule deer escape rates and the presence of perpendicular guide fence, this study did not evaluate intercept rates and escape rates independently. Other studies have not been able to determine the effectiveness of perpendicular fencing in guiding animals up a ramp (Gagnon et al. 2020; Huijser et al. 2015).

Intercept rates were also found to be related to ramp position in the landscape relative to the roadway. Mule deer were twice as likely to ascend a ramp located below the roadway (63%) than ramps located on slopes above the road grade (31%). This variable has not been evaluated in other monitoring studies. Anecdotally, the researchers observed that when mule deer were trapped inside the fenced ROW, they tended to gather in low points (fill slopes, drainages) along the roadway when traffic passed and hypothesized that ramps located in these low spots and, as a result of this behavior, may be more likely to successfully use ramps located below the roadway to escape the ROW.

Intercept rates also appeared to be influenced by distance to a crossing structure – the farther a ramp was from a crossing structure, the less likely deer were to successfully intercept the ramp. The reason for this behavioral response is unknown.

Ramp slope had little influence on mule deer intercept rates. While a monitoring study in Utah detected an intercept rate of 70% at escape ramps similar to the 2:1 slope ramps without perpendicular rail fence on SH 9 (Cramer and Hamlin 2020), other studies have determined that flatter 4:1 slope ramps are more effective at encouraging deer and elk ascents (Gagnon et al. 2020). In the context of these other studies, further investigation of ramps slopes flatter than 3:1 is recommended to determine the slope threshold for improving intercept rates.

Animals that successfully ascend or intercept a ramp then have the option of jumping down (escaping) or turning back down the ramp (repelling). While statistical analysis did not show any significant relationships between escape rates and the measured variables, it did detect a possible trend of decreasing escape rates with increasing ramp height. On SH 9, the ramp height specified in the design plans was six feet. However, actual heights among the monitored ramp locations varied from five feet five inches to seven feet four inches. A six-foot high escape may be effective in allowing elk to escape and preventing elk from entering back into the ROW; however, given the low escape rates even at ramps with higher intercept rates, ramps of this height or higher appear to be too high to encourage successful mule deer escapes. This finding is substantiated by other studies on mule deer use of escape ramps (Gagnon et al. 2020, Huijser et al. 2015, Huijser et al. 2016).

Did the Escape Ramps Prevent Wildlife from Entering into the Fenced Right-of-way?

No ungulates were documented attempting to jump from the habitat side of the fence into the ROW via the fence gap at the top of an escape ramp, despite the high number of animals documented walking along the fence line and, on occasion, looking up at the top of the ramp (Fig. 6-5). This 100% repel rate is likely due to the high ramp heights, which ranged from 65-88 inches. While these ramp heights were effective in keeping wildlife from breaching into the ROW via the escape ramps, they were also a factor in the low escape rates observed, demonstrating the need to optimize ramp height to increase successful escapes while continuing to prevent breaches at the escape ramps.

Figure 6-5. Elk investigating a ramp from the habitat side of the fence.

Recommendations for Adaptive Management on SH 9

Generally, where elk and mule deer are both present, it is recommended to design ramp heights to prevent elk from jumping back into the ROW at the risk of decreased mule deer escapes (Gagnon et al. 2020, Huijser et al. 2015). On SH 9, elk almost exclusively entered the ROW via the south fence end and elk breaches into the ROW could be significantly reduced if this entry point were eliminated, for example, by augmenting the fence to prevent wildlife entry or by extending the mitigation for a longer distance. In addition, because mule deer occur in far higher concentrations in the study area and were documented at all escape ramp locations, adjusting ramp heights to improve escape rates for mule deer is more important than preventing potential elk breaches into the ROW. Recognizing this need at the completion of this research, CPW initiated an adaptive management approach and will continue monitoring for two years at select escape ramps in an attempt to improve the mule deer escape rate. This follow-up study is using a before-after-control-impact (BACI) design focused on ramp height to determine whether reducing the ramp height to 5’6” has a positive effect on mule deer escapes.

Chapter 7. Fence End and Pedestrian Access Points

This chapter presents the results and discussion for two features related to the wildlife fence: the south fence end (the north fence end ties into the Colorado River Bridge at the north end of the project area), and pedestrian access points. The objective of the research at these features was to determine if the fence end design and pedestrian access point were effective at deterring wildlife (ungulates primarily) from entering the fenced road area.

RESULTS

South Fence End

Small herds of mule deer and elk were frequently documented making multiple approaches toward the roadway just beyond the fence end and being repelled by passing traffic. Ultimately, the animals either completed an at-grade crossing of SH 9, repelled from the roadway, or entered into the fenced right-of-way (ROW; Fig. 7-1). Animals were also photographed leaving the fenced ROW. In total, 1,481 individual mule deer and elk movements were recorded at the south fence end after the completion of construction activities. The majority of all movements were by animals crossing SH 9 beyond the fence end (83%). Thirteen percent of all movements were by deer and elk entering into the fenced right-of-way (n=235) and 4% were by deer and elk exiting from the fenced ROW. Other species documented at the south fence end include coyote, red fox, and mountain lion.

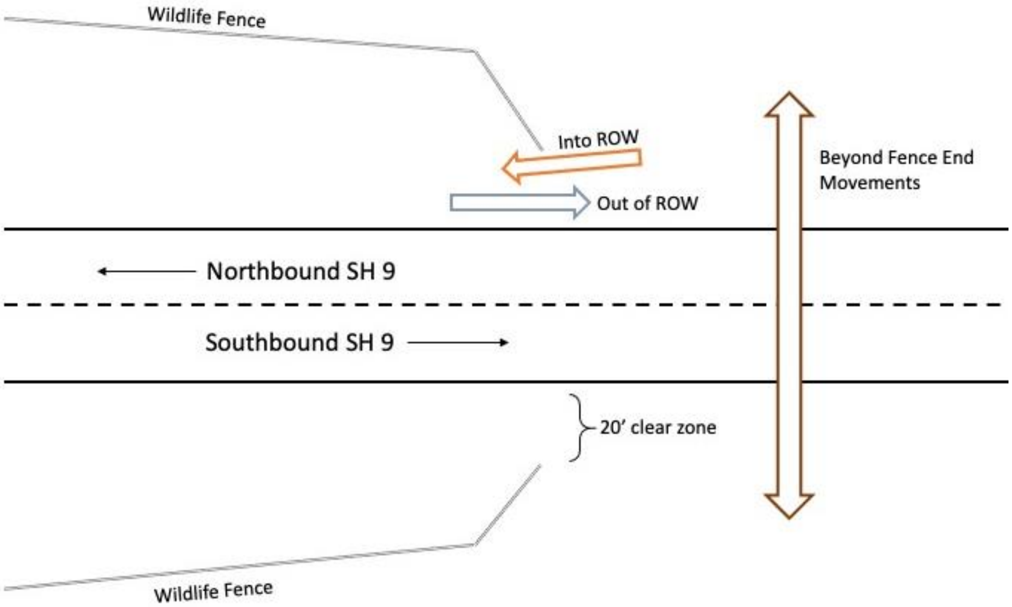

Figure 7-1. Diagram of types of the three types of wildlife movements at the south fence end.

Ungulate movements at the south fence end were highest during the winter months, corresponding with the greatest numbers of mule deer and elk on winter range, and dropped during the summer months. Figure 7-2 displays mule deer and elk movements at the fence end by movement type each season since construction was completed. The total number of individual ungulate movements at the south fence end increased by 17-40% each winter post construction. The greatest number of total movements was recorded in Winter 2019-2020; both ungulate movements beyond the fence end (n=407) and movements into the fenced ROW (n=101) exceeded prior year movements.

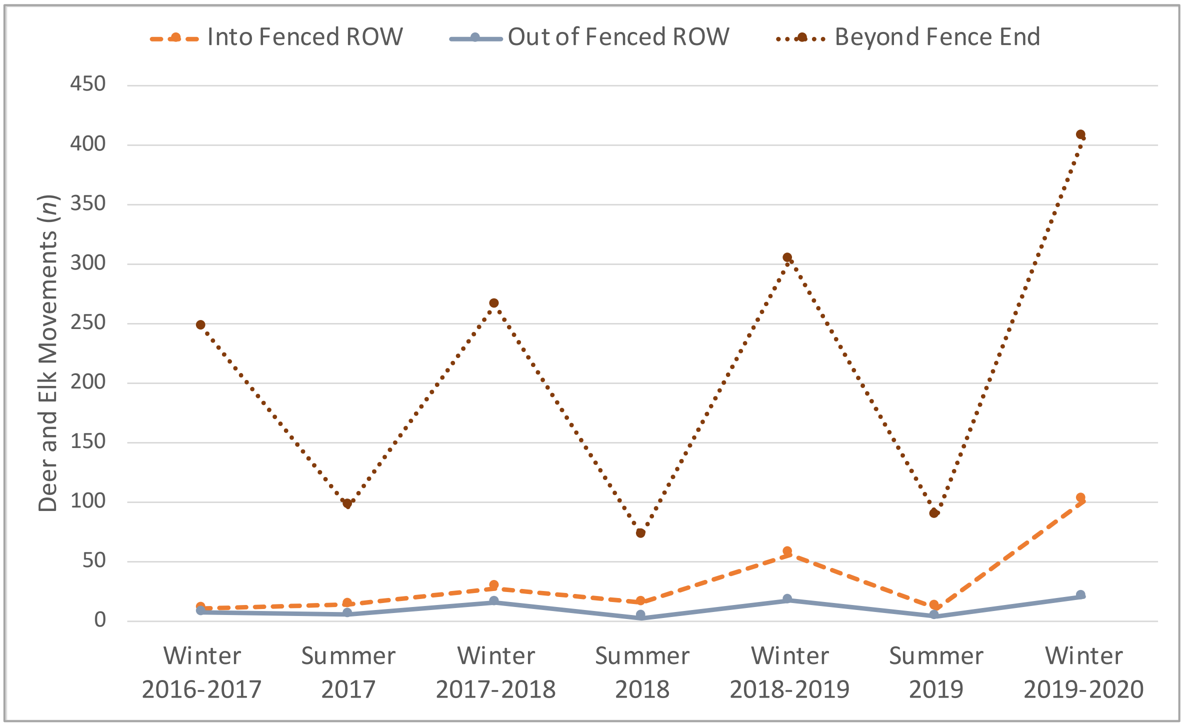

Figure 7-2. Three types of movements at the south fence end by deer and elk each season post construction.

Pedestrian Access Point

The purpose of the pedestrian access points was to allow people to cross through the fence line without use of a swing gate or ladder. The access points were designed to guide people through a series of sharp angles in the fencing while precluding wildlife, in particular ungulates. The design of the pedestrian access points used for the SH 9 project was derived from the Y-shape design used by the Montana Department of Transportation. 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 entirely within the CDOT ROW (Fig. 7-3).

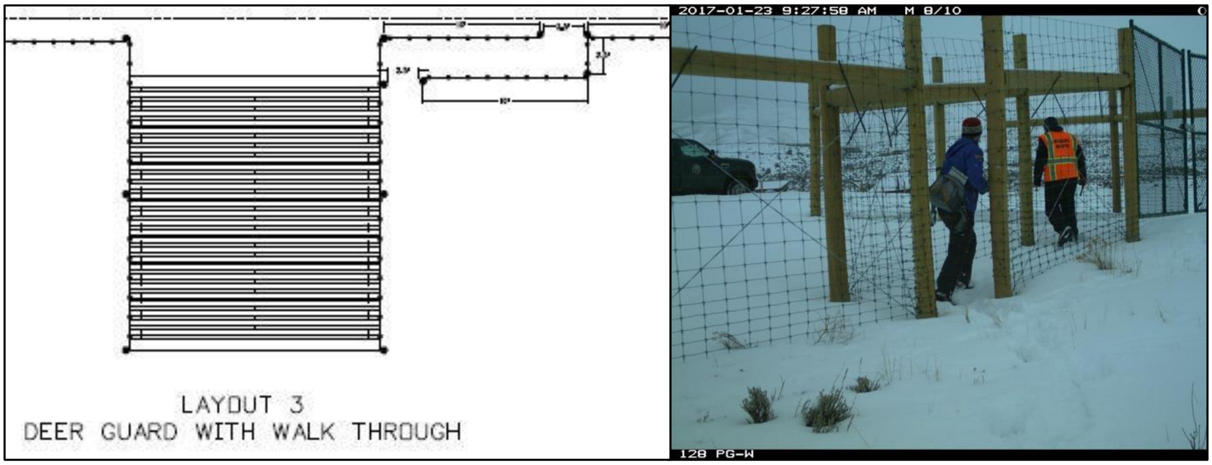

Figure 7-3. Left: CDOT design for pedestrian access point adjacent to a wildlife guard. Right: People walking through a pedestrian access point.

