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I-25 South Gap Wildlife Monitoring Study

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16. Abstract The Interstate 25 (I-25) South Gap project was a major highway expansion project aimed at alleviating congestion by adding lanes in each direction and incorporating safety enhancements. The Colorado Department of Transportation (CDOT) and its partners committed to designing a system of wildlife crossings - including five large bridge underpasses, wildlife exclusion fencing along 14.1 miles of the interstate, escape ramps, and wildlife guards – to reduce WVCs and improve habitat connectivity. This research evaluated the effectiveness of these mitigation investments using camera data and crash datasets from 2022 through 2024. The results from this study revealed that the wildlife infrastructure was one of the most effective components of the I-25 South Gap project in terms of crash reduction, yielding an 85% reduction in WVCs in the first two years post-construction. In addition, this study established the value of the five wildlife crossings for a wide range of wildlife, including the target species frequently involved in WVCs (deer and elk) and numerous other species, large and small. Variability in use and year-over-year increases in passage rates suggest wildlife continue to adapt and may increase their use as they become more accustomed to the crossing structures. This study notably included evaluation of purpose-built cover features designed to provide passage for small prey species, resulting in the detection of 17 species not otherwise captured by monitoring at the large underpasses, including two detections of the federally threatened Preble's meadow jumping mouse. This study also assessed other mitigation components, including wildlife guards, escape ramps, and the northern terminus of the wildlife exclusion fence. Overall, the I-25 South Gap wildlife crossings system met or exceeded most performance goals for wildlife use and collision reduction established at the outset of the study. The findings and recommendations from this research will guide future planning, siting, and design of wildlife mitigation systems, promoting safer, more connected landscapes along Colorado's busiest highways. Implementation: Several implementation recommendations are made related to maintenance, adaptive management, informing future wildlife mitigation projects, and future wildlife monitoring studies.			
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Executive Summary

The Interstate 25 (I-25) South Gap project was a major highway expansion project executed over five years between Castle Rock and Monument in southern Douglas County and northern El Paso County, Colorado. The project aimed to alleviate congestion by adding lanes in each direction and incorporating safety enhancements, including a comprehensive wildlife crossings system. This stretch of I-25 traverses the largest remaining protected open space along Colorado's Front Range between Fort Collins and Colorado Springs and, prior to construction, it was the primary barrier to wildlife movement. Despite high traffic volumes, wildlife continued to cross the highway, leading to frequent wildlife-vehicle collisions (WVCs) with larger wildlife, which were the third most common crash type along this segment of I-25.

In response, the Colorado Department of Transportation (CDOT) and its partners committed to designing a system of wildlife crossings - including five large bridge underpasses, wildlife exclusion fencing along 14.1 miles of the interstate, escape ramps, and wildlife guards – to reduce WVCs and improve habitat connectivity. From 2022 through 2024, this research conducted camera monitoring and analyzed crash datasets to evaluate the effectiveness of these mitigation investments. As Colorado's first comprehensive wildlife mitigation study on a large, six-lane interstate and one of a few in North America, this study provided valuable insights concerning wildlife adaptation to crossing structures on a major interstate system and the effectiveness of both large and small fauna mitigation features.

The results from this study revealed that the wildlife infrastructure was one of the most effective components of the I-25 South Gap project in terms of crash reduction, yielding an 85% reduction in WVCs in the first two years post-construction, compared to all vehicle crash types, which decreased by 20% relative to pre-construction levels.

In addition, this study established the value of the five wildlife crossings infrastructure on I-25 for a wide range of wildlife, including the target species frequently involved in WVCs and numerous other species, large and small. The research documented 16,749 mule deer, 1,791 white-tailed deer, and 866 elk successful passages through the five wildlife underpasses and an existing box culvert, all increasing annually, with post-construction success rates of 93%, 91%, and 76%, respectively. With only two years of post-construction data captured in this study, these findings suggest the crossings are highly effective for these species, with elk likely to increase their use over time due to longer habituation periods. While pronghorn was not observed using the crossings, they were captured near two crossing structures on

the east side of I-25. Whether pronghorn ultimately seek to expand into the grassland habitats on the west side of the interstate via the underpasses or the future Greenland Overpass remains unknown.

Eleven non-ungulate species, including black bear, bobcat, fox, and mountain lion, were observed using the crossings with high success rates. Variability in use and year-over-year increases in passage rates suggest wildlife will continue to adapt and may increase their use as they become more accustomed to the structures. This study notably included evaluation of purpose-built cover features designed to provide passage for small prey species. The small fauna photo booths created for this study marked a novel effort in targeted monitoring of small fauna at large crossings and resulted in the detection of 17 species not otherwise captured by monitoring at the large underpasses, including two detections of the federally threatened Preble's meadow jumping mouse.

This study also assessed other mitigation components, including wildlife guards, escape ramps, and the northern terminus of the wildlife exclusion fence. In the final year of the study, the total number of wildlife approaches to the guards decreased by 58% and the wildlife guards deterred ungulates from entering the fenced highway right-of-way 73% of the time, indicating improvements in the overall functioning of the mitigation system over time. Escape ramps showed an 81% ungulate intercept rate and a 40% escape rate, surpassing benchmarks from previous research on State Highway 9 in Grand County, Colorado, and establishing the value of the improved design standard but leaving room for future improvements to further increase escape rates.

Overall, the I-25 South Gap wildlife crossings system met or exceeded most performance goals for wildlife use and collision reduction established at the outset of this study. The findings and recommendations from this research will guide future planning, siting, and design of wildlife mitigation systems, promoting safer, more connected landscapes along Colorado's busiest highways.

Chapter 1. Introduction

Southern Douglas County supports extensive natural grasslands and forests, marking the transition from the eastern plains to the foothills of the Rocky Mountains. This region provides habitat for diverse wildlife, including mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), bighorn sheep (*Ovis canadensis*), mountain lion (*Puma concolor*), and black bear (*Ursus americanus*). The section of Interstate 25 (I-25) known as the South Gap travels through the heart of this landscape – a vital transportation and economic corridor between Colorado’s two largest cities, Denver and Colorado Springs. Truck traffic, commuters, and visitors rely on this highway, making an average of 76,000 vehicle trips each day and increasing (CDOT 2023). Under these conditions, wildlife’s ability to successfully cross over the interstate was severely compromised, preventing movements to access habitat and resources on either side. Yet, despite these high traffic volumes, crashes involving wildlife were the third most common crash type and there was an average of 32.2 reported wildlife-vehicle collision (WVC) crashes each year. The annual cost to society of reported WVC crashes was over \$800,000 annually, including the direct and indirect costs of the collision and the value of the wildlife killed (CDOT 2018).

In 2018, the Colorado Department of Transportation (CDOT) launched construction of the I-25 South Gap project, aimed at alleviating congestion and improving motorist safety between Castle Rock and Monument. The Environmental Assessment (EA) process identified wildlife-vehicle collisions (WVC) as a safety problem for motorists and the highway as a barrier to wildlife movement and population health (CDOT 2018). While there were multiple existing bridges and box culverts in the project area, most were too small for deer or elk passage or had other deterrents inhibiting wildlife use. Preconstruction camera monitoring detected limited wildlife use of the existing structures (Pinyon 2017).

The southern portion of Douglas County is home to the largest remaining protected open space along Colorado’s Front Range between Fort Collins and Colorado Springs due to the County’s efforts over multiple decades to protect these natural areas. In recognition of the ecological values of the landscape and safety concerns resulting from wildlife-highway conflict, the I-25 South Gap project included a comprehensive wildlife mitigation system for 14.1 miles – from milepost 162.1 to milepost 176.2 – including four large bridge underpasses, a major bridge replacement at Plum Creek, wildlife exclusion fencing, escape ramps, and wildlife guards. This system of wildlife crossings capitalizes on the County’s long-term land protection efforts by restoring connectivity for wildlife across the interstate to provide access to the protected habitats on either side.

The I-25 South Gap Wildlife Study monitored the wildlife infrastructure from late 2021 through 2024, marking the first comprehensive research study of a wildlife mitigation system on a large, six-lane highway in Colorado, and one of only a handful in North America. This research was important for measuring how wildlife adapt to the new crossing structures to access previously disconnected habitat on either side of a high-volume interstate. In addition, while most wildlife mitigation projects in western North America have focused on large mammals, this study offered a unique opportunity for evaluating how well purpose-built cover features work to promote small fauna use of large crossing structures, including the federally threatened Preble's meadow jumping mouse (*Zapus hudsonius preblei*).

This research further provided insights into the economic and ecological values of the mitigation investments on I-25; identified the need for adjustments to improve the effectiveness of the mitigation; and helped address gaps in our understanding of biologically and cost-effective mitigation designs for major infrastructure projects.

In 2023, the Greenland Wildlife Overpass Project was one of 19 projects nationwide to be selected for funding through the 2021 Infrastructure Investment and Jobs Act Wildlife Crossing Pilot Program. With the construction of the Greenland Overpass at milepost 165.4 in 2025, the I-25 South Gap project's wildlife crossing network was expanded by bridging a 3.7-mile gap between the Dogleg and Greenland Underpasses, providing the only opportunity for wildlife to cross over, rather than under, the interstate. The overpass construction will not be completed until after the conclusion of this study, although CDOT anticipates initiating a complementary research effort to monitor wildlife use of the Greenland Overpass.

1.1. Research Objectives

The following overarching research objectives were established by the research team and the Study Panel for the three-year research study: 1) Evaluate the effects of the mitigation infrastructure in improving motorist safety by reducing WVCs, and 2) Evaluate the effects of the mitigation in improving the ability of wildlife – including large and small fauna – to move across the interstate to access important habitats.

In addition, this monitoring study will provide CDOT and Colorado Parks and Wildlife (CPW) with recommendations for adaptive management; measure the economic value of these mitigation investments; and help to inform the design of future wildlife-highway mitigation projects in Colorado and beyond.

Chapter 2. Methods

This study evaluated mitigation effectiveness using two primary measures: 1) the number of movements made by deer, elk and other wildlife through the crossing structures, along with success and repel rates for each species; and 2) the reduction in WVCs. The research methods used to evaluate these measures are presented below. A complete species list is provided in Appendix A.

2.1. Camera Monitoring

Construction of the five wildlife underpasses was completed in 2021; however, construction of other mitigation features at several monitoring locations was not completed until December 2022. Cameras were set up at most monitoring locations between October and December 2021. The remaining cameras were deployed as construction activities were completed with the final cameras deployed on December 6, 2022, and, at two locations, May 1, 2023. Camera monitoring continued through December 2024. Cameras were visited every seven to eight weeks from June through December and every nine to ten weeks through the remainder of the year to exchange memory cards and batteries.

The following timeframes were defined for the monitoring study:

- Pre-construction: Prior to the onset of construction activities in 2018. Pre-construction camera monitoring was conducted by CPW and the consulting firm Pinyon Environmental at crossing structure locations. At each location, a camera was set up on either side of the highway. Data from these cameras are not included in this study.
- Construction: Occurred from 2018 through 2022. Construction phase camera monitoring was conducted from late 2021 through 2022. Construction phase camera monitoring documented initial responses to the mitigation and served as a pilot study period for testing and refining site-specific camera placement to best meet the research objectives. Construction phase monitoring involved the deployment of 52 cameras at 16 monitoring locations.
- Post-construction: Post- construction monitoring was conducted from 2023 through 2024.

Cameras were deployed at 19 monitoring locations including the five wildlife underpasses, an existing large 3-chambered box culvert that was included the mitigation system, selected wildlife guards and escape ramps, the north fence end on the east side, and small fauna cover features. Figure 1 shows each of the post-construction monitoring locations within the study area. Appendix B lists the monitoring locations, design specifications, and monitoring cameras at each location.