Three pedestrian access points were monitored in Years 1 and 2. A total of 361 approach movements by seven wildlife species were recorded at the pedestrian access points. Mule deer were the most frequently photographed species at pedestrian access points. In total, 32 mule deer breaches and four elk breaches were documented, both from the habitat side of the fencing to the ROW and vice versa. In some cases, it appeared that deer breached the access point, foraged on the ROW side of the fence, and then returned to the habitat side the same way it had come into the ROW. Most movements by all species were parallel movements. These animals were in the vicinity of an access point but did not investigate it or attempt to breach. Table 7-1 lists the total number of approaches to the pedestrian access points by each species across the combined locations and their corresponding breach, repel and parallel rates.

The majority of wildlife approaches to the pedestrian access points were parallel movements by animals walking near the fence line but did not investigate the access point. Mule deer, elk and bobcat were the only species that investigated these openings. Of the species that investigated an access point, the breach rate was 11% for mule deer, 4% for elk, and 0% for bobcat. Coyote, mountain lion, and white-tailed deer were only documented making parallel movements at the pedestrian access points.

Table 7-1. The total number of approaches by each species at the pedestrian access points and corresponding breach, repel and parallel rates.

Species	Total Approaches	Breach Rate	Repel Rate	Parallel Rate
Bobcat	1	0%	100%	0%
Coyote	8	0%	0%	100%
Elk	49	4%	8%	88%
Mountain Lion	2	0%	0%	100%
Mule Deer	297	11%	8%	81%
Red Fox	2	0%	0%	100%
White-tailed Deer	2	0%	0%	100%

At the onset of Year 3 (summer 2017), CPW determined that the pedestrian access point design was insufficient in deterring wildlife breaches into the ROW and posed a risk to motorists that could be eliminated by closing the entrances with swing gates (Fig. 7-4). Monitoring ceased at these locations with the addition of the swing gates.

Figure 7-4. Pedestrian access point outfitted with a swing gate.

DISCUSSION

Performance Measures

The performance measure relating to the pedestrian access point was not evaluated because the retrofit in 2017 marked the end of monitoring at these locations. The performance measure for the south fence end was not met and is discussed below (Table 7-2).

Table 7-2. Fence end and pedestrian access point performance measures evaluation.

Performance Measure	Met	Not Met
By the end of the study, 100% of the individual mule deer and elk approaches to each pedestrian access point will be deterred from entering the road right-of-way.	n/a	n/a
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.		(✔)

By the final year of the study, ungulate movements into the fenced ROW represented 17% of all movements at the south fence end; however, this represented a 58% increase in the number of ungulate movements into the ROW from Year 4. For this reason, it was determined that the performance measure was not sufficiently met.

South Fence End

Cameras at the fence end documented an annual average of 370 deer and elk movements at the south fence end. Eighty-three percent of these movements were by animals moving at-grade across the highway beyond the fence end, suggesting that animals in this portion of the study area may not be finding and using the nearest wildlife crossing structure which lies 1.1 miles north of the fence end (Williams Peak Underpass, MP 127.7). The total number of ungulate movements at the south fence end as well as the number of movements by deer and elk into the fenced right-of-way increased each winter of the research.

Ongoing and increasing ungulate activity at the south fence end indicate that the fence end design is not preventing wildlife from entering into the ROW around the fence end and that the project may not fully mitigate wildlife movements across SH 9 (Fig. 7-5). These findings are consistent with CPW's understanding of wildlife movements in the lower Blue River valley prior to the mitigation construction. Due to funding constraints and the lack of a suitable location for an additional wildlife crossing structure farther south, the design team opted to end the wildlife fence at MP 126.7 rather than risk blocking wildlife movements with additional wildlife exclusion fencing along this section of SH 9. Given the number of cross-highway movements at the fence end and an increase in post construction WVC south of the mitigated project area (Chapter 8), further consideration of this situation may be warranted.

Figure 7-5. Mule deer attempting to cross SH 9 at-grade just beyond the south fence end.

The landscape in this portion of the study is mostly flat sagebrush and does not present opportunities for tying the fence end into a landscape feature such as a cliff, cut slope, or other habitat feature. Therefore, the focus must be on reducing the ability of animals to enter into the fenced ROW. Several locations in Colorado are currently evaluating the use of an erosion webbing embedded in the soil across the gap between the fence end to the edge of pavement to prevent wildlife entries. Preliminary results from US 160 in southwest Colorado found that while the majority of mule deer do not attempt breaching into the fenced ROW at all (as on SH 9), of those that do, mule deer were more likely to breach the erosion webbing deterrent (n=8) either entering into or exiting from the fenced ROW than to be repelled (n=6; Cramer and Hamlin 2021). These in-soil deterrents do not function when snow cover is over two inches deep and may not work well for SH 9, as the project area is within mule deer and elk winter range and has semi-persistent snow cover during the winter months when most mule deer are present. Another alternative would be to install a driver warning and animal detection system, signs with flashing lights, or a seasonally active variable message board at the fence end to alert drivers of potential wildlife highway crossing this location (Huijser et al. 2015). Presently, there are static signs warning drivers of the fence end.

Pedestrian Access Points

The breach rate at pedestrian access points was 11% for mule deer (*n*=32) and 4% for elk (*n*=2) in the two years during which monitoring was conducted at these locations. While these numbers appear low, these breaches into the fenced ROW may have been completely eliminated once CPW retrofitted them with swing gates at the summer of 2017, thereby potentially ending the possibility of WVC as a result of breach events at these locations. These findings, coupled with the findings from Montana on a Y-shaped pedestrian access point (Huijser et al. 2016), indicate that current designs for fence mazes or other openings in the fence may not be sufficient for preventing wildlife breaches into the ROW at pedestrian access points (Fig. 7-6).

Figure 7-6. Mule deer breaching into the ROW via a pedestrian access point.

Chapter 8. Wildlife-Vehicle Collisions and Benefit-Cost Analysis

RESULTS

Analyses of pre- and post construction WVC crashes and carcasses in the study area are helpful in determining how effectively the mitigation reduced WVC. Within the study area, the majority of wildlife movements occurred during the winter months (November through April), when mule deer and other species of ungulates move into the lower elevation valley where SH 9 bisects winter range. Consequently, this is also the timeframe when most WVC occurred due to winter driving conditions and decreased hours of daylight combined with higher concentrations of wildlife.

This chapter is presented in five sections: 1) WVC data capture by three WVC datasets; 2) the spatial distribution of pre- and post construction crashes and carcasses; 3) before-after analyses of WVC crashes and carcasses; 4) Before-After-Control-Impact (BACI) statistical analysis of crash and carcass data; and 5) benefit-cost analysis of the mitigation investment.

WVC Data Capture by Three WVC Datasets

Most crash datasets only capture a small portion of WVC (Olson 2013) and, as a result, carcass data are often used to supplement crash data. The analyses on the reduction of WVC included evaluations using compiled crash data, CDOT maintenance carcass data, which is collected year-round across the state, and carcass reports from BVR/CPW. The BVR/CPW dataset is the result of a long-term carcass reporting effort initiated by the ranch and supplemented by CPW staff, resulting in a remarkably consistent and well documented dataset spanning over 15 years. These three data sets allowed for a robust analysis of the changes in WVC reported crashes and carcasses over time.

A comparison of the three datasets revealed that over the five preconstruction winters, crash and carcass data compiled by CDOT accounted for 19% and 63%, respectively, of the WVC carcasses recorded by BVR/CPW (Table 8-1). The BVR/CPW carcass dataset is the most comprehensive and accurate of the three datasets. Because the BVR/CPW carcass data collection focused on the winter months and only within the project area, they were best suited to before-after analysis of WVC carcass rates as a result of the mitigation. Despite being less comprehensive, the crash dataset and the CDOT carcass dataset, both of which were collected year-round and across the state, were best suited for BACI analysis.

Table 8-1. Comparison of WVC data from crash reports, CDOT carcass reports and BVR/CPW carcass reports based on five winters of preconstruction data (Winters 2010-2011 through 2014-2015) in the mitigation project area (10.3 miles). Reporting rate is calculated relative to the BVR/CPW dataset.

Data Source	Total 5-year Preconstruction Winter WVC Count	Average Recorded Preconstruction WVC per Winter	Reporting Rate
CDOT Crash Data	61	12.2	19%
CDOT Carcass Data	199	39.8	63%
BVR/CPW Carcass Data	314	62.8	100%

Spatial Distribution of Pre- and Post Construction Carcasses

The distribution of BVR/CPW reported carcasses both pre- and post construction can help elucidate the problem areas within the wildlife mitigation. With construction occurring from April 2015 through November 2016, the post construction period accounts for only four years, from Winter 2016-2017 through Winter 2019-2020. Therefore, a comparison of carcass data was limited to four winters preconstruction (Winter 2011-2014 through Winter 2014-2015). Figures 8-1 and 8-2 depict the distribution of carcasses inside the fenced project area four winters preconstruction and four winters years post construction. Prior to construction, carcasses were distributed throughout the project area with the greatest concentration from MP 129 through MP 130. The lowest carcass numbers were in the northern portion of the project both pre- and post construction. Post construction carcasses decreased overall, with the highest peak in carcasses remaining at MP 129. The area near the south fence end (MP 126) had the smallest decrease in carcasses post construction, where four-year post construction WVC rate remained at 71% of the four-year preconstruction WVC rate (from *n*=7 to *n*=5).