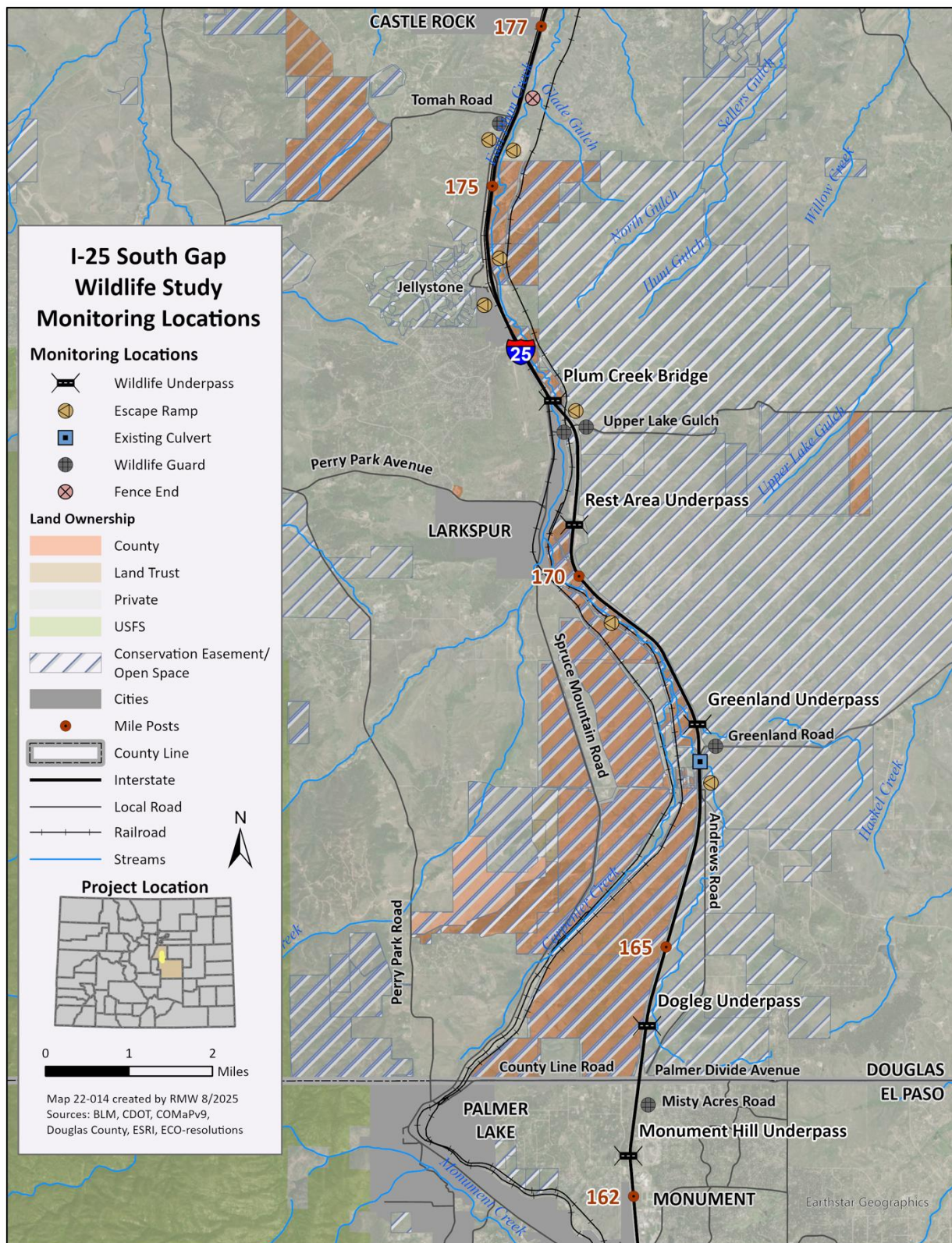


Figure 1. Map of monitoring locations in the I-25 South Gap Wildlife Study.

Several adjustments were made to study design during camera set up to address on-the-ground conditions, including 1) instead of placing a camera at the north fence end on the west side, the research team elected to place a camera at the wildlife guard that crosses the frontage road immediately south of the fence end, and 2) a new camera station was added at the Monument Hill Underpass to monitor wildlife responses to a small natural-surface bridge (the 'deer bridge') that was installed over the riprap that impedes direct access to the east entrance to/from this structure (Fig. 2). Monitoring was conducted continuously at each of the monitoring locations through the duration of the study, except for a camera that was stolen at the Misty Acres wildlife guard in Spring 2023 that was not replaced.



Figure 2. Riprap drainage running across the east entrance to the Monument Hill Underpass (left) and the natural surface 'deer bridge' installed over the riprap drainage to facilitate wildlife passage (right).

2.1.1. Camera Positioning

Motion-triggered cameras were deployed to monitor wildlife activity and behavior at wildlife crossing structures, wildlife escape ramps, wildlife guards, and the northern terminus of the wildlife fence. Reconyx HyperFire2 Professional Covert Infrared long-range cameras were mounted on T-posts using a U-bolt system and Reconyx security enclosures. In areas with human activity or that were visible from the roadside, the cameras were mounted inside metal utility boxes to disguise them. All cameras were code-locked and secured with padlocks and/or cable locks (Fig. 3). The cameras took photos day and night with a rapid-fire setting and no down time. Each camera was carefully positioned to optimize capture of wildlife responses to a given mitigation feature.



Figure 3. Camera mounted on T-post (left) with U-bolt mounting and security system (middle), and camera mounted in utility box (right).

2.1.1.1. Wildlife Crossing Structures

At the underpasses, the number of cameras positioned at each structure was based on the width of the underpass (as viewed by an animal using the crossing). Four of the five underpasses were ~100' wide and required four cameras to capture wildlife movements across the full width of the structure. On each side of a structure, one camera faced outward to capture an animal's behavior as they approached the structure. The second camera was positioned on the opposite side of the structure, facing inward to capture entry behavior and determine through passage or repel movements. The exception was at the Plum Creek Bridge where two cameras were placed next to each other on the north side of the structure - one facing outward, the other facing inward - on both the east and the west sides. This was done to provide additional security by locking the cameras to the bridge pillars. The Plum Creek Bridge is a 300'-wide three-span bridge with a recreation trail running under the southern-most span, furthest from the creek. Cameras were oriented to capture wildlife movements through the center span, away from the recreation trail. At the 60'-wide Monument Hill Underpass, only two cameras were needed to capture wildlife activity. Figure 4 depicts the camera positions at the 100' and 60'-wide underpasses.

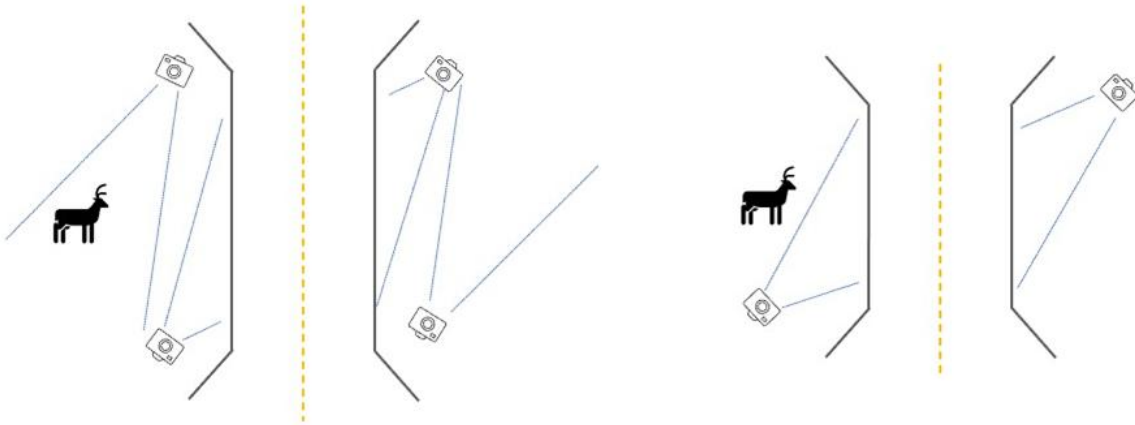


Figure 4. Camera set-up with four cameras at the 100'-wide underpasses (left); and with two cameras at the 60'-wide underpass (right).

At each crossing structure location, approach cameras were placed to observe species in the vicinity of a structure that may or may not approach the underpass. Crossing structure and approach cameras were set to take photos day and night in bursts of 10 photos per trigger and continue to trigger as long as movement was detected, with no down time.

2.1.1.2. Small Fauna Photo Booths

The small fauna cover features, or brush windrow habitat connectivity features, were a unique aspect of the overall mitigation system and a specific focus of the camera monitoring effort. At each large crossing structure, a continuous linear cover feature was constructed from logs and branches salvaged from elsewhere in the project to connect into the habitat on either side of the crossing (Fig. 5).



Figure 5. Small mammal photo booth placed within the habitat cover feature under the Plum Creek Bridge.

The researchers created dedicated 'photo booths' to capture small fauna (including mammals, reptiles, and amphibians) use of the habitat cover features. To the researchers' knowledge, this was the first study to conduct targeted monitoring of small fauna cover features at a large crossing structure. The design of the photo booths, therefore, was based on more general methods of small mammal camera trapping (McCleery et al. 2014) and refined to fit the linear habitat cover features.

Monitoring was conducted at five small fauna connectivity features at four underpass locations. The Greenland Underpass had two connectivity features that were monitored: one running along the north side of the underpass and one on the south side. A small tributary to Carpenter Creek runs through this underpass and flows into the mainstem of the creek due west of this location. The riparian habitat on Carpenter Creek has documented use by Preble's meadow jumping mouse and photo booths were set up at both small fauna cover features at the Greenland Underpass to maximize detection opportunities. The Plum Creek Underpass has one small fauna connectivity feature running along the north side of the underpass on the south side of East Plum Creek, which also has documented use by Preble's meadow jumping mouse. The Dogleg Underpass also has two small fauna cover features, but only the one running through the south side of the underpass was monitored with a photo booth. Although all three of the above-mentioned structures have riparian features, the stream at the Dogleg structure is more ephemeral. The Rest Area Underpass and the Monument Hill Underpass are both upland sites with one small fauna cover feature each, although only the feature at the Rest Area Underpass was monitored.

The photo booths were positioned near the middle of the underpasses and were designed to capture wildlife using the habitat cover feature. Photo monitoring could not confirm through passage by individual animals; however, the assumption was made that an animal detected in the middle of a habitat cover feature could cross all the way through, if desired. Photo booth cameras were set to video mode rather than still images to facilitate species identification by fast-moving rodents in this confined space. Videos were up to 10-seconds long with a 1-minute quiet period between videos to reduce the number of triggers by rodents moving back and forth through the cover feature.

2.1.1.3. Wildlife Guards, Escape Ramps, and Wildlife Fence End

Monitoring cameras were also placed at select wildlife guards, escape ramps, and the north fence end. At wildlife guards, one camera was placed on the habitat side of the wildlife fence and was positioned to look across the guard to detect animals that approach the guard and determine response behaviors (breach, repel, ignore). Two types of escape ramps were included in the monitoring effort: traditional 1-

sided ramps; and a novel 2-sided design that has been successfully employed in Utah (Cramer and Hamlin 2020) (Fig. 6).



Figure 6. Example of one-sided escape ramp (left) and two-sided escape ramp (right).

Two cameras were set up at each monitored escape ramp location, one at the base of the ramp in the right-of-way to capture wildlife approaching the ramp (intercepts and escapes) or walking around the ramp; and the other at the top of the ramp to capture wildlife responses (escapes) and jump up attempts from the habitat side.

Only one fence end was monitored – at the north end of the mitigated project area along the east frontage road. The corresponding fence end along the west frontage road lies in a narrow strip between the interstate and the frontage road and a camera could not be deployed without constantly being triggered by passing traffic. Instead of placing a camera at this location, the research team elected to place a camera at the wildlife guard that crosses the frontage road immediately south of the fence end. Neither of the south fence ends were monitored.

At the northeast fence end, one camera was positioned to detect wildlife activity near the fence end and, specifically, to capture wildlife responses to the erosion control webbing (Geocell) placed between the pavement edge and the fence (Fig. 7).



Figure 7. North fence end Geocell treatment along the east frontage road.

Escape ramp and fence end cameras were set to take photos day and night in bursts of 10 photos per trigger and continue triggering as long as movement was detected with no down time. At wildlife guards, cameras were set to 5 photos per trigger and scheduled to trigger only between two hours before sunset to two hours after sunrise (specific hours vary depending on the time of year) to minimize the number of photo events triggered by vehicles crossing over the guards.

2.1.2. Photo Processing and Data Entry

To help ease the challenges associated with collecting large volumes of photographic data, the research team developed a custom computer vision model and database system to automatically assist in the processing of photographic data. The computer vision model is a convoluted neural network with a “Faster RCNN” object detection architecture and a ResNet-50 backbone that was trained and deployed using Python. The automated data processing system batch imported and automatically organized photos into the appropriate storage hierarchy for each movement event; captured a photo’s metadata (e.g., date, time, location); automated tasks (e.g., assign event identification number; calculated time of day, season and week of year); and, augmented with machine learning, supported efficient photo processing, including the filtering of false positives (i.e., images not triggered by an animal such as a vehicle or blowing vegetation) (Fig. 8).



Figure 8. Automated processing technique to filter photo events triggered by wildlife and assist in species identification.

Machine learning models optimize the flow of results to reporting platforms, making preliminary results available quickly for each new batch of images (Tabak et al. 2019).

The automated tasks described above included inserting records into Access database tables for photos containing animals and Quality Assurance and Quality Control (QA/QC) measures to guarantee that the format and values of the data inserted into the database tables matched expectations. Manual data tasks for each record were performed using Access forms which serve as a link between the data technician and the raw data. As part of the QA/QC strategy, database forms minimized data entry errors by restricting user entry options to predetermined acceptable data types and values or ranges. The photo database and all photo data were stored on the Cloud with two external hard drive backups. Manual data entry was conducted by a data entry team trained in classifying and interpreting wildlife behavior and responses to the mitigation features (Table 1). Photo data were systematically processed to identify movement events every time a camera was triggered. At monitoring locations with more than one camera (underpasses and escape ramps), movement events were evaluated across all camera stations simultaneously. Some events were comprised of multiple individuals of the same species whose movement originated from the same side of a mitigation feature. Large mammal events were defined as 15-minute time periods because animals may move within the view frame multiple times before concluding a movement and typically leave the camera area within 15 minutes if they have not made a successful passage in that time (Cramer 2012). 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 successfully, repelled, or the 15-minute period ended, in which case a new event was recorded.

Unique movements by individual animals were each tallied once, even when two or more cameras recorded the movement. Individual repel and parallel movements were tallied only once when the same animals moved in front of a camera multiple times in a 15-minute event period. Total Movements were calculated for each wildlife crossing structure as the sum of success movements, repel movements, parallel/ignore movements, and foraging/rest movements. Total Approaches were calculated for each wildlife crossing structure as the sum of success and repel movements.

Table 1. Definitions of approach behaviors and responses to the mitigation features.

Passage Behavior – Crossing Structures and Existing Box Culvert	Definition
Hesitate	Animal pauses before entering the structure.
Walk	Animal walks without pause.
Run	Animal runs without pause.
Startle	Animal freezes or makes a sudden change in movement.
Response to Mitigation – Crossing Structures and Existing Box Culvert	Definition
Through Passage	Animal moves all the way through the crossing structure.
Through Passage – Multiple Attempts	Animal turns back the way it came one or more times before moving all the way through the crossing structure.
Repel	Animal initially moves near the entrance or into the structure but then turns back the way it came from rather than moving through the structure.
Forage/Rest	Animal is eating or resting near or in the structure but does not exhibit behaviors indicative of directional travel through the structure.
Parallel/Ignore	Animal is captured moving near the structure but is either headed in a direction beyond the structure entrance or is exhibiting behaviors that are not indicative of attempts to use the structure.

Response to Mitigation – Wildlife Guard		Definition
Breach		Animal successfully jumps or walks over the guard or, by another method, moves from the habitat side of the guard into the highway right-of-way or from the right-of-way side to the habitat side
Repel		Animal approaches the guard and then turns away. Some repel movements involve an animal making an initial attempt to breach the guard before repelling.
Parallel/Ignore		Animal walks in front of or near a guard but shows no interest in attempting to breach the guard.
Right-of-Way Side Responses – Escape Ramp		Definition
Walk Around Ramp		Animal is present inside the right-of-way but does not ascend the ramp, and instead walks around the base of the ramp.
Walk up Ramp and Turn Around		Animal ascends the ramp but then turns back down the ramp inside the right-of-way.
Walk up Ramp and Escape		Animal ascends the ramp and successfully jumps down to the habitat side.
Habitat Side Response – Escape Ramp		Definition
Parallel/Ignore		Animal walks near the escape ramp on the habitat side but shows no interest in attempting to breach the ramp.
Jump up - Unsuccessful		Animal attempts to climb or jump up to the top of the ramp from the habitat side but is unsuccessful.
Jump up - Successful		Animal attempts to climb or jump up to the top of the ramp from the habitat side and is successful.
Fence End/Geocell Response		Definition
Breach		Animal successfully jumps or walks over the Geocell.
Repel		Animal approaches the Geocell and then turns away. Some repel movements involve an animal making an initial attempt to breach the Geocell before repelling.
Walk Around		Animal successfully walks around the Geocell.
Parallel/Ignore		Animal that ignores/moves beyond the fence end and shows no interest in attempting to breach the Geocell.

Most events at crossing structures involved mule deer and larger groups of deer were the most challenging and time-consuming to process. Due to the large volume of data, a sampling methodology

was implemented beginning July 1, 2022, to more efficiently process mule deer events at crossing structures. Events were processed one week out of every four to capture seasonal variations in activity.

Approach cameras documented non-mule deer species presence and abundance. Tallying the presence of other species at habitat cameras allowed comparisons of species composition and abundance in the habitat near a crossing structure with the species successfully using the crossing structure.

For small fauna at the habitat cover features, the monitoring objective was to detect species and relative abundance. Species presence was tallied based on daily rather than actual counts because small mammals often make multiple back and forth movements in front of a camera. Because species diversity was low during the colder months, videos recorded at the photo booths were processed from June 1 through September 30.

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

2.1.3. Photo and Video Data Analysis

To achieve the research objectives, data were analyzed with respect to changes in wildlife activity and movement patterns over time and in space. Analyses over time capture annual trends in wildlife responses to mitigation and compare pre- and post-construction species abundances at each crossing structure location. Analyses over space address changes in the spatial patterns of wildlife activity and responses to each wildlife underpass or other mitigation feature with respect to the characteristics of the mitigation itself, its position in the landscape and the local landscape context.

Post-construction phase photo data were evaluated relative to the performance measures, including:

- Species abundance by gender/age class approaching and successfully using each underpass.
- Success, repel, and parallel rates at crossing structures, by species.
- Number of successful passages at each underpass by season/month.

- Species type and abundance at small fauna cover features.
- Breach and repel rates at wildlife guards and fence ends, by species.
- Intercept and escape rates at escape ramps, by species.

To account for the sampling approach used to process mule deer events at crossing structures, data processed on and after July 1, 2022, through December 31, 2022, were adjusted using a sampling factor of 3.76. This number was derived from the percentage of weeks sampled: 7 out of 26.3 or 26.6%. A sampling factor was then calculated to reach 100%, resulting in a sampling factor of 3.76 for this time frame. Data processed in 2023 and 2024 were adjusted using a sampling factor of 4.02. Again, this number was derived from the percentage of weeks sampled: 26 out of 104.4 or 24.9%. Thus, the sampling factor that needed to be applied to reach 100% was 4.02. There are assumptions that come with a sampling approach, most notably, that the weeks for which mule deer data were processed were representative of the unsampled weeks; and that mule deer occurrences were normally distributed among the weeks in the sampling period.

Table 2 lists the indices calculated for each monitoring location, as applicable. These indices are the basis for evaluating mitigation effectiveness (Section 2.3).

Table 2. Indices calculated for each monitoring location, as applicable.

Index	Definition
Success rate	For each species at a given crossing structure location, the total number of individual movements of the species that were recorded approaching a crossing structure divided by the sum of success and repel movements by that species.
Repel rate	For each species at a given crossing structure location, the total number of individual movements of the species that were recorded being repelled at a structure divided by the sum of total approaches (success and repel movements) by that species. Repel rate was also calculated for ungulates at wildlife guards and fence ends. In these cases, a repel movement is the desired wildlife behavior response to the mitigation features.
Parallel rate	For each species at a given monitoring location, the total number of movements of the species that were recorded moving parallel to the mitigation feature divided by the total detections by that species.

Index	Definition
Intercept rate	This metric was calculated for ungulates at escape ramps. It is the total number of times ungulates were recorded ascending an escape ramp divided by the number of times they approached an escape ramp.
Escape rate	This metric was calculated for ungulates at escape ramps. It is the total number of times ungulates were recorded successfully jumping down from an escape ramp divided by the number of times cameras captured ungulates walking up the escape ramp.
Breach rate	This metric was calculated for ungulates at wildlife guards, escape ramps, and the fence end. It is the total number of times individual ungulates breached the mitigation divided by the total number of times they approached that mitigation feature. For example, at a wildlife guard, breaches occurred when animals crossed 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 the fence end, breaches occurred when animals entered the fenced right-of way from beyond the fence end.

2.1.4. Statistical Analyses

Statistical models were developed to evaluate potential structural and environmental variables influencing the effectiveness of the mitigation infrastructure for ungulates. R statistical software was used for all statistical modelling (R Core Team 2025).

Throughout, the following assumptions and criteria are held:

- Model selection was based on residual diagnostics using the DHARMA package (Hartig 2024).
- Sampling effort offset terms were used for modeling rates at wildlife guards and escape ramps due to unequal sampling effort across locations. Sampling effort offset terms were used for modeling counts at underpasses but were not used for modeling rates.
- Estimates were marked as significant when p-values were less than 0.05.
- Models relating to the evolution of behavior over time used simplified time variables of season start date, i.e. the first date of the season in which the observation took place, or month start date, i.e. the first date of the month in which the observation took place. These variables are abbreviated as SSD and MSD, respectively.

- When possible, mule deer and white-tailed deer were considered as one category, deer.

2.1.4.1. Wildlife Crossing Structures

Statistical modeling examined potential associations between ungulate use and structure variables such as direction of origin, structure width, structure height, structure length, presence of grass/forbs and brush, riparian drainage, and approach slope to the wildlife crossing structures. Generalized linear mixed models were developed to understand ungulate use of newly constructed underpasses on the I-25 corridor.

Ungulate use was defined as the count of successful passages at a structure, aggregated by the fixed and random effects included in the model. In the evaluation of relationships between structural variables and ungulate usage, some structural variables were simplified to improve modelling (Table 3). The variables direction of origin, structure width, structure height, structure length, grass/forbs, brush, trees, bare ground and riprap were used as provided (Table 4).

Table 3. Simplified underpass variables.

Variable	Original Values	Simplified Levels
Riparian Drainage	None	None
	Ephemeral	Some
	Perennial	
Approach Slope	Flat	Flat
	Moderate Downhill	Downhill
	Moderate Uphill	Uphill
	Steep Uphill	
Livestock Fence	None	None
	Within 50'	Within 100'
	Within 100'	
Distance to Train Track	NA	None
	Continuous (distance in feet)	Within 2 miles

Table 4. Other underpass variables.

Variable	Value
Direction of Origin	East West
Structure Width	Width measured in feet
Structure Height	Height measured in feet
Structure Length	Length measured in feet
Percent Landcover on each side of the underpass	For each landcover class (grass/forbs, brush, trees, bare ground), percent cover was assessed, where: 0% = 0 ≤25% = 12.5 26-50% = 38 51-75% = 63 >75% = 88

Initially, model development was tested across the three ungulate species represented in the data: mule deer, elk and white-tailed deer. However, models that included data from all three species failed to converge, failed residual diagnostic tests and/or showed signs of unmodeled heterogeneity without inclusion of species as a fixed effect. To better understand potential impacts of structural variables for different species, three species-specific models were produced. Across structural variables, tree cover and bare ground cover were removed from consideration due to high correlation with other structural variables ($r > 0.7$). When applicable, the baseline for categorical variables was an eastern direction of origin, no riparian drainage, and a downhill approach slope.

2.1.4.1.1. Mule Deer Underpass Use Model

The following model was used to evaluate mule deer use of the underpasses:

Count ~ Direction of Origin + Structure Width + Structure Height + Structure Length + Grass/Forbs + Brush + Riparian Drainage + Approach Slope + SSD + (1 | Season) + offset(effort)

A generalized linear mixed effects model was used to assess the effect of underpass structure variables on the number of successful crossing events by mule deer. During the study, the sampling design switched from recording every mule deer event detected to sampling mule deer events every four weeks. Using the entirety of the mule deer set negatively impacted model convergence and residuals, despite the inclusion of an offset term to account for sampling effort. Due to these issues, the period of time when events were recorded every week was also subsampled according to the same scheme as the second half of the study.

The model used a negative binomial distribution with a log link function. Year, monitoring location, and season were considered as random effects and season was selected for the final model. The variables riprap, distance to livestock fence, distance to disturbance, and distance to train track were further removed from consideration due to collinearity. A log-transformed offset of the number of sampling days per season was used to account for sampling effort. Although the focus of this model was structural variables rather than variation over time, model convergence was poor without inclusion of a time variable, SSD.