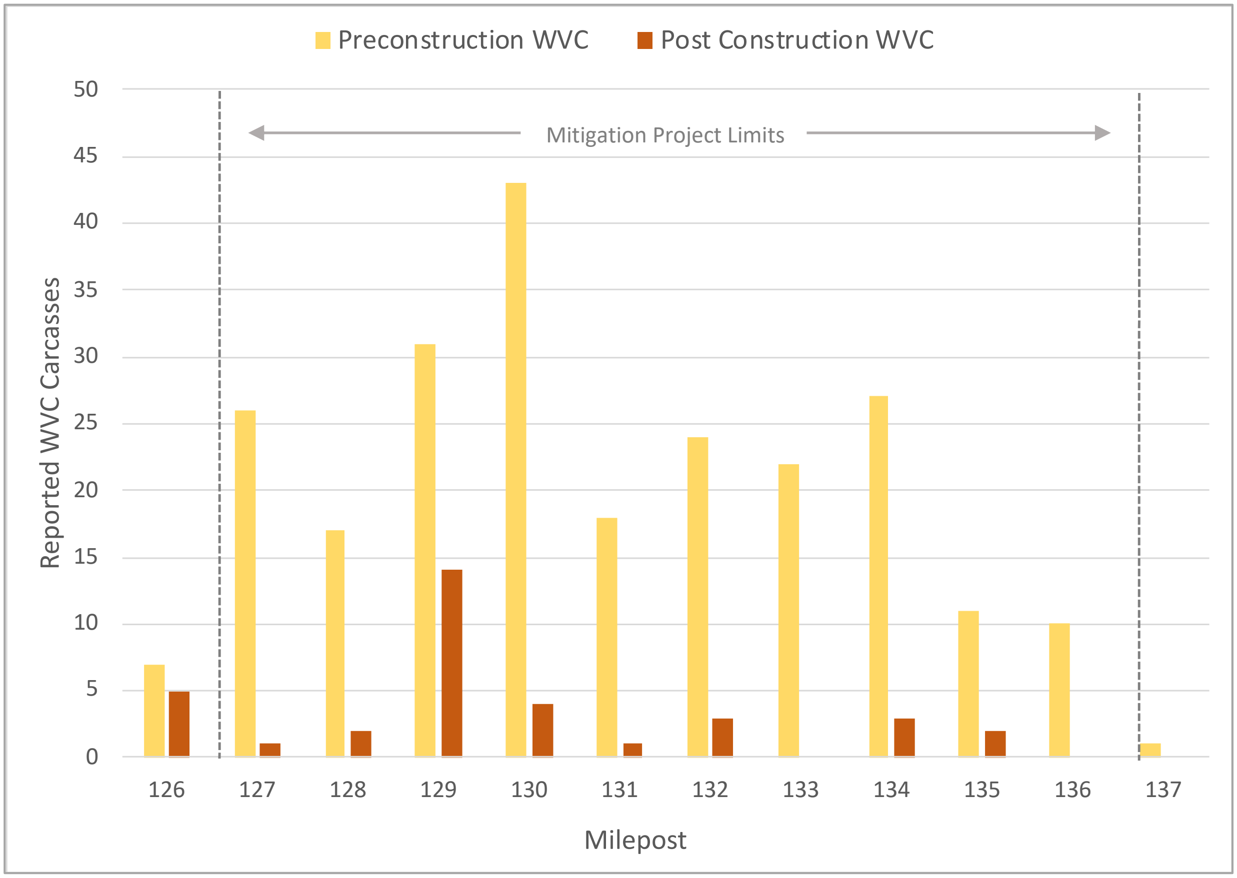

Figure 8-1. Distribution of BVR/CPW reported carcasses within the project area four years preconstruction (Winter 2011-2012 through Winter 2014-2015) and four years post construction (Winter 2016-2017 through Winter 2019-2020). Carcass data comparisons were curtailed to four years pre- and post construction due to the construction season from April 2015 through November 2016.

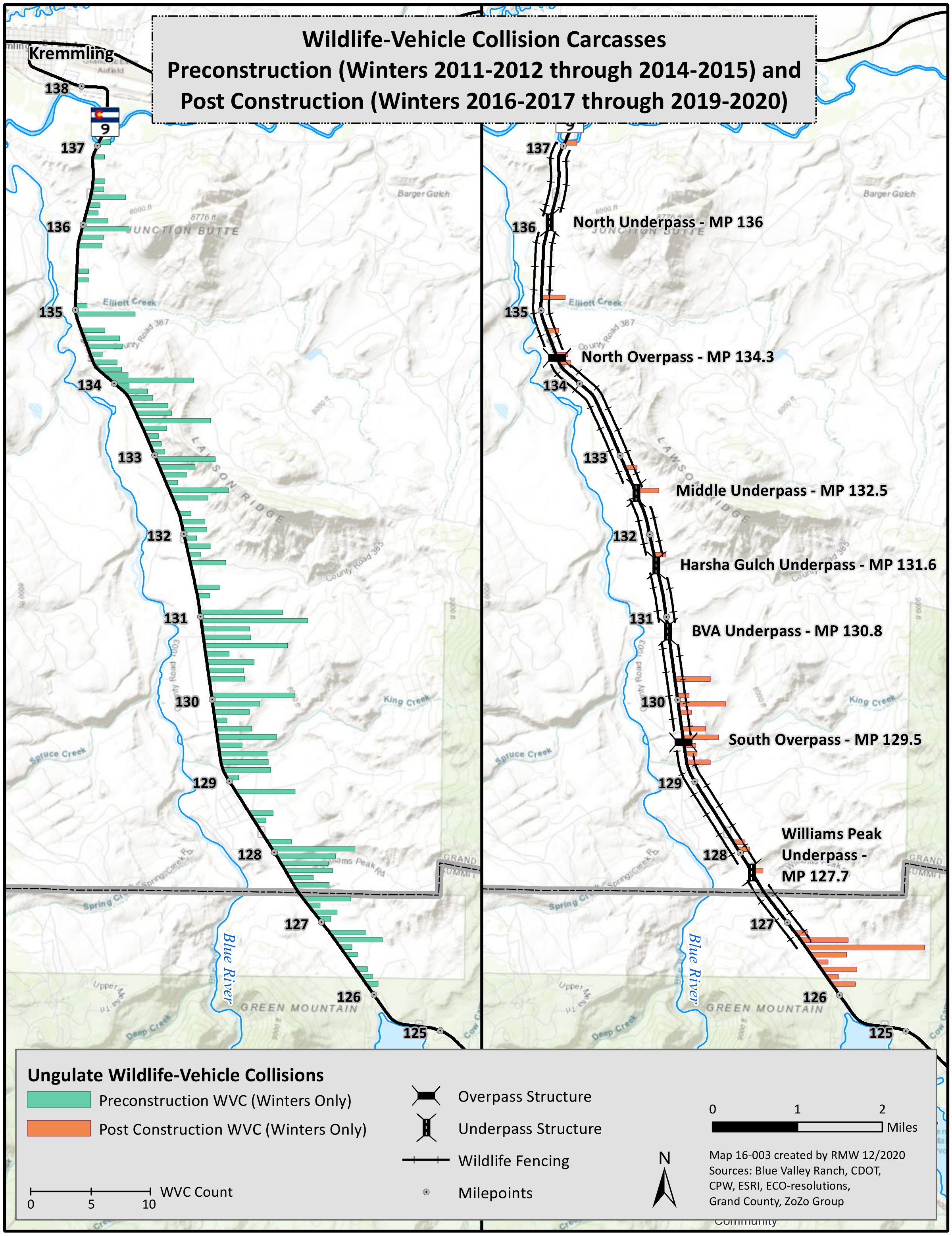

Figure 8-2. Map of the distribution of WVC carcasses reported by BVR/CPW four winters preconstruction (Winter 2011-2012 through Winter 2014-2015) and four years post construction (Winter 2016-2017 through Winter 2019-202). Carcass data comparisons were curtailed to four years pre- and post construction due to the construction season from April 2015 through November 2016.

Before-After Analysis of Wildlife-Vehicle Collision Carcasses and Crashes

The WVC crash and carcass datasets were analyzed to calculate the decrease in WVC detected in each dataset post mitigation construction. All three WVC datasets documented a decrease in WVC relative to the five-year preconstruction annual winter average (Fig. 8-3; Table 8-2). There was a 90% decrease in BVR/CPW annual winter carcass counts in each of the last two years of the study (6.5 carcasses per winter) when compared to the preconstruction annual winter average (62.8 carcasses). There was a 92% post construction decrease in reported crashes and CDOT carcasses relative to the five-year preconstruction averages of 12.2 crashes per winter and 39.8 carcasses per winter. In the final two years of the study, there was an annual average of one crash and three CDOT carcasses reported each winter.

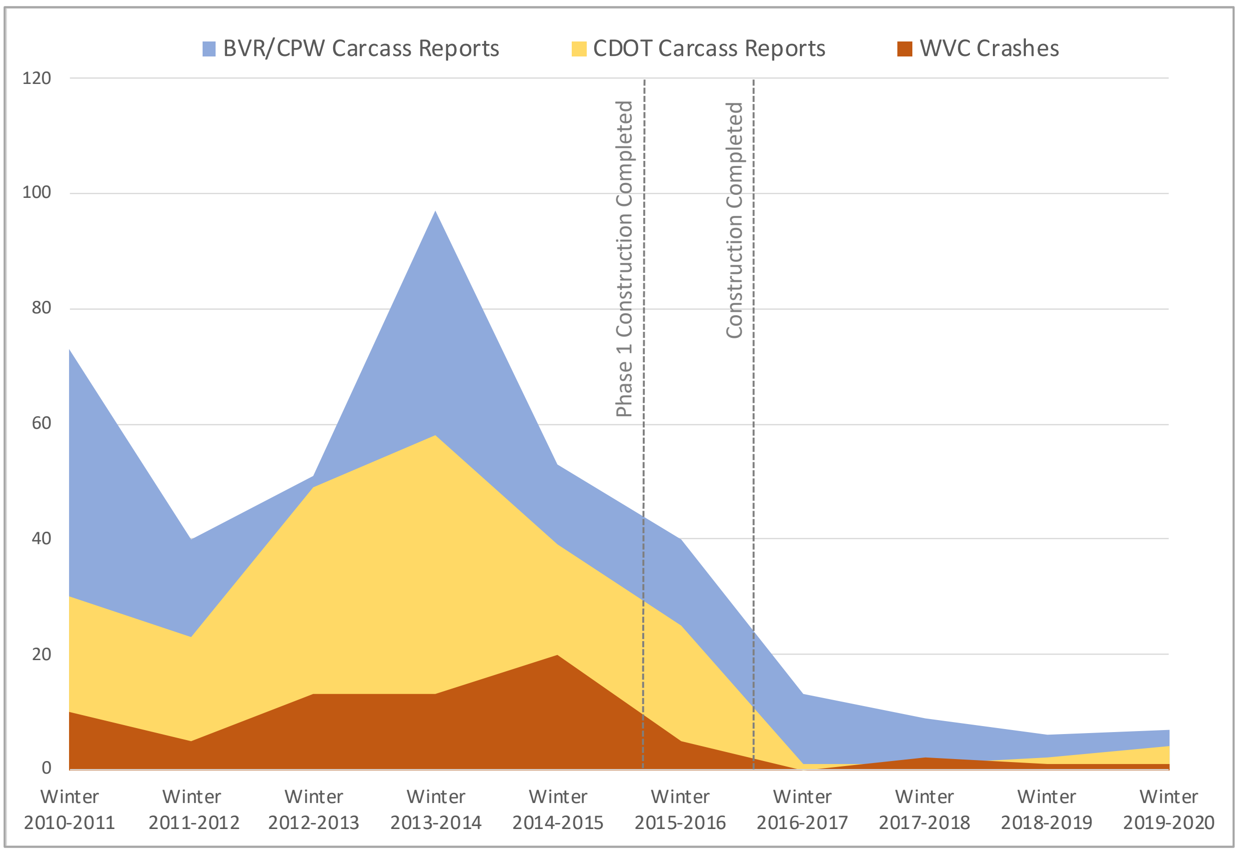

Figure 8-3. Pre- and post construction WVC carcasses and crashes reported each winter as documented by BVR/CPW carcass reports, CDOT carcass reports, and CDOT crash reports.

Table 8-2. Winter WVC carcass counts reported by BVR/CPW and CDOT Maintenance, and reported crashes during preconstruction, construction, and post construction periods.

Winter Year	BVR/CPW Carcasses	CDOT Maintenance Carcasses	CDOT Compiled Crashes
Preconstruction			
Winter 2010-2011	73	30	10
Winter 2011-2012	40	23	5
Winter 2012-2013	51	49	13
Winter 2013-2014	97	58	13
Winter 2014-2015	53	39	20
Annual Winter 5-Year Preconstruction Average	**62.8**	**39.8**	**12.2**
Construction			
Winter 2015-2016	40	25	5
Post Construction			
Winter 2016-2017	13	1	2
Winter 2017-2018	9	1	2
Winter 2018-2019	6	2	1
Winter 2019-2020	7	4	1
Final Two-Year Post Construction Average	**6.5**	**3**	**1**
Final Two-Year Post Construction WVC Decrease from Five-Year Preconstruction Average	**90%**	**92%**	**92%**

Given the more comprehensive nature of the BVR/CPW winter carcass reporting, this dataset was used to examine winter monthly (November through April) patterns in WVC pre- and post construction. Wintertime carcasses decreased from an average of 10.4 per month preconstruction to 1.1 WVC per month in the final two years post construction. Preconstruction winter carcass counts varied monthly and annually with the peak in carcasses generally occurring in January or

February (Fig. 8-4). Post construction carcass counts were much lower and had less variation from one month to the next, as compared to preconstruction. The first two years after construction was completed, the highest carcass counts were in November, as animals were arriving on winter range. In later years the highest carcass counts were in March, as animals began departing winter range for higher elevation summer habitats.