2.1.4.1.2. Elk Underpass Use Model

The following model was used to evaluate mule deer use of the underpasses:

Count ~ Direction of Origin + Structure Width + Structure Height + Structure Length + Grass/Forbs + Brush + (1 | Season) + (1 | MonitoringLocation) + offset(effort)

A generalized linear mixed effects model was used to assess the effect of underpass structure variables on the number of successful crossing events by elk. The model used a negative binomial distribution with a log link function. Year, monitoring location, and season were considered as random effects, and season and monitoring location were used in the final model. The variables riprap, distance to livestock fence, distance to disturbance, distance to train track, riparian drainage, and approach slope were further removed from consideration due to collinearity or lack of variation. A log-transformed offset of the number of sampling days per season was used to account for sampling effort. Unlike the mule deer model, including a time variable as a fixed effect was not necessary for model convergence.

2.1.4.1.3. White-tailed Deer Underpass Use Model

The following model was used to evaluate white-tailed deer use of the underpasses:

Count ~ Direction of Origin + Structure Width + Structure Height + Structure Length + Grass/Forbs + Brush + (1 | Season) + (1 | Year) + (1 | MonitoringLocation) + offset(effort)

A generalized linear mixed effects model was used to assess the effect of underpass structure variables on the number of successful crossing events by white-tailed deer. The model used a negative binomial distribution with a log link function. Year, monitoring location, and season were considered as random effects, and all were used in the final model. The variables riprap, distance to livestock fence, distance to disturbance, distance to train track, riparian drainage, and approach slope were further removed from consideration due to collinearity or lack of variation. A log-transformed offset of the number of sampling days per season was used to account for sampling effort. Unlike the mule deer model, including a time variable as a fixed effect was not necessary for model convergence.

2.1.4.1.4. Ungulate Successful Passage Rate Model

The following model was used to evaluate ungulate passage rates at the underpasses:

Response ~ Direction of Origin + Structure Width + Structure Height + Structure Length + Grass/Forbs + Brush + Trees + Bare Ground + Riparian Drainage + (1|SSD)

Successful passage rate was defined as the portion of animal approaches (excluding parallel movement and resting/foraging) resulting in a through passage of the underpass. A binomial generalized linear mixed effects model was used to assess the effect of underpass structure variables on successful ungulate passage rate. It was not necessary to separately model each species to achieve model convergence. year, season, monitoring location, and season start date were considered as random effects, and season start date was included in the final model. The variables riprap, distance to livestock fence, distance to disturbance, distance to train track, riparian drainage, and approach slope were further removed from consideration due to collinearity or lack of variation.

2.1.4.1.5. Ungulate Passage Use Over Time Model

The following model was used to evaluate changes in ungulate use over time at the underpasses:

Count ~ MSD*Species + (1|MonitoringLocation) + offset(effort)

A negative binomial generalized linear mixed effects model was used to assess changes in counts of successful passage use over time across species. Mule deer and white-tailed deer could not be collapsed into one group in this case due to the difference in sampling effort across the two species. Season and monitoring location were considered as random effects, and monitoring location was included in the final model. A log-transformed offset of the number of sampling days per season was used to account for sampling effort. The removal of the interaction term between MSD and species was tested, as well as the removal of species from fixed effects. Mule deer were the default species of the model.

2.1.4.1.6. Ungulate Passage Rate Over Time Model

The following model was used to evaluate mule deer use of the underpasses:

Response ~ Species Category *MSD + (1|MonitoringLocation) + (1|Season)

A binomial generalized linear mixed effects model was used to assess changes in successful passage rate over time across species. In this model, mule deer and white-tailed deer were collapsed into one category, deer, to improve model fit. This was possible because it was not necessary to include a sampling effort offset term when considering monthly successful passage rate rates. Monitoring location and season were tested as potential random effects and both were included in the final model. The removal of the interaction term between MSD and species was tested, as well as the removal of species from fixed effects. Deer were the default species category of the model.

2.1.4.1.7. Passage Rate Over Time by Demographic Groups Model

The following model was used to evaluate changes in ungulate passage rate over time across demographic groups at the underpasses:

Response ~ MSD + Gender/Age Class + Species Category + (1|Season) + (1|MonitoringLocation)

A binomial generalized linear mixed effects model was used to assess changes in successful passage rate over time across demographic groups including species and gender/age class, with female deer as the model baseline. For this analysis, observations for which the gender/age class was unknown were removed from consideration. Mule deer and white-tailed deer were collapsed into one category, deer, to improve model fit. This was possible because it was not necessary to include a sampling effort offset term when considering rates. Season, monitoring location and year were tested as potential random effects, and season and monitoring location were included in the final model. Interaction terms were considered between the time variable, MSD, and both gender/age class and species category.

2.1.4.1.8. Hesitation Rate Over Time Model

The following model was used to evaluate changes over time in hesitation rate in successful passages:

Response ~ MSD + Species Category + (1|Season) + (1|MonitoringLocation)

Hesitation rate was calculated as the portion of successful passage in which the animals had hesitant behavior per month. A binomial generalized linear mixed effects model was used to assess changes in hesitation behavior over time across species categories. Mule deer and white-tailed deer were collapsed into one category, deer, to improve model fit. This was possible because it was not necessary to include a sampling effort offset term when considering rates. Season, year, and monitoring location were tested as potential random effects, and season and monitoring location were included in the final

model. An interaction term between MSD and the species category was considered, as well as the removal of species category as a model variable.

2.1.4.2. Wildlife Guards

Statistical modeling examined potential associations between ungulate breach and repel movements and guard and landscape characteristics over the three years of the study. Generalized linear mixed effects models were used to assess the effect of distance from nearest building, guard width, and crossing distance (fixed effects) on breach or repel events (responses). The breach rate and repel rate models incorporated the same variables but used different estimates for the covariables. The following factors were considered: a binomial conditional distribution; season, year, and season nested within year as random effects; and an offset term for the number of days that cameras at a given monitoring location were active. Selection of the final model was based on residual diagnostics, assessed using the package DHARMA (Hartig 2024), and included only year as the random effect.

The following models were used to evaluate breach and repel movements relative to structural and environmental variables:

Breach ~ Building Distance + Guard Width + Crossing Distance + (1 | Year) + offset(effort)

Repel ~ Building Distance + Guard Width + Crossing Distance + (1 | Year) + offset(effort)

2.1.4.3. Escape Ramps

Statistical modeling examined potential associations between the overall ungulate intercept rate or escape rate over the three years of the study relative to ramp type and landscape variables (distance to nearest crossing structure, and distance from road). Generalized linear mixed effects models were used to assess the effect of ramp type, road distance and crossing distance (fixed effects) on intercept events and escape ramp use (responses). Ramp height was not included as a variable in the escape ramp use model due to the lack of variation in height among the sampled escape ramps. The following factors were considered: beta binomial and binomial conditional distributions; season, monitoring location, and year as random effects; and including an offset term for the number of days cameras at a given monitoring location were active.

$$\log(\mu_i) = \beta_0 + \beta_1 \cdot RampType_i + \beta_2 \cdot RoadDistance_i + \beta_3 \cdot CrossingDistance_i + b_{Year[i]} + \log(effort_i)$$

where μ_i is the expected value of the response variable for observation i , β_1 , β_2 , and β_3 , are the fixed effect coefficients for the predictors, $b_{year[i]}$ is the random intercept for the grouping factor, and $b_{year[i]}$ is the offset term.

Selection of the final model was based on residual diagnostics, assessed using the package DHARMA, and only year was retained as a random effect and a binomial conditional distribution was used.

2.2. Wildlife-Vehicle Collision Data Analysis

This portion of the study measured changes in WVCs in space and over time in the mitigated project area. WVC analyses were based on two primary datasets:

- Crash data are compiled by CDOT Traffic and Safety. This dataset included all crashes, including WVCs, reported to law enforcement. These data are consistently collected across the state and include the species involved in a WVC, where known.
- Carcass data have been recorded by CDOT Maintenance patrols on a voluntary basis since the early 2000's.

While WVC crashes are widely recognized as being underreported to law enforcement (e.g., Kintsch et al. 2021; Olson 2013), crash data reflect annual trends and spatial patterns in WVCs. Carcass data collection in the I-25 South Gap project was inconsistent prior to project development, limiting the utility of these data for before/after analysis. Construction phase carcass reporting was compiled by RockSol and included reports from CDOT Maintenance patrols, CPW local staff, and construction crews. Available carcass data nonetheless provided an important complement to the crash data, particularly for evaluating the spatial distribution of post-construction WVCs.

2.3. Performance Measures

Performance measures support a quantitative evaluation of how well the wildlife mitigation achieved the stated objectives of a highway improvement project. These measures help agencies take adaptive management actions to increase the effectiveness of the mitigation and help inform future mitigation projects in other locations. It is essential to define specific, measurable, and achievable performance measures at the outset of a project to objectively evaluate project success (van der Grift et al. 2013).

Performance measures were established at the outset of this study to evaluate the effectiveness of the I-25 South Gap Project wildlife mitigation system with respect to wildlife underpass use and motorist

safety. Wildlife connectivity performance measures were developed to evaluate how well the mitigation features facilitated wildlife movement across the interstate barrier, thereby helping to restore connectivity and enhance population viability (Beier and Noss 1998; van der Grift 2005). Motorist safety performance measures were developed to evaluate the degree to which the wildlife mitigation prevented wildlife from accessing the roadway, thereby contributing to a reduction in WVCs (Table 5). Appendix C summarizes the performance measures evaluation.

Table 5. Performance measures for evaluating wildlife underpass use.

Number	Wildlife Crossing Use Measures
1	Mule deer success movements at each structure will increase over time with a minimum of success rate of 80% and a goal of 90%.
2	The number of successful elk passages at all structures will be at least 50% of the number of elk movements captured at associated control (habitat) cameras.
3	Elk success movements at each structure will increase over time with a minimum success rate of 70% and a goal of 80%.
4	Mule deer movements east-west through the crossing structures will be roughly equivalent to west-east movements.
5	Over time, mule deer and elk movements through the crossing structures will be represented by males, females, and juveniles.
6	Successful passages through the crossing structures by less common species will remain constant or increase over time (e.g., pronghorn, white-tailed deer, mountain lion, bear).

Number	Motorist Safety Measures
7	The proportion of ungulate movements at the northeast fence end that enter the fenced right-of-way will decrease to 20% or less.
8	Over time, detections of ungulates attempting to breach wildlife guards to enter the road right-of-way will decrease and ungulates will be deterred from entering the road right-of-way at least 80% of the time.
9	Over time, ungulate detections at escape ramps will decrease; of ungulates that ascend an escape ramp the proportion that successful escape to the habitat side will increase; and no ungulates will jump up onto the ramp from the habitat side.
10	The annual average number of reported WVC crashes (CDOT Traffic and Safety data) within the mitigated area will decrease over time by a minimum of 80% and with a goal of a 90% reduction compared to the five-year preconstruction average.

Chapter 3. Ungulate Use of Wildlife Underpasses

The goal of monitoring wildlife at the wildlife underpasses and the existing box culvert was to document wildlife activity and behavior at each structure and document successful through passages and repel movements. Five ungulate species were detected at or near the five underpasses and the existing 3-Chambered Box Culvert. Mule deer was the most detected species ($n=19,056$), followed by white-tailed deer ($n=2,334$) and elk ($n=1,854$). Moose was documented using a structure on one occasion and while pronghorn were captured on the approach cameras, they were not observed approaching any of the crossing structures.

This chapter focuses on mule deer, white-tailed deer, and elk activity and use of the crossing structures. All reported mule deer tallies have been adjusted by the sampling factor as discussed above in the Methods (Chapter 2).

3.1. Results

Over the course of the study, the active monitoring timeframes varied at each crossing structure location due to differing camera deployment dates and occasional battery depletions or storage capacity being reached on SD cards. Over the three years of the study, each structure was monitored for an average of 1,087 days, ranging from 1,076.5 days at the Greenland Underpass to 1,096 days at both the Monument Hill Underpass and the 3-Chambered Box Culvert. There was little year-to-year variation in the number of monitoring days across the monitored structure locations (range=362-362.7 days).

3.1.1. Ungulate Successful Passages

From January 2022 through December 2024, cameras recorded a total of 16,749 mule deer successful passages through the five crossing structures and existing box culvert. Cameras also documented 1,791 and 866 white-tailed deer and elk successful passages, respectively.