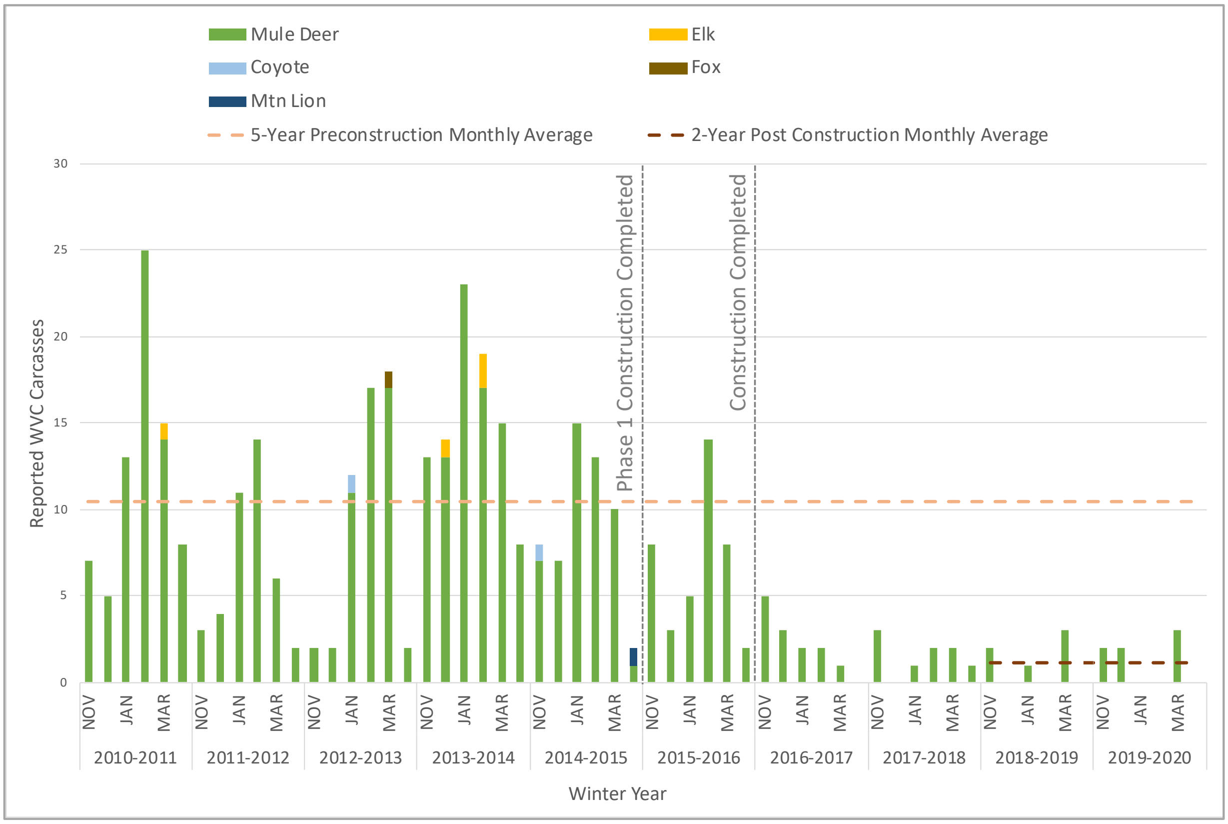

Figure 8-4. Monthly large mammal WVC carcass counts by species recorded by BVR/CPW during the winter months compared to the five-year preconstruction winter monthly average (10.4) and the final two-year post construction winter monthly average (1.1). Winter months include November through April.

The BVR/CPW summertime carcass collection effort was not consistently reported preconstruction, thus yearly patterns of WVC are best examined with the other WVC datasets. Both the CDOT carcass and the crash reports demonstrate that WVC rates were substantially lower during the summer months. CDOT carcasses decreased from an annual average of 41.4 carcasses during the five years preconstruction to an average of two carcasses per year post construction. Figure 8-5 displays the seasonal variation in CDOT WVC crashes pre- and post construction relative to the five-year preconstruction average of 14 crashes per year and the final two-year post construction average of 1.5 crashes per year.

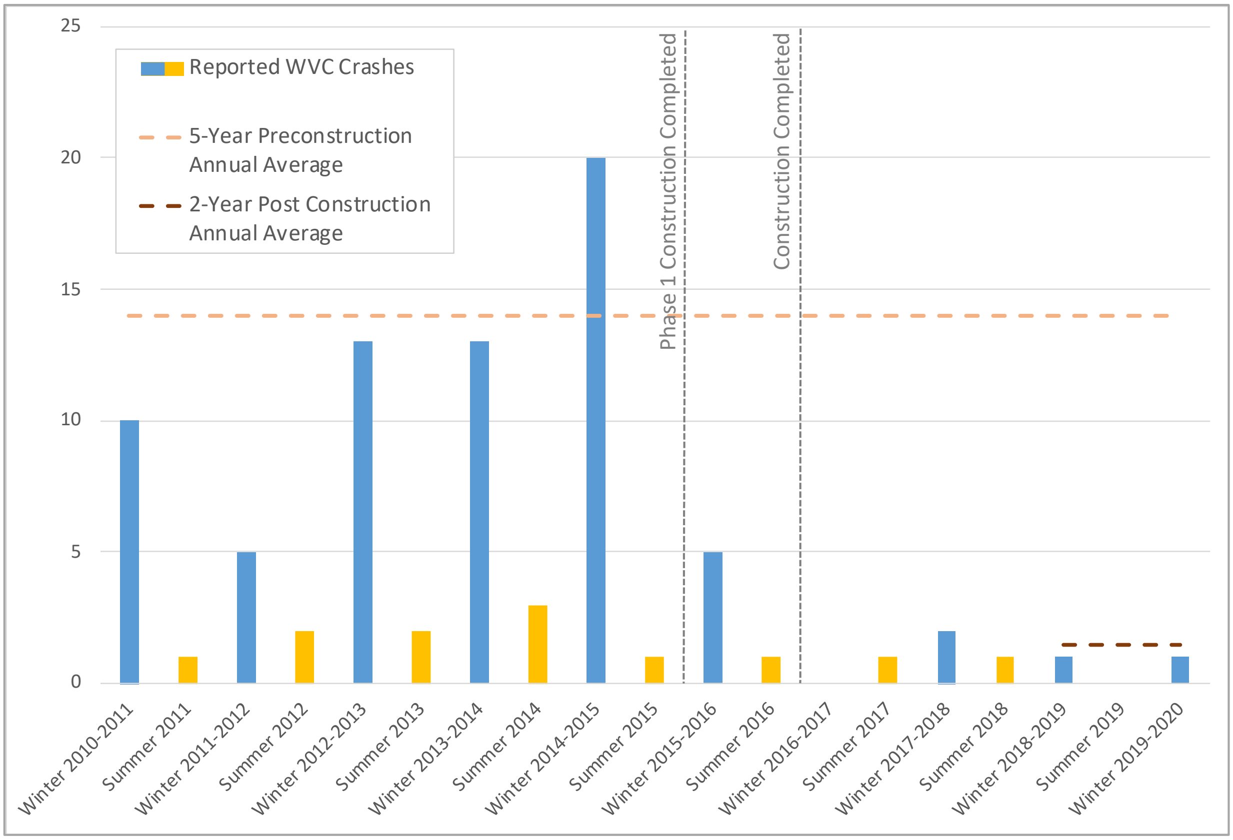

Figure 8-5. Wildlife-vehicle collision reported crashes by winter and summer seasons. The five-year preconstruction annual average was 14 crashes and the final two-year post construction annual average was 1.5 crashes.

Before-After Analysis of Wildlife-Vehicle Collisions at the South Fence End

BVR/CPW carcass reports were not collected south of the project area prior to 2013. Hence, preconstruction analyses of these data south of the fence end can only examined for the 2014 and 2015 preconstruction winters. The available data demonstrated that in the one-tenth mile, unmitigated are adjacent to the south fence end (MP 126.6), post construction carcasses were six times higher (*n*=6) in the final two years of the study compared to the two years preconstruction (*n*=1). Looking north into the mitigated project area, in the one-tenth mile segment north of the fence end (MP 126.7), carcass counts were the same pre- and post construction (*n*=4). An increase in post construction WVC in one-tenth-mile segments in either direction of the fence end was not detected in either CDOT carcass reporting or WVC crashes reports; however, these two datasets captured just 46% and 15%, respectively, of the post construction carcasses recorded in the BVR/CPW dataset.

Pre- and post construction differences in CDOT carcasses and crashes become apparent at a broader scale. One of the safety performance measures is that by the final year of the study, the average annual number of WVC reported crashes within one mile south of the project end will not increase over the five-year preconstruction average. Before-After analysis of reported WVC crashes in the one-mile segment beyond the south fence end (MP 125.7-126.6) demonstrates a 79% increase in WVC crashes in the final year of the study relative to the five-year preconstruction annual average (from 1.4 to 2.5 WVC crashes per year) beyond the fence end. In the same segment, reported CDOT carcasses decreased 52% post construction.

Before-After-Control-Impact Analyses of Wildlife-Vehicle Collision Carcasses and Crashes

The effect of the wildlife crossing structures, fencing and other mitigation on the frequency of WVC was assessed using a linear mixed model for a Before-After-Control-Impact (BACI) design. BACI analysis helps to control for changes in the landscape, weather, traffic, and wildlife populations by comparing changes in the rates of crashes and carcasses for control and impact (mitigated) road segments that were similarly influenced by changes in these variables over the same time period. The analysis was based on ungulate WVC reported by CDOT (deer and elk carcasses, and deer, elk, and unknown WVC crashes) collected during winter months in each of five years preconstruction (2010-2011 through 2014-2015) and three years post construction (2017-2018 through 2019-2020) on three highway segments. The post construction analysis period excluded Year 1 of the study when construction was still ongoing and Year 2, which was the first year following the completion of construction when animals were first encountering the mitigation. The impact segment was defined as the mitigation project area. Two segments served as controls – one on SH 9 south of the project area and one on US 40, a two-lane, east-west highway north of the project area (Table 8-3).

Table 8-3. CDOT WVC crash counts and CDOT carcass counts for the control and impact segments defined for the BACI analyses for five winters preconstruction (Winter 2010-2011 through 2014-2015) and three winters post construction (Winter 2017-2018 through 2019-2020).

Route Segment		**SH 9 MP 125-125.9**	**SH 9 MP 126.7-136.9**	**US 40 MP 186-194.9**
Control/Impact		Control	Impact	Control
Segment Length		1 mile	10.3 miles	9 miles
5-Year Preconstruction WVC	CDOT Carcass Count	19	199	50
	Annual Mean Number of Carcasses per Mile	3.8	3.9	1.1
	Reported WVC Crashes	1	61	21
	Annual Mean Number of Crashes per Mile	0.2	1.2	0.5
3-Year Post Construction WVC	Carcass Reports	19	7	19
	Annual Mean Number of Carcasses per Mile	6.3	0.2	0.7
	Reported WVC Crashes	2	4	27
	Annual Mean Number of Crashes per Mile	0.67	0.13	1

Carcass Data BACI Analysis Results

The preconstruction difference between the number of reported carcasses per mile in the control and impact segments was shown to be unlike the post construction difference (interaction $p < 0.001$). The mean numbers of carcasses per mile on the combined control segments were similar in the pre- and post construction periods (1.47 and 1.81, respectively; Figure 8-6), but the number of carcasses per mile on the impact segment decreased from pre- to post construction periods (3.678 and 0.194, respectively), suggesting that the mitigation effectively reduced the number of carcasses per mile on the impact segment relative to control segments.

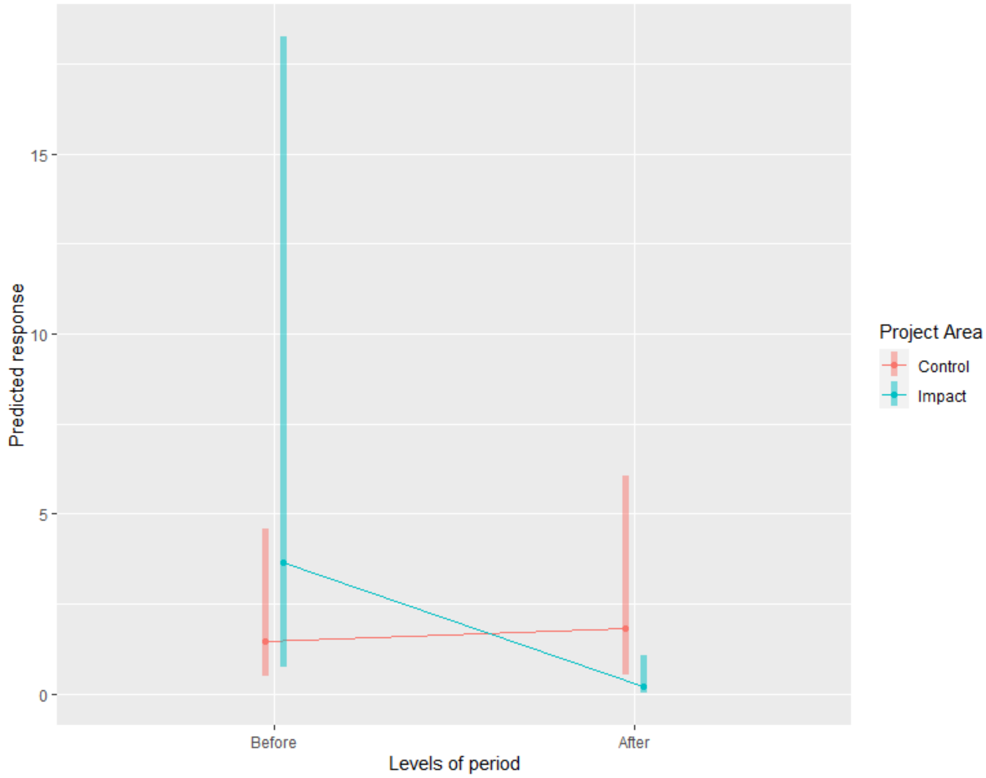

Figure 8-6. Estimated mean number of WVC carcasses per mile by project area and period, with 95% confidence interval.

Crash Data BACI Analysis Results

The preconstruction difference between control and impact groups was shown to be unlike the post construction difference (interaction $p < 0.001$). The mean number of crashes per mile on control segments in the preconstruction period (0.162) was similar to the mean in the post construction period (0.355; Figure 8-7), but the number of crashes per mile on the impact segment decreased from preconstruction to the post construction period (1.084 and 0.124, respectively), suggesting that crossing structures and fencing effectively reduced the number of WVC crashes per mile on the impact segment relative to control segments.

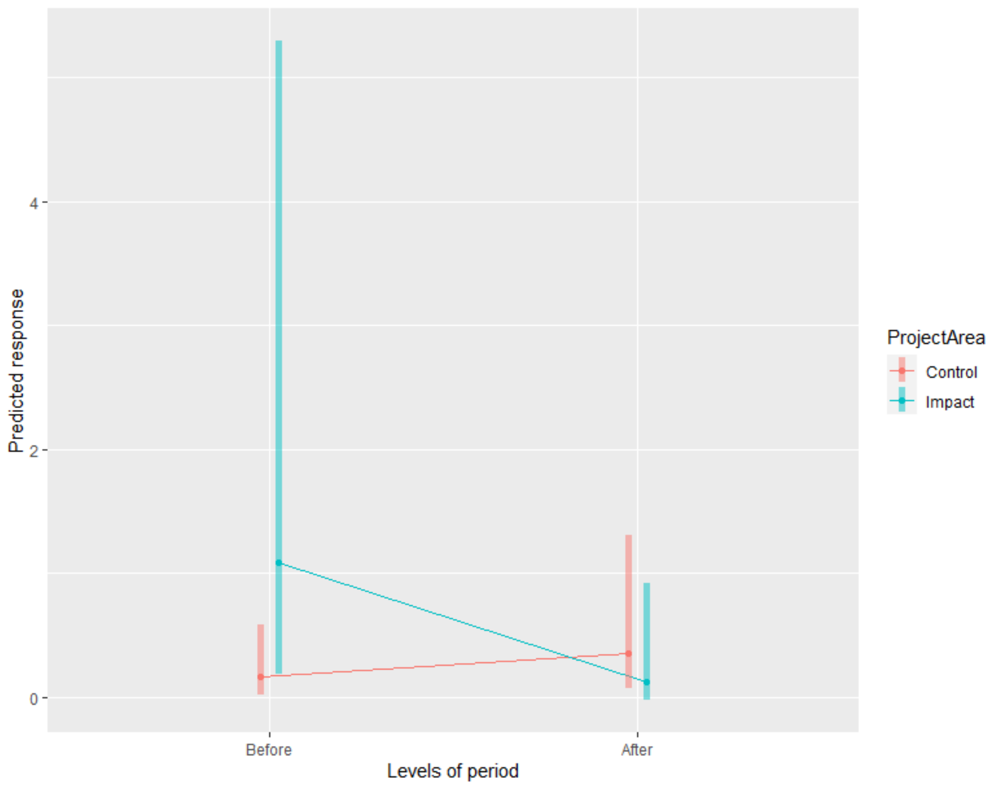

Figure 8-7. Estimated mean number of WVC crashes per mile by project area and period, with 95% confidence interval.

Benefit-Cost Analysis of Mitigation Investment

A benefit-cost analysis using valuations described in Kintsch et al. (2019) indicated that the investment in wildlife mitigation on SH 9 saves $280,040 in costs to society each year as a result of the reduction in WVC crashes. These cost savings include the direct (medical costs, crash cleanup) and indirect (lost productivity and wages, lost quality of life) costs of a crash and the value of the wildlife killed in WVC. The value of wildlife killed in WVC is calculated for both reported crashes and carcasses (less the number of reported crashes to avoid double counting) that are indicators of WVC but for which no associated damage or injury costs are assumed. The payoff period for these investments is 56 years, which is 25% less than the minimum 75-year lifespan of the crossing structures (Table 8-4). This is a high-end estimate that does not include increases in the cost of crashes and value of wildlife over time or discounted costs over the life of the crossing structures. This benefit-cost analysis also does not include other unquantifiable benefits or passive values such as wildlife population health or the ecosystem value of connectivity.

Table 8-4. Benefit-cost analysis based on five years of preconstruction CDOT crash and BVR/CPW carcass data. All costs are in 2016 dollars, the year that construction was completed. Total mitigation project cost includes unit and installation costs for seven wildlife crossing structures, fencing, and associated mitigation features.

Cost Description	Unit Cost Source	Units	Unit Cost (2016 $)	Total Cost
Injury accident	CDOT Traffic and Safety (2016)	2	$96,100	$192,200
Property damage only accident		58	$10,200	$591,600
Value of deer killed in reported accidents	Carcass reports (BVR/CPW) CDOT/CPW valuations (Kintsch et al. 2019).	57	$2,007	$114,399
Value of elk killed in reported accidents		3	$2,329	$6,987
Value of additional reported deer carcasses		323	$2,007	$648,261
Value of additional reported elk carcasses		1	$2,329	$2,392
Total 5-year Cost of WVC (prior to the mitigation)				**$1,555,776**
Average Annual Cost of WVC (prior to the mitigation)				**$311,155**
Total Mitigation Project Cost				**$15,755,144**
Average Annual Cost Savings (90% Crash Reduction)				**$280,040**
Payoff Period				**56 Years**

DISCUSSION

The discussion address three topics: 1) the evaluation of how well the wildlife mitigation met the WVC performance measures; 2) factors that may have contributed to the reduction of WVC; and 3) whether wildlife crossing structures in mule deer winter range are worth the cost.

Performance Measures Evaluation

Both safety performance measures related to WVC rates within the mitigation project area were met. The performance measure evaluating changes in WVC rates south of the project area was not met (Table 8-5).

Table 8-5. Safety performance measures evaluation.

Performance Measure	Met	Not Met
The annual average number of reported WVC 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 preconstruction average.	✔	
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 preconstruction average.	✔	
By the final year of the study, the average annual number of reported WVC crashes within one mile south of the south fence end will not increase over the five-year average annual preconstruction crash rate for this section of road.		✔

Reduction in Reported WVC Carcasses and Crashes

In the final two years of the study, reported WVC crashes decreased by 92% and BVR/CPW carcasses decreased by 90% in the mitigation project area, confirming that the first two performance measures were met. Despite differences among the three WVC datasets, each documented similar decreases in WVC. The decrease in WVC started immediately following construction of the Phase 1 (north) portion of the project in Year 1, and with the completion of construction activities in Year 2, decreased by 80%. No elk-vehicle collisions were documented inside the fenced mitigation area post construction, despite elk having been documented entering into fenced right-of-way via the wildlife guards (Chapter 5) and the south fence end (Chapter 7).

Immediately south of the mitigation project, in the mile beyond the south fence end (MP 125.7 – 126.6) the annual average number of reported crashes increased 79% in the final two years of the study relative to the five-year preconstruction average from 1.4 WVC to 2.5 WVC per year, all of which involved mule deer. This performance measure was not met, and these results suggest a continued need for cross-highway wildlife movement beyond the south fence end and that the mitigation may not fully capture the WVC hotspot.

Had the mitigation project not been constructed, WVC with mule deer along SH 9 would be predicted to increase over time, based on mule deer herd numbers and annual traffic volumes. CPW population estimates for the Middle Park herd, of which the Blue River valley is a subpopulation, fluctuated between 15,242 and 17,965 from 2010-2019. During this timeframe, traffic volumes increased from 2,800 vehicles per day to 3,900 vehicles per day. Despite fluctuations in the mule deer herd size and management designed to bring the herd size closer to the objective of 10,500-12,550 deer (Lamont 2020), WVC would be expected to remain stable or increase over time with additional increases in traffic volume (Charry and Jones 2009, Jaeger 2005). In light of this prediction, the 90-92% reduction in WVC carcasses and crashes achieved as a result of the mitigation project has major safety and wildlife benefits: an average of 13 crashes and 56 WVC mule deer mortalities will be prevented in this segment each year.

The BACI analysis allowed an evaluation that controlled for changes in traffic volume, mule deer population size, and other landscape-scale variables that may influence crash rates. The dramatic decrease in WVC crashes and carcasses in the mitigated-impact area, and the relatively stable and even increasing WVC crashes and carcasses in the control areas support the assertion that the wildlife crossing structures mitigation system has been effective in reducing WVC on SH 9.

The decreases in reported carcasses (90-92%) and reported WVC crashes (92%) on SH 9 were greater than the decreases in WVC observed in other mule deer mitigation projects. Sawyer et al. (2012) documented a 79% decrease in mule deer WVC on a two-lane highway in central Wyoming following the construction of two overpasses and six bridge underpasses. In southeast Wyoming, Sawyer and Rodgers (2015) reported an 81% decrease in deer-vehicle collisions following the construction of seven large box culverts and 13 miles of fencing on a two-lane highway. In southern Utah, the construction of 12.5 miles of wildlife fencing in conjunction with three new and four existing wildlife crossing structures resulted in a 53% decrease in reported crashes (Cramer and Hamlin 2019). The SH 9 wildlife mitigation is among the top performing mitigation projects in the western U.S. In ongoing studies in Arizona, mitigation projects on State Road 260 that performed well initially saw an increase in WVC crash over time. It is believed that this is due, in large part, because the wildlife exclusion fence was not maintained (N. Dodd, personal communication, 2020). It is important that the SH 9 fence, guards, and escape ramps be maintained over time to continue keeping the road safe for motorists and wildlife.

What Factors Influenced Post Construction WVC?