Total approaches to the crossing structures and successful passages increased each year of the study for all three species (Fig. 9). For mule deer, the number of successful passages increased by 3% from construction to post-construction (2022 – 2023) and by an additional 18% from the first year to the second year post-construction (2023 – 2024). For white-tailed deer, the number of successful passages increased by 119% from 2022 to 2023 and an additional 2% from 2023 to 2024. Elk successful passages experienced the largest year-over-year growth, with an 848% increase from 2022 to 2023, and 104% increase from 2023 to 2024.

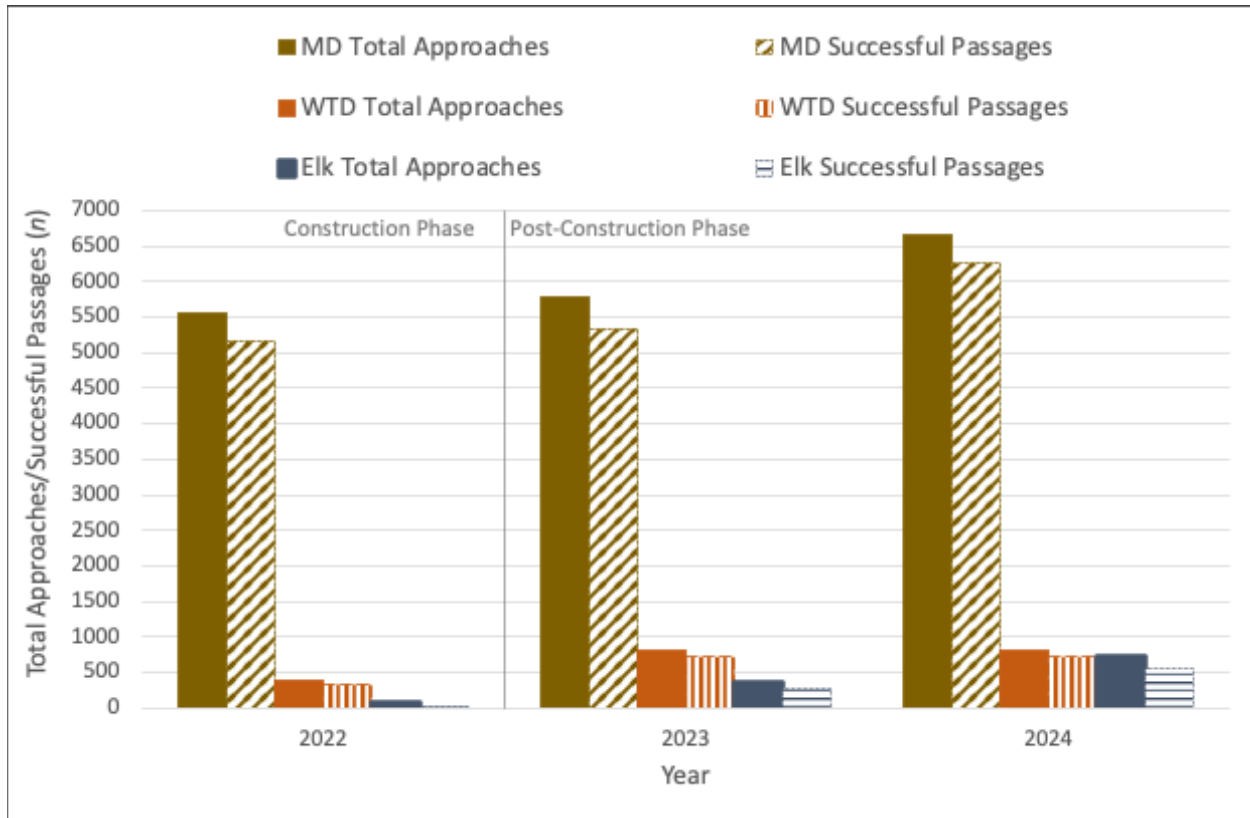


Figure 9. Total approaches and successful passages for mule deer, white-tailed deer and elk by year.

Figure 10 depicts changes in success rate over the course of the study for mule deer, white-tailed deer, and elk. While the total number of mule deer detections and successful passages was lowest during the construction phase (2022), mule deer nonetheless made 5,157 successful passages during this timeframe with a success rate of 93%. White-tailed deer made 329 successful passages with a success rate of 88% during this same timeframe. Elk on the other hand, only made 29 successful passages and had a success rate of 38% during the construction phase. Following the completion of construction activities in 2022, there were an average of 5,796 mule deer successful passages each year at the five crossing structures and existing box culvert with an overall success rate of 93%. White-tailed deer had an annual average of 731 successful passages and an overall success rate of 91%, and for elk, there was an annual average of 418.5 successful passages with a post-construction success rate of 76%.

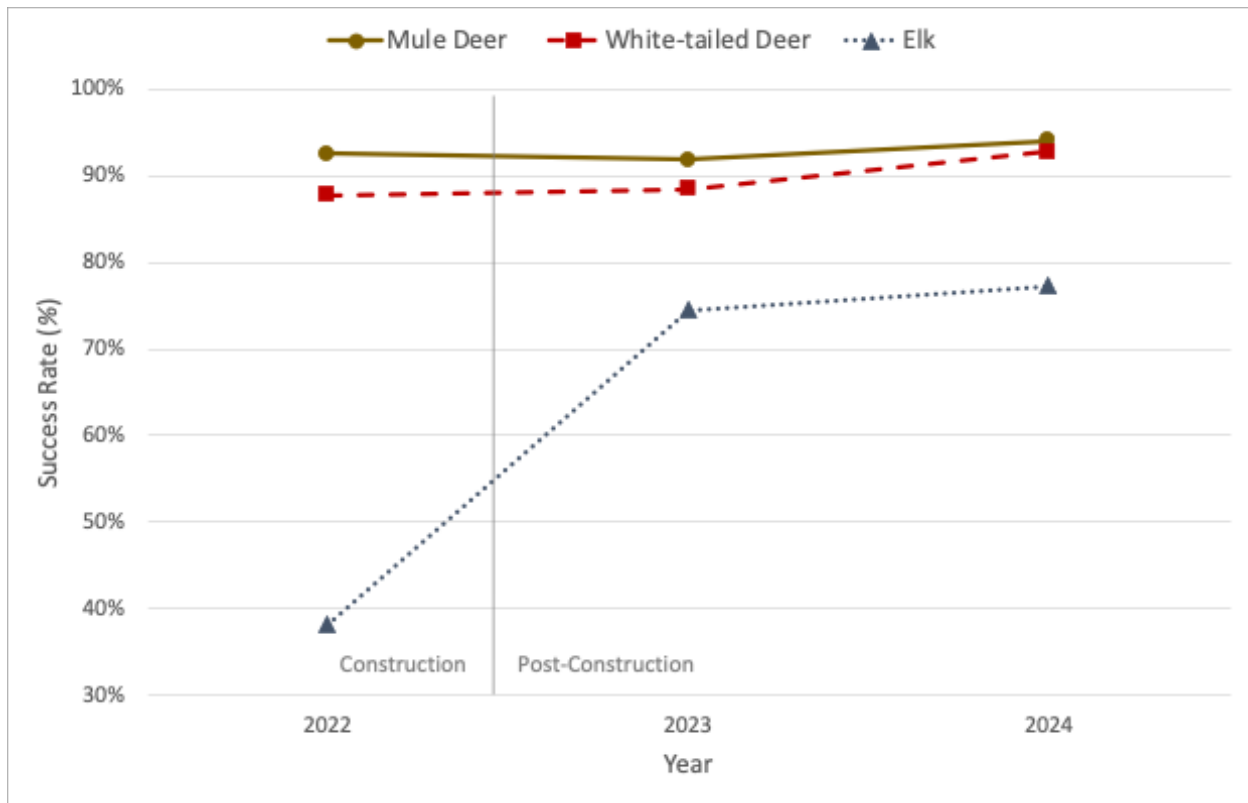


Figure 10. Success rates for mule deer, white-tailed, and elk by year.

3.1.2. Ungulate Passages by Location

Total detections and successful passages varied among the crossing structures and from year to year for each species (Table 6). Mule deer activity was greatest at the Monument Hill Underpass over all three years of the study, accounting for 45% of all approaches ($n=8,097$). Approaches included repel, through passage and through passage with multiple attempts, but not forage/rest and parallel/ignore movements. Thirty-three percent of all mule deer approaches occurred at the Greenland Underpass ($n=5,898$). The Rest Area Underpass accounted for 18% of all mule deer approaches ($n=3,172$), and the 3-Chambered Box Culvert, Dogleg Underpass and Plum Creek Bridge all accounted for less than 2% of all mule deer approaches ($n=447, 238, 172$, respectively). Mule deer success rates at the crossing structures ranged from 83% at the Dogleg Underpass to 96% at the Plum Creek Bridge.

Table 6. The number of total detections, success passages, repel movements, and success rates for each ungulate species at each wildlife underpass and existing box culvert during the 3-year study. Detections included repel, through passage and through passage with multiple attempts, repel, forage/rest, parallel/ignore movements. Success rates were calculated as the proportion of total approach movements (success and repels) that resulted in successful through passage.

Structure Mile Post and Name	Species	Total Detections	Success Passages	Repels	Success Rate
162.5 – Monument Hill	Mule Deer	8,493	7,510	587	93%
-	White-tailed Deer	1	0	1	0%
-	Elk	0	0	0	-
164.1 – Dogleg	Mule Deer	327	197	40	83%
-	White-tailed Deer	211	156	32	83%
-	Elk	293	152	77	66%
167.3 – 3-Chambered Box	Mule Deer	460	395	52	88%
-	White-tailed Deer	463	402	50	89%
-	Elk	1	0	0	-
167.7 – Greenland	Mule Deer	6,186	5,588	310	95%
-	White-tailed Deer	550	502	30	94%
-	Elk	220	135	60	69%
170.6 - Rest Area	Mule Deer	3,372	2,892	280	91%
-	White-tailed Deer	210	177	30	86%
-	Elk	100	13	51	20%
172.2 - Plum Creek	Mule Deer	219	166	6	96%
-	White-tailed Deer	889	554	55	91%
-	Elk	1,240	566	118	83%

The Plum Creek Bridge saw the greatest use by both white-tailed deer and elk over all three years of the study, accounting for 31% of all white-tailed deer approaches ($n=609$) and 58% of all elk approaches ($n=684$). The Greenland Underpass accounted for the second highest number of white-tailed deer approaches ($n=532$, 27%). The Dogleg Underpass accounted for the second highest number of elk approaches ($n=229$, 20%), but the fewest for white-tailed deer ($n=188$, 9%). No elk were detected at either the Monument Hill Underpass or the 3-Chambered Box Culvert, and only one white-tailed deer was detected at Monument Hill. Figure 11 depicts the number of successful passages for these species at each crossing structure.

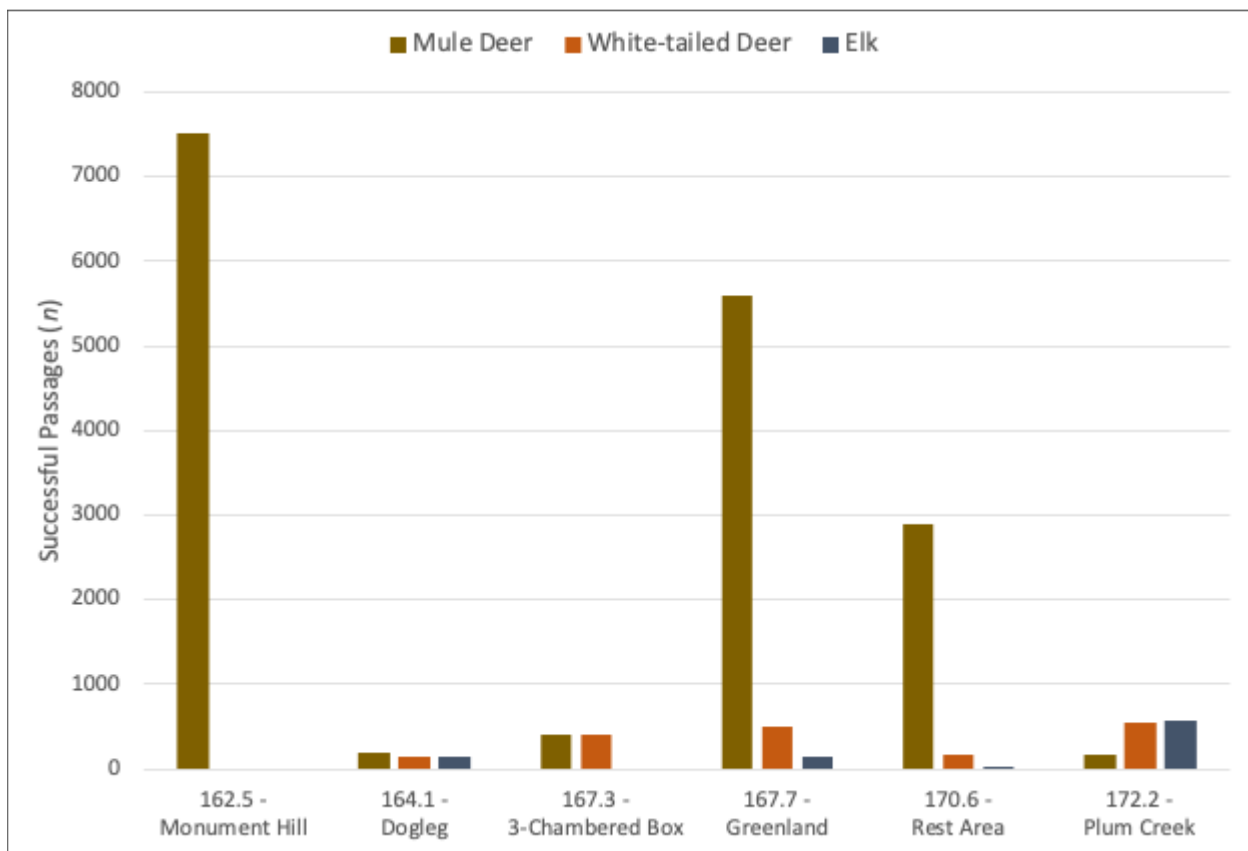


Figure 11. Number of successful passages for mule deer, white-tailed deer and elk at each crossing structure and existing box culvert.