While the mitigation resulted in a 90-92% decrease in WVC carcasses, post construction WVC were not evenly distributed in the project area. The highest concentration of post construction WVC occurred between MP 129.2 – 130.2. This section of roadway includes the South Overpass, where the third highest rate of successful mule deer passages was recorded (Chapter 3). The high concentration of mule deer activity in this portion of the project area combined with the presence of six wildlife guards in the mile-long segment were likely contributing factors in the number of post construction WVC observed. Wildlife guards, while important components of a wildlife crossing mitigation system, are semi-permeable, depending on the guard characteristics and other factors such as snow build-up in the guards – an issue documented at the Shaw Guard (MP 130.1), which had the highest breach rate (62%) of all the monitored wildlife guards (Chapter 5). In comparison, no post construction WVC were recorded in the mile-long section of roadway around the BVA Underpass (MP 130.8), which had the greatest number of preconstruction WVC and the highest rate of successful mule deer passages post construction. This road segment contains only one wildlife guard – a round bar guard at County Road 1002 with a breach rate of 10%. Other contributing factors to this post construction WVC concentration in the project area may have included deer exploiting gaps in the fencing where the fence did not fully reach the ground level; when a vehicle ran off the road and created a temporary hole in the fence; or when a gate was temporarily left open. As determined by other monitoring studies (e.g., Sawyer et al. 2102, Sawyer and Rodgers 2015), these findings reinforce the conclusion that better management of the fence infrastructure, including preventing snow build-up in the wildlife guards, ensuring that gates remain closed and that damaged fence segments are quickly repaired, would further reduce WVC in mitigated highway segments.

A second concentration of post construction WVC was detected within 0.1 miles of the south fence end, similar to results reported by Huijser et al. (2016) on US 93 North in Montana. This fence end effect was most evident in the one-tenth-mile segment immediately beyond the south fence end, where BVR/CPW carcass reports increased 83% from the two years preconstruction to the two years post construction. Whereas, inside the fenced segment carcass reports remained constant pre- and post construction from the fence end for one-tenth-mile north. These results indicate the continued need for cross-highway wildlife movement beyond the mitigated project area, which does not fully encompass the WVC hotspot. Ongoing WVC inside the mitigation project area near the fence end suggest that the fence end design is not preventing wildlife from entering into the ROW around the fence end (Chapter 7). No increase in WVC was associated with the north fence end, which ties into a bridge over the Colorado River and, north of which, WVC were low both pre- and post construction.

Monitoring research in Utah similarly reported an increase in WVC at fence ends (Cramer and Hamlin 2019). However, other studies of wildlife crossing structures and fencing have not detected an increase in WVC beyond a fence end where wildlife was able to move freely across a highway at-grade (e.g., Sawyer et al. 2012), suggesting that these other mitigation projects fully captured cross-highway wildlife movements and associated WVC hotspots. Despite lingering issues at discrete locations, the SH 9 mitigation project has successfully reduced WVC in this segment.

The wildlife-highway mitigation on SH 9 does not appear to be influencing WVC rates on US 40, which was used as a control segment for the BACI analysis. Wildlife-vehicle collision carcasses reported by CDOT on US 40 were relatively high in Winter 2010-11 and again in Winter 2015-16, the latter timeframe corresponding with construction of Phase 1 mitigation on SH 9. However, each winter post construction, WVC carcass counts on US 40 from MP 186-195 were lower than the preconstruction average of 10 WVC carcasses for this segment, with the exception of Winter 2019-2020, which saw a total of 12 WVC carcasses. These variations in WVC rates on US 40 may be due to a number of factors outside of the mitigation on SH 9, such as annual weather and snow depths, variation in mule deer and elk population numbers, traffic volumes, and human activity in the landscape.

Are Wildlife Crossings in Mule Deer Winter Range Worth the Cost?

With an observed 90% reduction in WVC, the results of the benefit-cost analysis demonstrated that the mitigation investment on SH 9 will pay for itself in 56 years in terms of the costs of prevented WVC. This estimated payoff period is likely overly conservative as it does not account for the costs to motorists of collisions that are not reported to law enforcement (often less than $1,000 in property damage per incident); discounted costs over the life of the crossing structures; passive values resulting from increased connectivity and decreased WVC; or the value to motorists and communities of avoiding collisions with wildlife.

The benefit-cost analysis demonstrated that the payoff period is less than the minimum lifespan of 75 years of the wildlife crossings infrastructure. The benefits derived from investing in the SH 9 wildlife crossings project outweigh the costs of construction and ongoing maintenance. While this is the first monitoring study to document the benefits and costs of a wildlife crossing mitigation system in mule deer winter range, other studies have documented the benefits of mitigation on mule deer migration routes in locations with high WVC (e.g., Sawyer et al. 2012, Sawyer and Rodgers 2015, Stewart 2015).

Chapter 9. Recommendations

Multiple recommendations were derived from five years of monitoring the wildlife crossing mitigation system on SH 9. These recommendations are categorized as: recommendations for maintenance and adaptive management on SH 9; recommendations to inform future wildlife mitigation projects; and recommendations for future wildlife monitoring research studies. Recommendations to inform future wildlife mitigation projects and future wildlife monitoring research are not exhaustive and are focused on the specific findings of this study.

RECOMMENDATIONS FOR MAINTENANCE AND ADAPTIVE MANAGEMENT ON SH 9

Maintenance Recommendations

- Regularly inspect the fencing (minimum twice a year) for holes, gaps, and other repairs, such as where erosion causes gaps under the fence. Consider creating a process for engaging partner agencies and organizations as well as the local community to assist in reporting fence repair needs to the local CDOT Maintenance office. Budgeting for annual maintenance of the wildlife fence, wildlife guards, and escape ramps is essential.
- Add soil to the tops of escape ramps where the soil has settled below the height of the backing boards and inspect escape ramps annually.
- Inspect wildlife guards annually for damage and sediment build up in the vaults and coordinate with county and private plow drivers to minimize snow becoming packed in between the bars or along the edges of the wildlife guards.
- Inspect gate hardware to assure that gate latches and hinges are functioning properly; install gate hardware that can sustain daily use over time.

Adaptive Management Recommendations

- Investigate whether lower ramp heights will improve escape rates at escape ramps. To this end, CPW, with support from BVR, initiated an adaptive management study in fall 2020. Ramp height was adjusted to 5’5” at a subset of escape ramps by building up the soil on the landing pad. A Before-After-Control-Impact study design will support additional analysis of the effect of ramp height on ungulate escape rates. This study will be completed in 2022.

- Retrofit the south fence end to reduce wildlife entry into the fenced right-of-way. Consider the use of break-away posts to bring the fence end closer to the pavement edge inside the clear zone (Gagnon et al. 2020) or other alternatives. To address ongoing WVC south of the project area over the long term, extend the mitigation (crossing structures, fencing and associated features) farther south to fully encompass the WVC hotspot and ongoing at-grade wildlife movements across SH 9. Implementing this recommendation would require additional funding and coordination with local partners.
- Enhance small mammal passages at underpasses and overpasses by adding logs, stumps, and large boulders through or on the structures.

RECOMMENDATIONS TO INFORM FUTURE WILDLIFE MITIGATION PROJECTS

Crossing Structures

- Both the overpass and underpass designs used on the SH 9 project are recommended as effective crossings for mule deer and may be sufficient for elk as they adapt to crossing structures over four or more years.
- Locate wildlife crossing structures in areas traditionally used by wildlife to maximize crossing structure use. Crossing structures that are well designed for the target species and generally located in the portions of the landscape where wildlife is concentrated and most active will have the greatest benefit in maintaining or restoring connectivity.
- Include a variety of structure types and sizes with adequate spacing to accommodate ungulates and carnivores with different structure preferences, including non-target species that are also present in the project area.
- Overpasses are recommended to facilitate movements by bighorn sheep, across genders and demographic groups.
- Carefully consider drainage through a wildlife underpass to prevent icing inside the underpass during the winter months. If local drainage is not addressed, icing may become problematic even at crossing structures where a separate drainage culvert is provided.

- Create micro-terrain and add cover features for small fauna on overpasses and at underpasses to compensate for the lack of vegetation cover in the first few years following construction.
- Box and pipe culverts that are 7.5-8 feet wide and high and 100 feet or longer are not adequate for mule deer passage but do function well for black bear and bobcat.

Wildlife Guards

- Where possible, a round bar guard design is recommended to prevent breaches into the fenced right-of-way, although further study of this guard design is needed. However, round guards can be nosier and rougher for drivers to cross.
- Install angle iron on the support beams of both flat bar and round bar wildlife guards.
- Continue installing wildlife guards without concrete sides, with the wildlife fence abutting the edge of the guard and extending the entire length of the wildlife guard.
- Explore alternatives for facilitating pedestrian movements through the fencing near wildlife guards where people with children and small pets need to cross the guards.

Escape Ramps

- Site escape ramps near fence ends and in locations below the road grade to maximize use by ungulates that become trapped in the fenced right-of-way.
- Findings from the SH 9 study recommend constructing ramps without perpendicular rail fence.
- A ramp height of 5' to 5'6" is recommended where mule deer is the primary target species. Higher ramp heights (up to 6') may be appropriate in project areas where elk are abundant and the primary target species (Gagnon et al. 2020).
- A ramp slope of 3:1 or less is recommended. Investigate the effectiveness of escape ramps with flatter slopes, e.g. 4:1 or less, to determine whether flatter slope ramps may be more effective at intercepting wildlife in the right-of-way. Also continue exploring other ramp designs.

- Use seed mixes with lower stature vegetation on and immediately surrounding escape ramps to increase ramp visibility by approaching wildlife. Trim vegetation annually or as needed to prevent the view of the escape ramp from becoming obscured.
- Construct escape ramps without a void against the ramp backboard and do not leave the moisture barrier at the top of the ramp exposed.

Wildlife Fence

- Explore other design options at wildlife fence ends to discourage breaches into the fenced right-of-way where the fence end cannot be tied into a landscape feature. This may include continued investigation of the use of erosion control webbing between the pavement edge and the fence end as on US 160, US 285, and I-25 in Colorado; or install break-away posts to bring the fence end closer to the pavement edge inside the clear zone (Gagnon et al. 2020). However, the proportion of wildlife entering into the ROW at the fence end must be evaluated relative to the cost of additional fence end mitigation.
- Continue exploring new design alternatives for permitting pedestrian access through the fencing while preventing wildlife breaches into the fenced ROW. Two designs for pedestrian mazes through fencing have proved ineffective at preventing breaches into the ROW (the present study and Huijser et al. 2016).

RECOMMENDATIONS FOR FUTURE WILDLIFE MONITORING RESEARCH STUDIES

- Ideally, monitoring research would include at least one-year preconstruction. Despite a limited field of view, preconstruction camera monitoring can provide an accurate reflection of post construction crossing structure use by different species.
- A minimum three-year study period is necessary to document wildlife use of the crossing structures under changing seasonal and annual conditions. Monitoring studies less than five years long are unlikely to capture adaptation periods by some species or document a plateau in crossing structures use within a natural range of variation. While continuous monitoring over the entire study period may not always be necessary depending on the research goals, one should be aware of what may be missed by monitoring only during

targeted timeframes. On SH 9, monitoring only during the winter season would have missed the diversity of wildlife that used the crossing structures during the rest of the year. Time and effort to deploy and remove equipment for each study period should also be considered.

- Establish performance measures at the outset of a research study and include measures that evaluate the effectiveness of wildlife crossing structures in providing functional connectivity for all target species, including movements by all genders and age classes and in numbers representative of the population.
- Use top quality motion triggered cameras. The Reconyx cameras performed exceptionally well over the five-year study and in temperatures that regularly dropped below -10 degrees Fahrenheit and as low as -30 degrees Fahrenheit for extended periods.
- Continue to explore new advances in camera technologies, including thermal versus visual photos, long-range cameras, and video. Keep in mind the limitations of different cameras.
- Incorporate the use of emerging artificial intelligence programs to assist in image processing but be cautious in balancing the gains in efficiency with potential data losses.
- Work with state and federal agency partners and tribes to initiate GPS collar studies of wildlife movements to help locate wildlife crossings in the most optimal locations.
- Share monitoring results and the importance of carcass data reporting with CDOT Maintenance personnel to help encourage consistent and spatially accurate carcass reporting. CDOT and CPW are in the process of developing and piloting a carcass reporting app, which will also enhance carcass data quality.