The number of mule deer and white-tailed deer successful passages varied among locations and from year to year. Mule deer successful passages increased post-construction at the Monument Hill, Greenland, and Rest Area Underpasses, but decreased from 2023 to 2024 at the Dogleg Underpass, the 3-Chambered Box Culvert, and Plum Creek Bridge (Fig. 12). White-tailed deer successful passages increased at all locations except the Dogleg Underpass from construction to post-construction (2022-

2023). From the first to the second year post-construction, the number of white-tailed deer through passage movements generally leveled out at all the structure locations, with smaller increases or decreases in the number of success movements from 2023 to 2024 (Fig. 13). The Greenland Underpass was the only structure where white-tail deer successful passages increased across all three years.

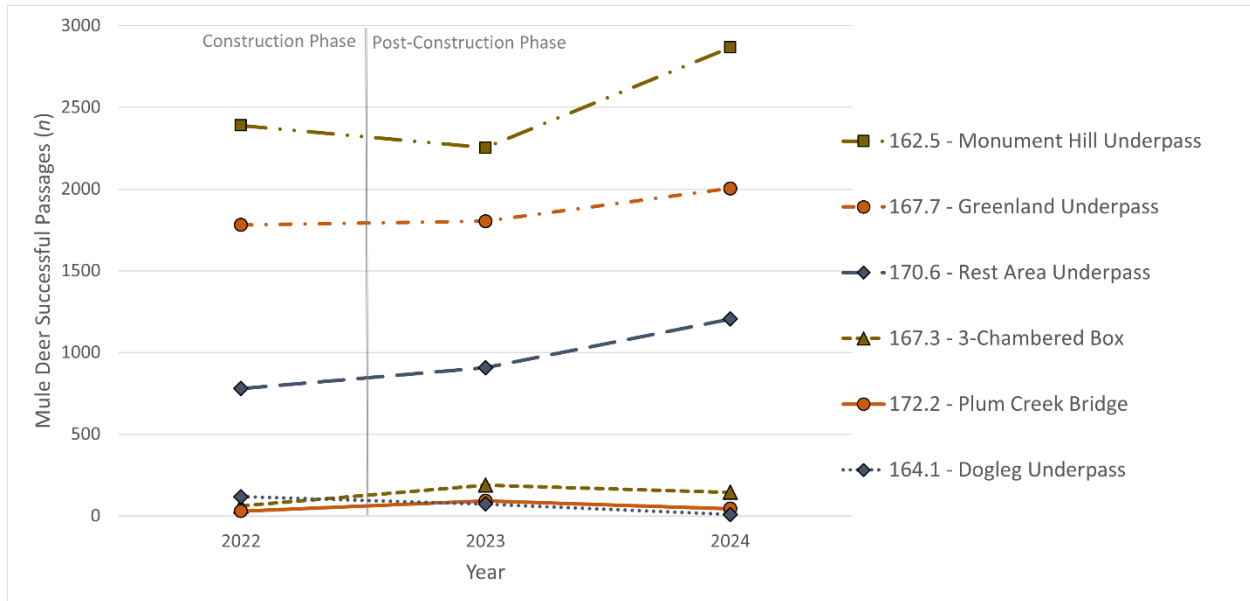


Figure 12. Annual number of mule deer successful passages at each crossing structure and the existing culvert each year of the three-year study.

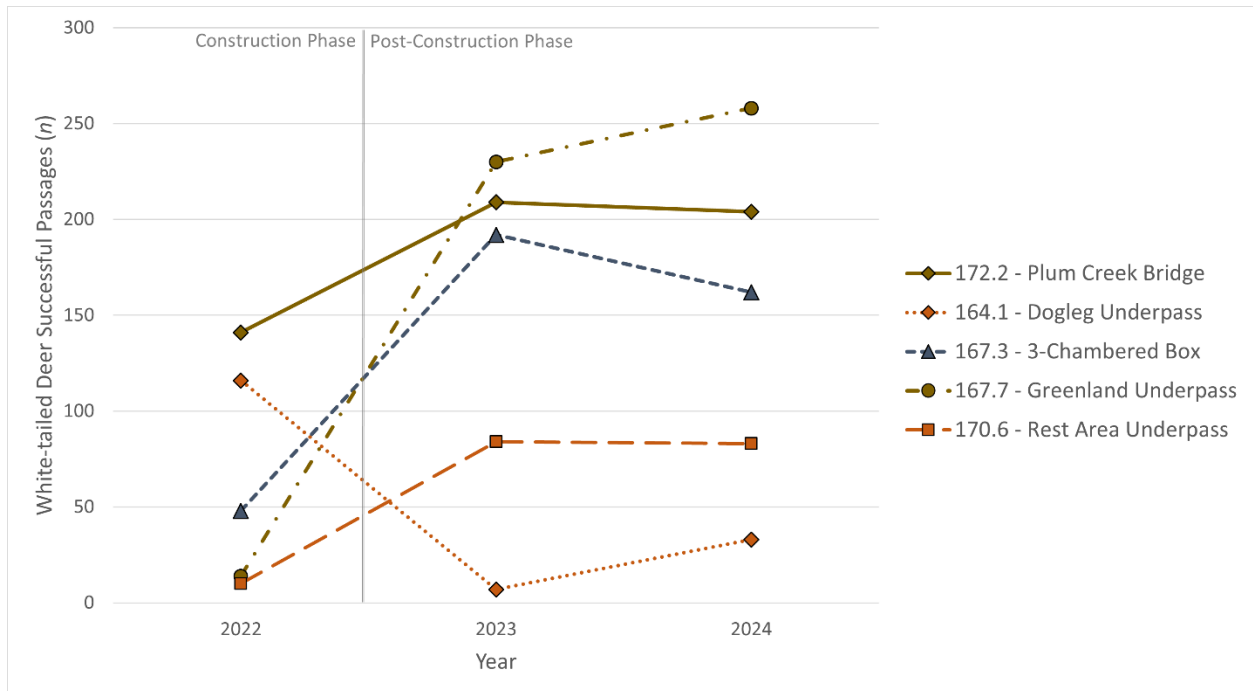


Figure 13. Annual number of white-tailed deer successful passages at each crossing structure and the existing culvert each year of the three-year study.

Elk successful passages increased year-over-year at all structures where elk was detected, except for the Greenland Underpass, where a small decrease in activity was documented in 2024 (Fig. 14). The largest increase in elk successful passages was observed at the Plum Creek Bridge.

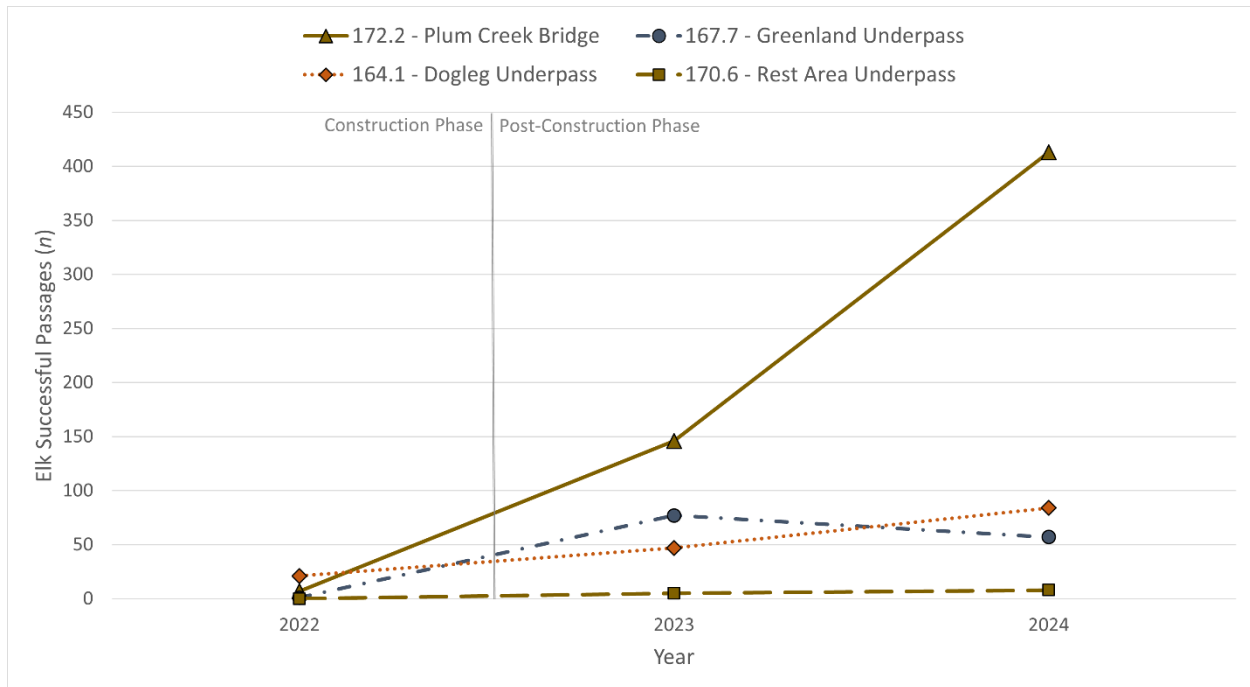


Figure 14. Annual number of elk successful passages at each crossing structure each year of the three-year study.

Standardizing the number of successful passages by monitoring days at each location, there were 6.9 mule deer successful passages per day at the Monument Hill Underpass, followed by 5.2 at the Greenland Underpass and 2.7 at the Rest Area Underpass. For white-tailed deer, there were 0.5 successful passages per day at the Greenland Underpass and the Plum Creek Bridge, followed by 0.4 at the 3-Chambered Box, 0.2 at the Rest Area Underpass and 0.1 at the Dogleg Underpass. Elk successful passages per day were highest at the Plum Creek Bridge (0.5 successful passages per day), followed by 0.1 at the Dogleg and Greenland Underpasses and 0.01 at the Rest Area Underpass (Table 7).

Table 7. Mule deer, white-tailed deer and elk successful passages and daily successful passage rates at the crossing structures. The average number of Successful Passages per Monitoring Day are calculated based on the total number of active camera monitoring days.