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Appendix A

MONITORING LOCATIONS

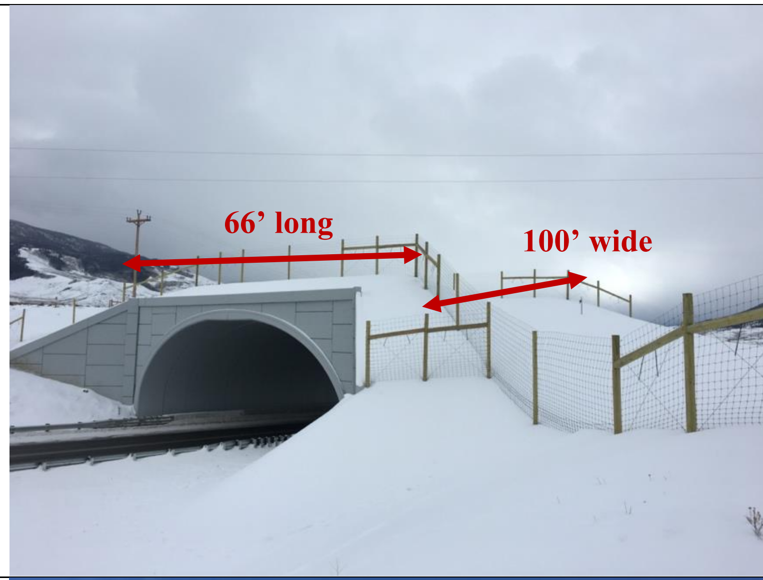
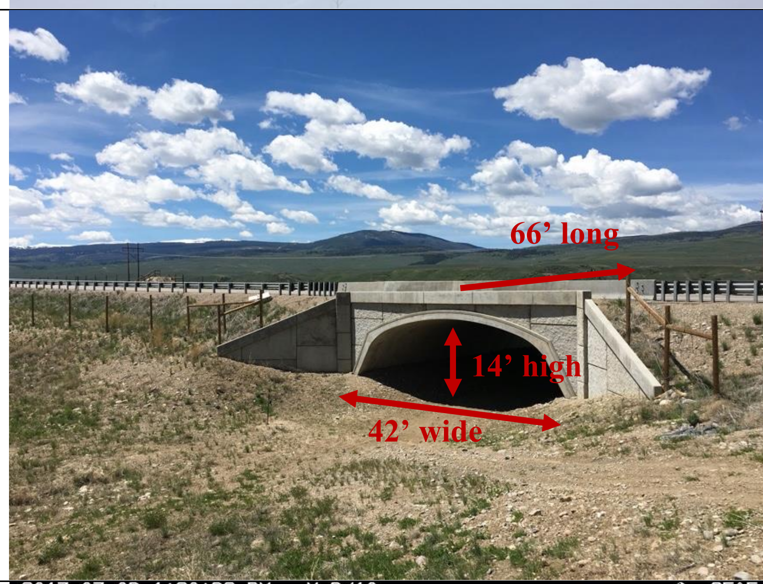
Monitoring locations and structure specifications. Monitoring activities commenced in the Phase 1 (north) segment in December 2015. Monitoring in the Phase 2 (south) segment commenced following the completion of all construction activities in the fall of 2016. Camera monitoring periods are defined as: Year 1 (December 2015 – April 2016); Year 2 (May 2016 – April 2017); Year 3 (May 2017 – April 2018); Year 4 (May 2018 – April 2019); Year 5 (May 2019 – April 2020). Monitoring locations are listed in the table below from north to south, reflecting the construction phasing. Photos depicting each type of mitigation feature follow.

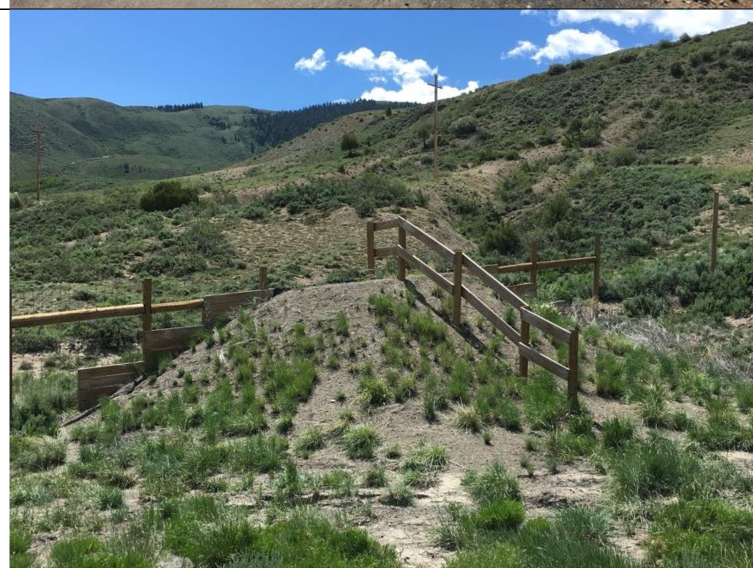
MP	LOCATION NAME	MITIGATION TYPE	SPECIFICATIONS	MONITORING PERIOD	NOTES
PHASE 1 (NORTH) SEGMENT – CONSTRUCTED SUMMER/FALL 2015					
137.0	Colorado River Bridge	Bridge Underpass	Existing bridge	Year 3	Human activity and camera malfunctions prevented a longer monitoring period
136.9	County Road 33 Wildlife Guard	Wildlife Guard	Flat bar	Years 1-5	
136.9	Thompson Wildlife Guard	Wildlife Guard	Round bar (flat bar Yr. 1)	Years 1-5	Replaced with round bar July 2016
136.8	Thompson Escape Ramp	Escape Ramp	2:1 slope with rail fence	Year 1-2	
136.6	Trough Road Wildlife Guard	Wildlife Guard	Flat bar	Years 1-5	
136.6	Trough Road 3:1 Escape Ramp	Escape Ramp	3:1 slope without fence	Years 2-5	Constructed Summer 2016
136.5	Trough Road 2:1 Escape Ramp	Escape Ramp	2:1 slope with rail fence	Years 2-5	
136.0	North Underpass	Arch Underpass	42'W x 14'H x 66'L	Years 1-5	
136.0	North Underpass Habitat	Adjacent Habitat	Habitat camera	Years 1-5	
135.9	SWA Escape Ramp	Escape Ramp	2:1 slope with rail fence	Year 1-2	
135.6	SWA Pedestrian Gate	Pedestrian Gate	n/a	Years 1-2	Gated Fall 2017
135.1	Culbreath 2:1 Escape Ramp	Escape Ramp	2:1 slope with rail fence	Years 2-5	
135.1	Culbreath 3:1 Escape Ramp	Escape Ramp	3:1 slope without fence	Years 2-5	Constructed Summer 2016
135.1	Culbreath Concrete Box Culvert	Small Culvert	8’W x 7.5’H x 99’L	Years 2-5	

MP	LOCATION NAME	MITIGATION TYPE	SPECIFICATIONS	MONITORING PERIOD	NOTES
135.1	Culbreath Wildlife Guard	Wildlife Guard	Round bar (flat bar with pedestrian grate Yr. 1)	Years 1-3	Replaced with round bar July 2016
134.5	Rusty Spur Wildlife Guard	Wildlife Guard	Flat bar with pedestrian grate	Year 1	Location gated Summer 2016
134.3	North Overpass Escape Ramp	Escape Ramp	2:1 slope without fence	Years 1-5	
134.3	North Overpass	Overpass	100'W x 66'L	Years 1-5	70’ wide between fences
134.3	North Overpass Habitat East	Adjacent Habitat	Habitat camera	Years 1-5	
134.3	North Overpass Habitat West	Adjacent Habitat	Habitat camera	Years 1-5	
134.2	BVR Concrete Pipe Culvert	Small Culvert	8’ diameter x 193’L	Year 1-2	Plus 23’L concrete drainage trough
133.8	BVR Concrete Box Culvert	Small Culvert	8’W x 6’H X 132’L	Years 2-5	Plus 30’L concrete drainage trough
132.5	Middle Underpass	Arch Structure	42'W x 14'H x 66'L	Years 1-5	
132.5	Middle Underpass Habitat	Adjacent Habitat	Habitat camera	Years 1-5	
132.4	BLM Pedestrian Gate	Pedestrian Gate	n/a	Years 1 & 2	Gated Fall 2017
131.6	Harsha Gulch Wildlife Guard	Wildlife Guard	Flat bar	Year 1-2	
131.6	Harsha Gulch Underpass	Arch Underpass	42'W x 14'H x 66'L	Years 1-5	
131.6	Harsha Gulch Habitat	Adjacent Habitat	Habitat camera	Years 1-5	
131.6	Harsha Jump down Escape Ramp	Escape Ramp	Jump down without rail fence	Years 3-5	Ramp graded into natural downslope

MP	LOCATION NAME	MITIGATION TYPE	SPECIFICATIONS	MONITORING PERIOD	NOTES
PHASE 2 SEGMENT – CONSTRUCTED SUMMER/FALL 2016					
130.8	BVA Underpass	Arch Underpass	42'W x 14'H x 66'L	Years 2-5	
130.8	BVA Habitat	Adjacent Habitat	Habitat camera	Years 2-5	
130.8	CR 1002 Wildlife Guard	Wildlife Guard	Round bar	Years 2-5	
130.1	Shaw Wildlife Guard	Wildlife Guard	Flat bar with pedestrian grate	Years 3-5	
129.7	CR 1000 Wildlife Guard	Wildlife Guard	Flat bar	Years 2-5	
129.5	South Overpass	Overpass	100'W x 66'L	Years 2-5	68’ wide between fences
129.5	South Overpass Habitat	Adjacent Habitat	Habitat camera	Years 2-5	
129.1	Badger Road Escape Ramp	Escape Ramp	3:1 slope without fence	Years 2-5	
129.0	Badger Road Wildlife Guard	Wildlife Guard	Round bar	Years 3-5	Half of fence along length of the guard removed late summer 2017
128.5	Triangle Road Wildlife Guard	Wildlife Guard	Round bar	Years 2-5	
128.5	Spring Creek Wildlife Guard	Wildlife Guard	Flat bar	Years 2-5	
128.5	Spring Creek Escape Ramp	Escape Ramp	3:1 slope without fence	Years 2-5	
128.4	South Spring Creek Escape Ramp	Escape Ramp	3:1 slope with rail fence	Years 2-5	
128.0	Summit County Pedestrian Gate	Pedestrian Gate	n/a	Year 2	Gated Fall 2017

MP	LOCATION NAME	MITIGATION TYPE	SPECIFICATIONS	MONITORING PERIOD	NOTES
127.7	Williams Peak Underpass	Arch Underpass	42'W x 14'H x 66'L	Years 2-5	
127.7	Williams Peak Habitat	Adjacent Habitat	Habitat camera	Years 2-5	
126.7	East Fence End Escape Ramp	Escape Ramp	3:1 slope without fence	Years 2-5	
126.7	West Fence End Escape Ramp	Escape Ramp	3:1 slope with rail fence	Years 2-5	
126.7	South Fence End	Fence End	Angles in to within 20’ of payment edge (clear zone)	Years 2-5	

Wildlife Overpass	
Wildlife Underpass	
Small Culvert (BVR box culvert)	

Wildlife Guard – round bar	
Escape Ramp – 2:1 slope with perpendicular rail fence	
Escape Ramp – 3:1 slope without perpendicular rail fence	

<table>
<tr><td>Escape Ramp – Jump Down</td><td></td></tr>
<tr><td>Pedestrian Access Gate</td><td>
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<tr><td>South Fence End</td><td>
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Appendix B