Structure Mile Post and Name	Species	Total Successful Passages	Monitoring Days	Average # Successful Passages per Day
162.5 - Monument Hill	Mule Deer	7,510	1,096	6.9
-	White-tailed Deer	0	1,096	-
-	Elk	0	1,098	-
164.1 – Dogleg	Mule Deer	197	1,088	0.2
-	White-tailed Deer	156	1,088	0.1
-	Elk	152	1,088	0.1
167.3 - 3-Chambered Box	Mule Deer	395	1,096	0.4
-	White-tailed Deer	402	1,096	0.4
-	Elk	0	1,096	-
167.7 – Greenland	Mule Deer	5588	1,076.5	5.2
-	White-tailed Deer	502	1,076.5	0.5
-	Elk	135	1,076.5	0.1
170.6 - Rest Area	Mule Deer	2,892	1,078	2.7
-	White-tailed Deer	177	1,078	0.2
-	Elk	13	1,078	0.01
172.2 - Plum Creek	Mule Deer	166	1,088.75	0.2
-	White-tailed Deer	554	1,088.75	0.5
-	Elk	566	1,088.75	0.5

In addition to through passage and repel movements, ungulates were also documented making parallel/ignore movements or foraging/resting in the vicinity of the crossing structures. The structure with the highest proportion of mule deer parallel/ignore and forage/rest detections relative to the total number of detections was the Dogleg Underpass (27%). The next highest portion was at the Plum Creek Bridge (21%). All other locations had proportions of 6% or less. The number of white-tailed deer parallel/ignore and forage/rest detections relative to the total number of detections was greatest at the Plum Creek Bridge (31%). The next highest portion was at the Dogleg Underpass (15%). All other locations were under 3%. For elk, the number of parallel/ignore and forage/rest detections relative to the total number of detections was greatest at the Plum Creek Bridge (45%). Other locations ranged from 11% at the Greenland Underpass to 36% at the Rest Area Underpass. Only one elk was detected at the 3-Chambered Box Culvert, resulting in a parallel/ignore movement.

3.1.3. Ungulate Success Rates

The post-construction success rates for mule deer, white-tailed deer and elk across all the crossing structures were 93%, 91% and 76%, respectively. Mule deer success rates at each of the structure locations ranged from 80-100% across all study years, except at the Dogleg Underpass, where there was a steep decline in the success rate in the final study year, dropping from 86% in 2023 ($n=72$ successful passages) to 40% in 2024 ($n= 8$ successful passages). Both the number of successful passages and the success rate increased at the Monument Hill Underpass each year of the study (Fig. 15). Overall post-construction success rates for mule deer ranged from 77% at the Dogleg Underpass to 97% at Plum Creek Bridge. The Dogleg Underpass was the only location with a mule deer success rate less than 85%.

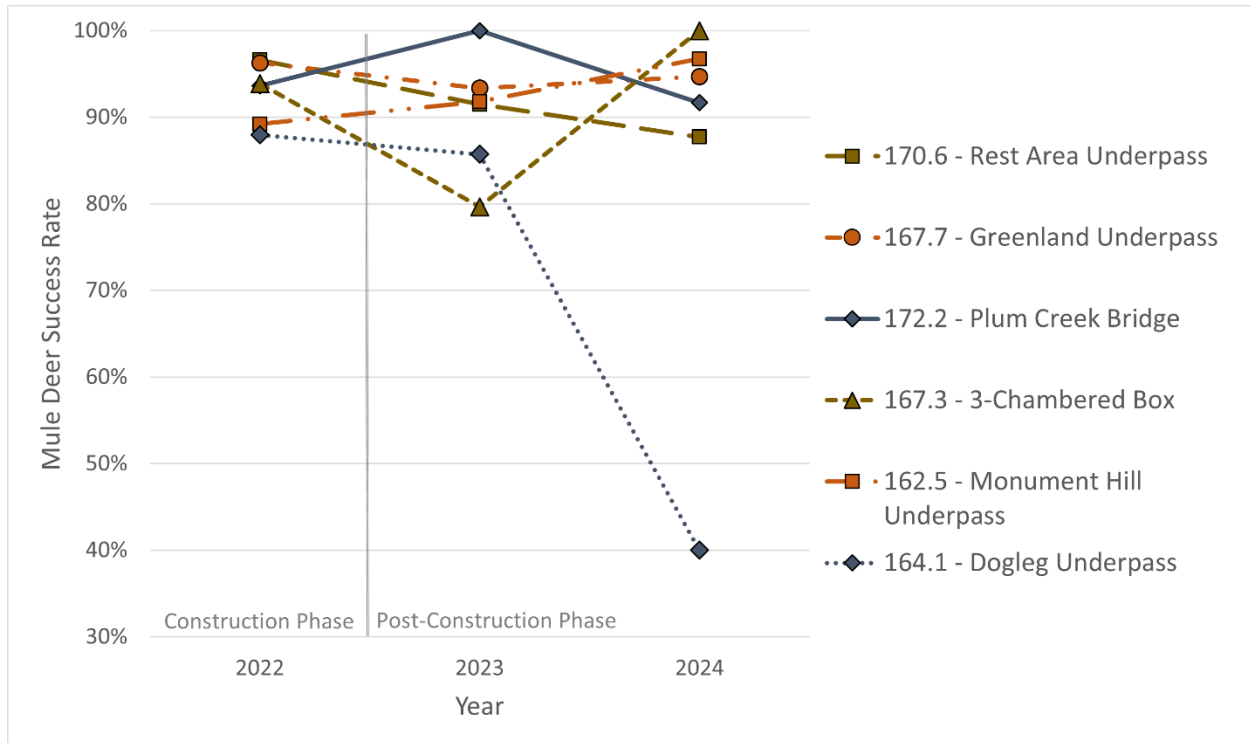


Figure 15. Mule deer success rates across years at each of the five wildlife crossing structures and one existing box culvert.

Success rates for white-tailed deer ranged from 83% at the Dogleg Underpass ($n=188$) to 94% at the Greenland Underpass ($n=532$). There was only one white-tailed deer detection at the Monument Hill Underpass that resulted in a repel movement that was not included in the presentation of these results. The overall success rate for white-tailed deer at the crossing structures was 90%. White-tailed deer success rates increased in the final year of the study at most crossing structures or remained stable (Rest Area Underpass), except for the Dogleg Underpass, where there was a decrease in the success rate from 2023 (100%, $n=7$) to 2024 (77%, $n=33$) (Fig. 16).

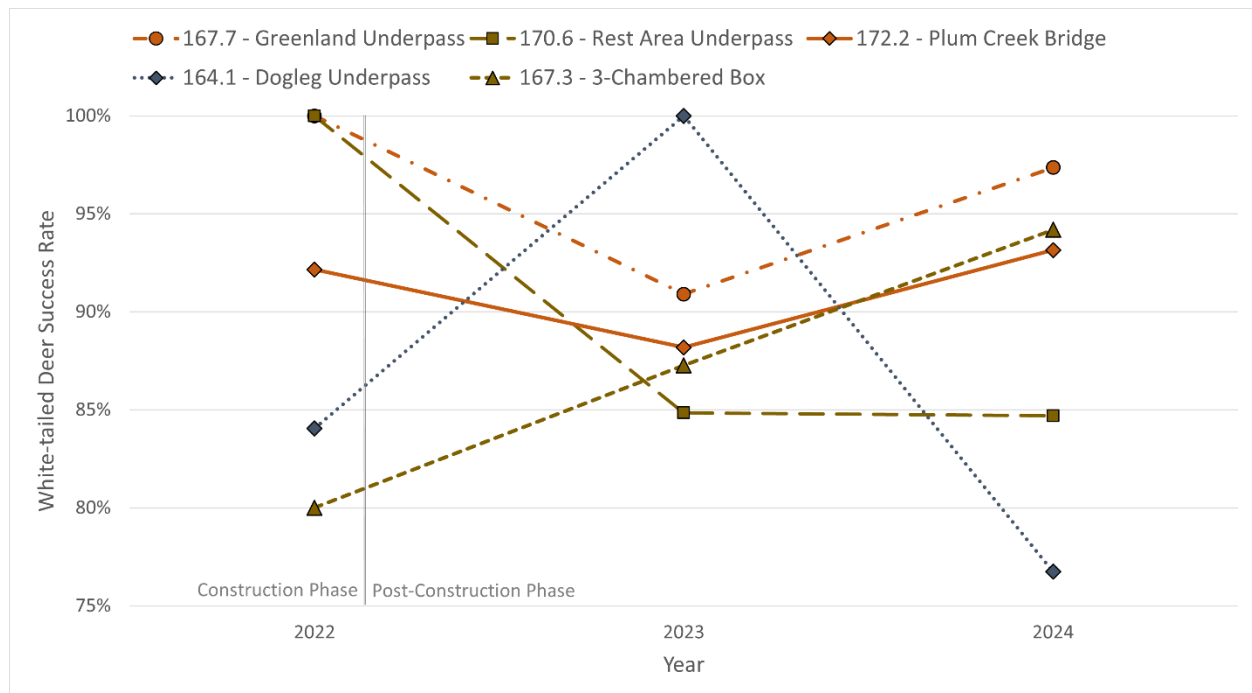


Figure 16. White-tailed deer success rates across years at each wildlife crossing structure and one existing box culvert where white-tail deer were detected.

Elk success rates ranged from 20% at the Rest Area Underpass ($n=64$) to 83% at the Plum Creek Bridge ($n=684$). No elk approaches were documented at the Monument Hill Underpass or the 3-Chambered Box Culvert. Elk success rates increased from the construction phase to post-construction at Greenland Underpass and the Plum Creek Bridge, while remaining stable at the Dogleg Underpass. At all three crossing structures, success rates continued to remain roughly stable through the two post-construction years of the study, ranging between 65% and 87%; however, at the Rest Area Underpass the elk success rate never exceeded 23% (Fig. 17).

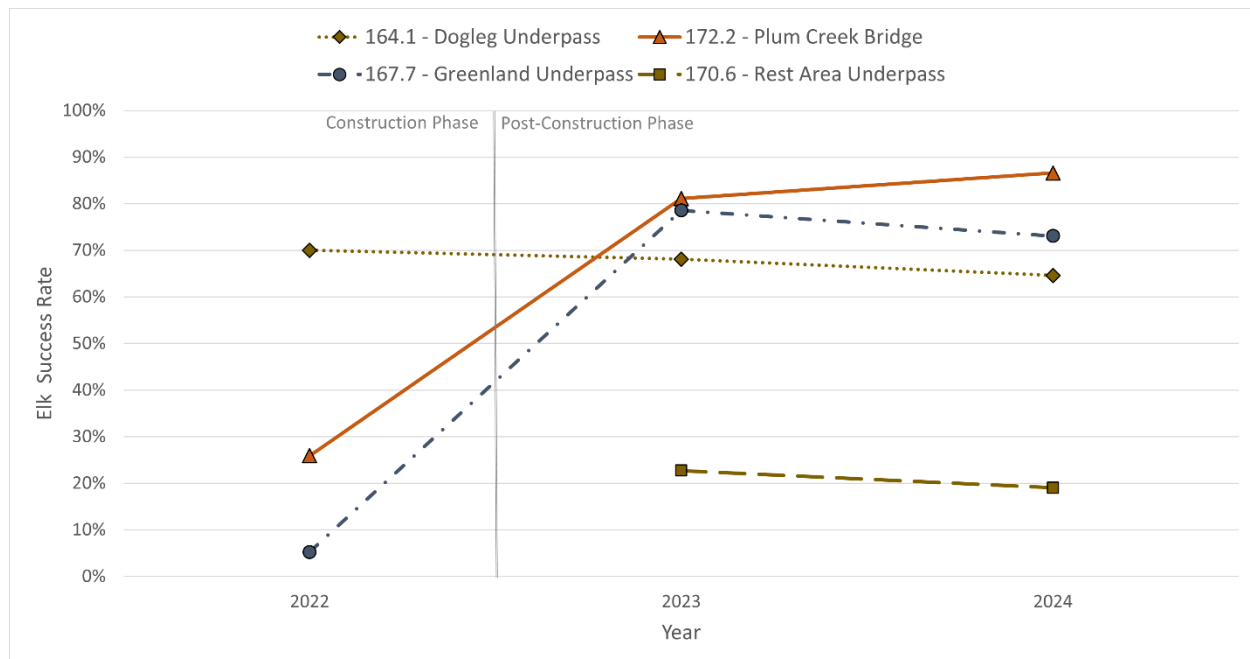


Figure 17. Elk success rates across years at each wildlife crossing structure where elk were detected.

3.1.4. Ungulate Seasonal Use of Crossing Structures

Successful passages by species across all the wildlife crossing structures and existing box culvert were plotted for each month from January 2022 through December 2024 (Fig. 18). Ungulate activity and successful passages were highest for all three species from late spring through fall (May – November). In general, mule deer successful passages peaked each year in the fall months, except in 2024 when mule deer successful passages peaked in June with the highest monthly level recorded during the study period ($n=1,000$).