SPECIES LIST

Common Name	Scientific Name
Badger	*Taxidea taxus*
Bighorn Sheep	*Ovis canadensis*
Black Bear	*Ursus americanus*
Bobcat	*Lynx rufus*
Coyote	*Canis latrans*
Elk	*Cervus canadensis*
Moose	*Alces alces*
Mountain Lion	*Puma concolor*
Mule Deer	*Odocoileus hemionus*
Pronghorn	*Antilocapra americana*
Rabbit/Hare	*Sylvilagus and Lepus species*
Raccoon	*Procyon lotor*
Red Fox	*Vulpes vulpes*
River Otter	*Lontra canadensis*
Striped Skunk	*Mephitis mephitis*
Turkey	*Meleagris gallopavo*
White-tailed Deer	*Odocoileus virginianus*

Appendix C

PERFORMANCE MEASURE EVALUATION

	Performance Measure	Met	Not Met	Chapter Reference
Wildlife Connectivity – Success Rates				
1	Mule deer success rates 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), and Wyoming (Sawyer et al. 2012).*	✔		Chapter 3
2	Elk success rates 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).*	✔		Chapter 4
3	Success rates for all meso to large mammal species (other than deer and elk) detected at 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 (Purdue 2013).*	✔		Chapter 4
Wildlife Connectivity – Successful Passages				
4	By the end of the study, buck and doe mule deer passages through all crossing structures will be in the same proportion of bucks and does estimated for the local population. *Based on post-hunt population estimates determined by CPW.*	✔		Chapter 3
5	By the end of the study, bull and cow elk passages through all crossing structures will be in the same proportion of bulls and cows estimated for the local population. *Based on post-hunt population estimates determined by CPW.*		✔	Chapter 4
6	By the end of the study, the number of successful elk passages at all structures, will be at least 50% of the number of elk movements captured at associated habitat cameras (animals documented in the vicinity of the structures, but not necessarily using structures), irrespective of season. *Based on Arizona (Gagnon et al. 2011).*	✔		Chapter 4

7	Each year there will be an increase in the number of mule deer successful passages 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), and Montana (Cramer and Hamlin 2016).*	(✔)		Chapter 3
8	Each year there will be an increase in the number of successful elk passages 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), and Montana (Cramer and Hamlin 2016).*	(✔)		Chapter 4
9	Each year, there will be at least one to several successful passages at the 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, mountain lion, black bear, bobcat, and other species. *Based on Utah, (Cramer 2016) and Montana (Cramer and Hamlin 2016).*	✔		Chapter 4
Wildlife Connectivity – Prevention of Breaches into Fenced Right-of-way				
10	By the end of the study, at least 80% of the individual mule deer, elk and other ungulate approaches to each wildlife guard will be deterred from entering the road right-of-way. *Based on Utah (Cramer and Flower 2017, Flower 2016).*	✔		Chapter 5
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) and Colorado (Siemers et al. 2015).*		✔	Chapter 6
12	By the end of the study, 100% of the individual mule deer and elk approaches to each pedestrian access gate will be deterred from entering the road right-of-way. *Gates were retrofitted with swing gates in 2017 and this performance measure was eliminated from the study.*	n/a	n/a	Chapter 7
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).*		✔	Chapter 7

Safety				
14	The annual average number of reported WVC 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 preconstruction average. *Based on Alberta, Canada (Clevenger and Barrueto 2014), Wyoming (Sawyer et al. 2012), and a compiled study (Huijser et al. 2009).*	✔		Chapter 8
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 preconstruction average. *Based on Alberta, Canada (Clevenger and Barrueto 2014), Arizona (Gagnon et al. 2015), and Washington (McAllister et al. 2013).*	✔		Chapter 8
16	By the final year of the study, the average annual number of reported WVC crashes within one mile south of the south fence end will not increase over the five-year average annual preconstruction crash rate for this section of road. *Based on Arizona (Gagnon et al. 2015) and Wyoming (Sawyer et al. 2012).*		✔	Chapter 8

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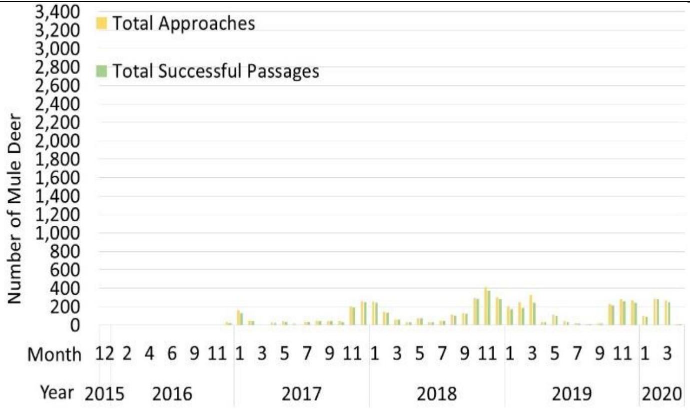
Appendix D

MULE DEER RESULTS BY LOCATION

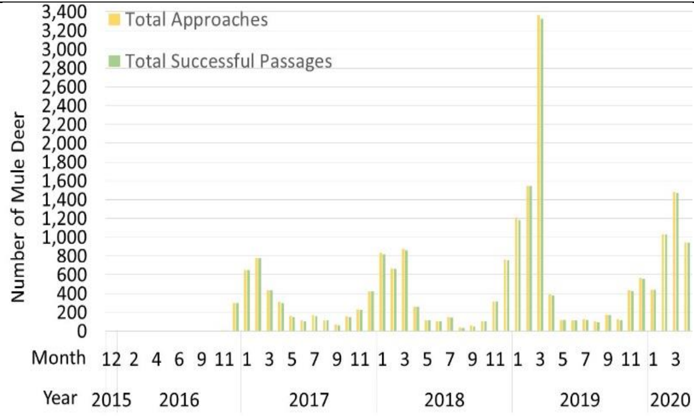
The number of mule deer successful passages through each structure varied among the structure locations but followed distinct annual patterns. The number of total approaches and successful passages per month each year of the study were plotted for each structure using the same y-axis scale (Fig. D-1). The three southernmost structures (Williams Peak Underpass, South Overpass, and BVA Underpass) were not completed until the fall of 2016, thus there are no data at those sites until November 2016. Several patterns emerged:

- Across study years and crossing structure locations, mule deer numbers began increasing each November, generally peaked in February or March, and began decreasing in April
- Mule deer successful passages were documented through the summer months at all crossing structure locations, though in much lower numbers. These results confirm structure use by year-round residents as well as seasonal migrants.

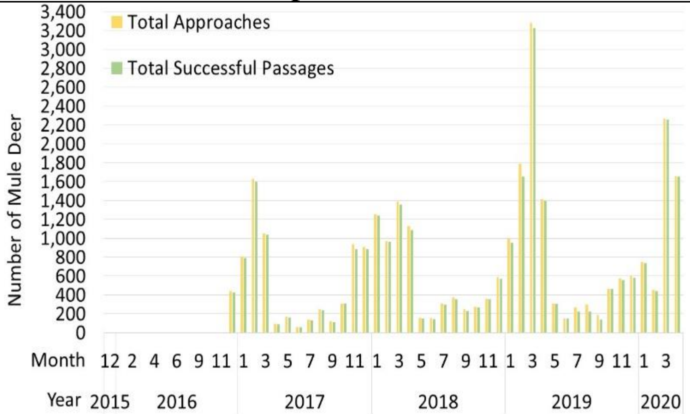
Two of the crossing structures with the greatest number of mule deer successful passages (BVA Underpass, MP 130.8, and the South Overpass, MP 129.5) were located in the area with the highest number of WVC carcasses reported preconstruction. These data support the finding that structure location was an important variable influencing mule deer use. Notably, the North Overpass (MP 134.3) also had high numbers of mule deer successful passages though it was not in are with high WVC carcasses preconstruction; high mule deer use at this location may have been more heavily influenced by structure type



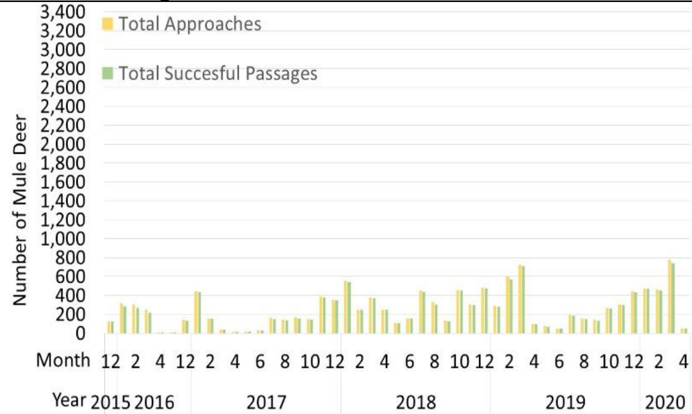
Williams Peak Underpass, MP 127.7



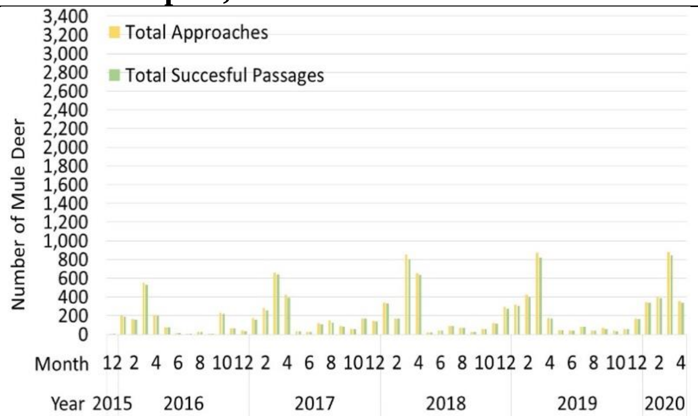
South Overpass, MP 129.5



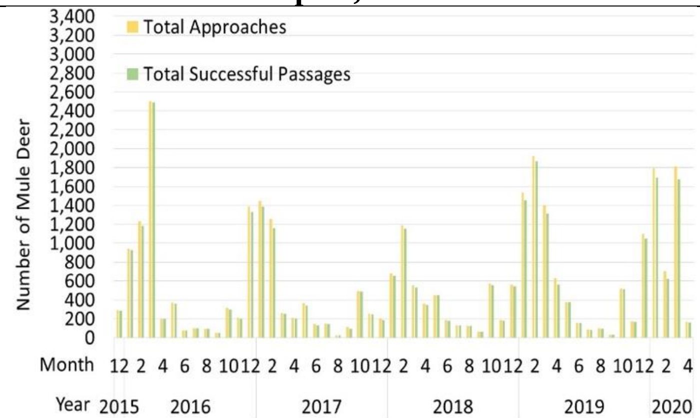
BVA Underpass, MP 130.8



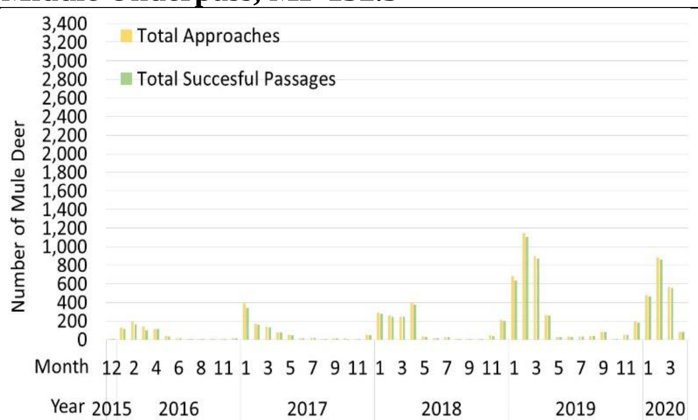
Harsha Gulch Underpass, MP 131.6



Middle Underpass, MP 132.5



North Overpass, MP 134.3



North Underpass, MP 136

Figure A-1. Number of mule deer approaches and successful passages per month each year of the study. All graphs were plotted on the same y-axis scale with a maximum of 3,400.