White-tailed deer followed a similar seasonal pattern to that of mule deer, although in much lower numbers. Notably, white-tailed deer were not detected at any structures until May of 2022. Successful passages by white-tailed deer activity peaked in the summer and fall months, with the largest monthly peak in activity observed in November 2023 ($n=167$). Like mule deer, in 2024 successful passages peaked earlier in May of that year ($n=132$).

Elk activity and successful passages were low throughout the first year of the study but reliably peaked during the summer months each year. In 2024, a second peak was documented in October with 109 successful passages. Each year of the study, no elk were detected at any structures for three to four months of the year.

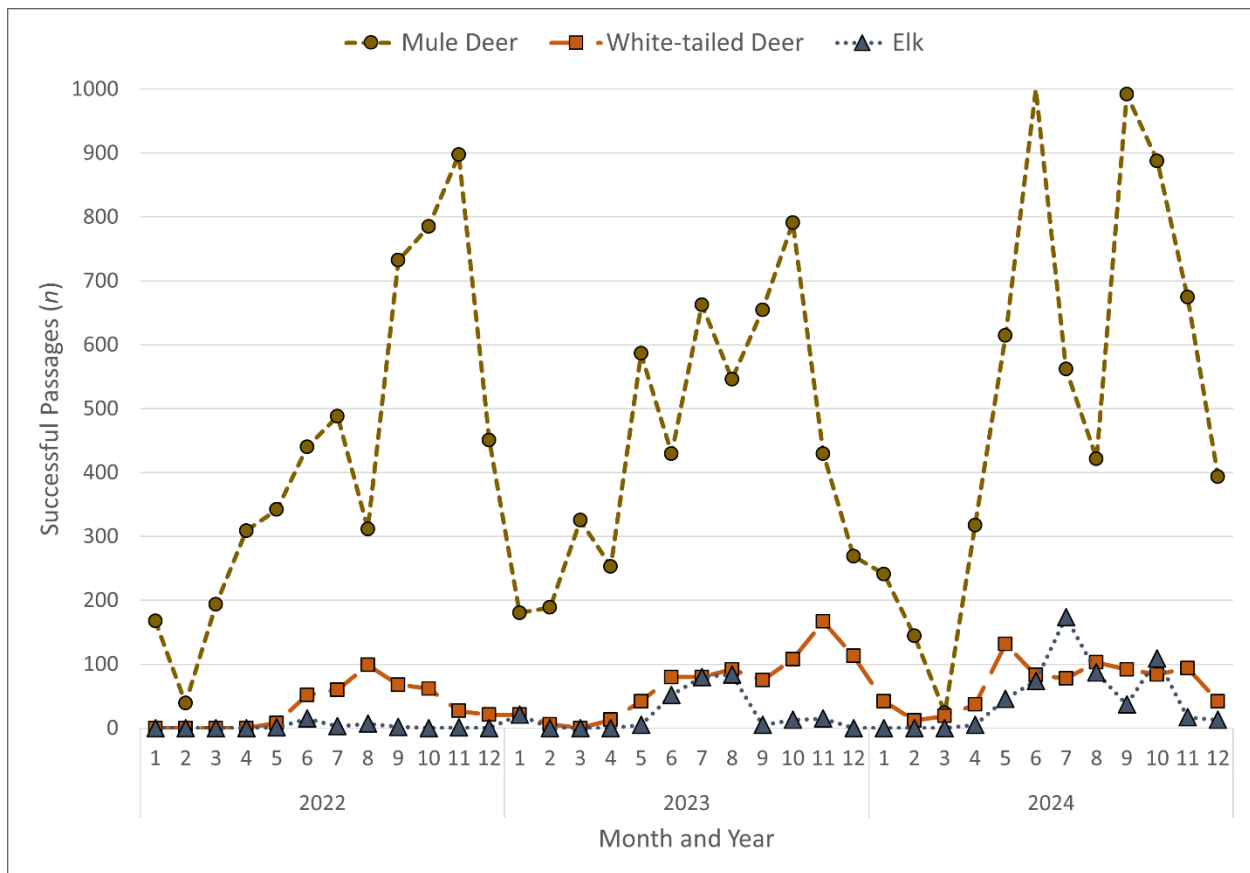


Figure 18. Successful passages by species by month and year from 2022 to 2024.

Periods of peak use varied among ungulate species at each crossing structure and from one year to the next. For mule deer, the only structure to have a consistent seasonal peak in activity was the Greenland Underpass which recorded the greatest number of successful passages for mule deer during September and October in all three years of the study. Mule deer activity at all other structures had more annual variation (Fig. 19).

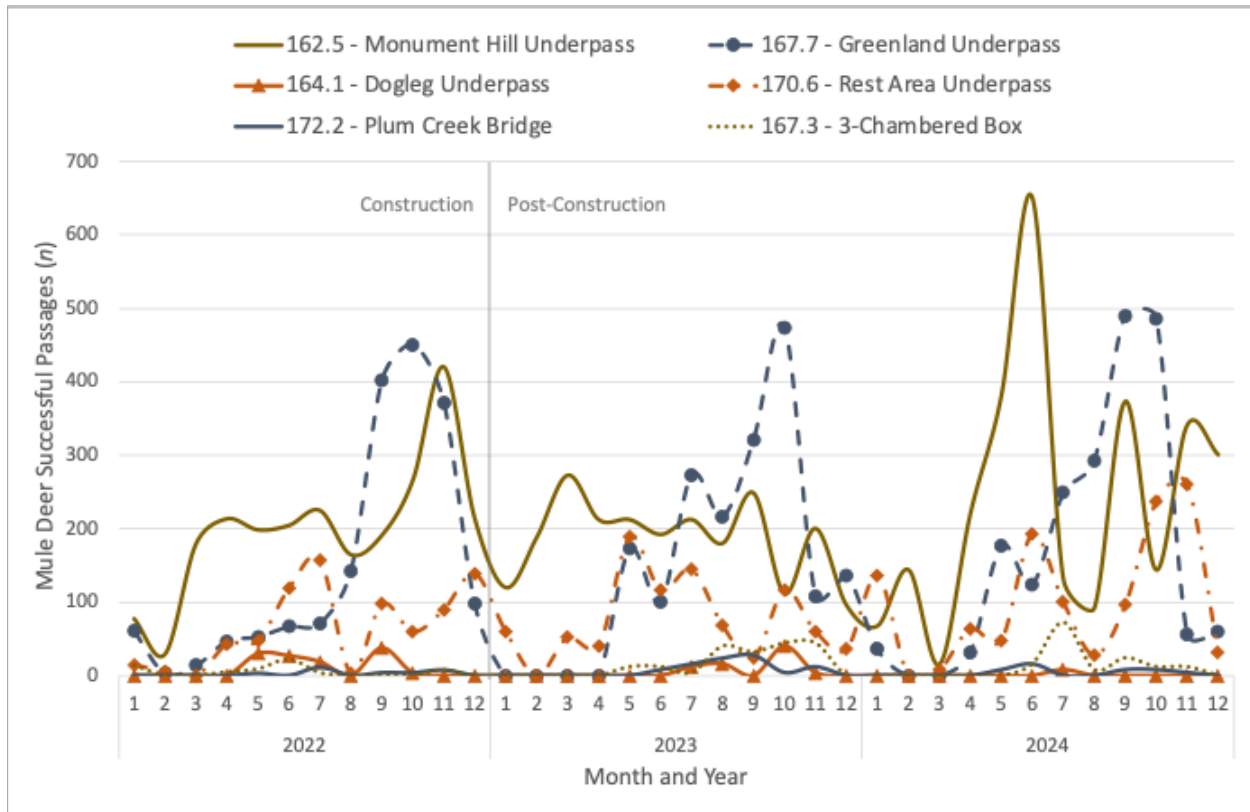


Figure 19. Mule deer successful passages by month and year at each of the wildlife crossing structures and existing box culvert over the three-year study period.

White-tailed deer successful passages were lowest December through March, except at the Plum Creek Bridge, which saw a small peak in activity in January 2023. In general, white-tailed deer activity and successful passages ramped up in the late spring and peaked in the late summer and fall (Fig. 20). The greatest peaks in white-tailed deer passages were documented at the Greenland Underpass and the nearby 3-Chambered Box Culvert in November 2023 and again in May and August 2024 at the Greenland Underpass.

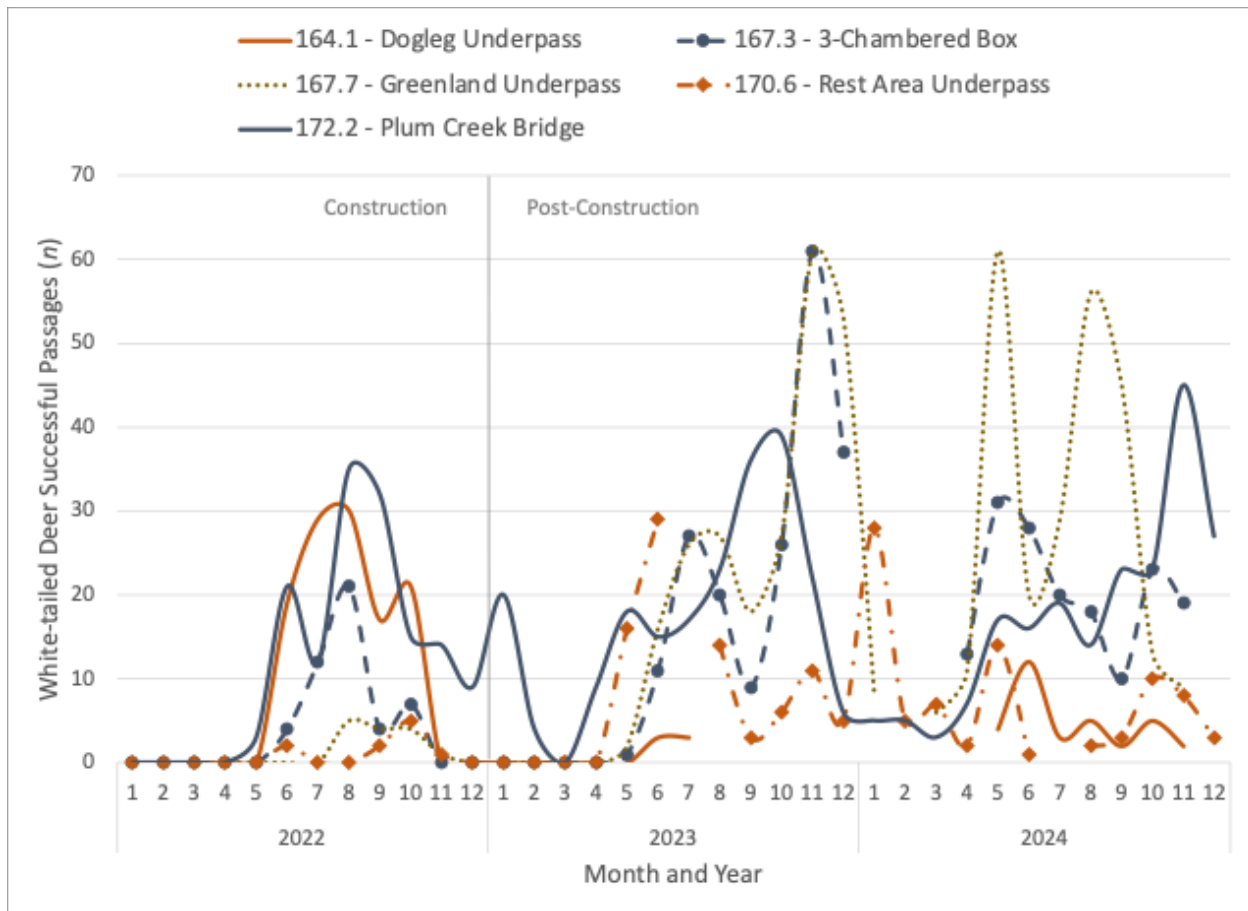


Figure 20. White-tailed deer successful passages by month and year at each of the wildlife crossing structures and existing box culvert where they were detected over the three-year study period.

Elk activity and successful passages remained low through the construction phase and began to increase the first post-construction year with an additional increase in 2024 (Fig. 21). Elk had the most consistent seasonal peaks of any of the ungulate species highlighted in this chapter, beginning in May and peaking August and September. In 2024, a second peak in elk activity was documented at the Plum Creek Bridge in October. Elk successful passages were lower at the other three crossing structures where elk were detected but followed similar seasonal patterns. An anomaly to this pattern was a small peak in elk passages in January 2023 at the Plum Creek Bridge and, to a lesser degree, the Greenland Underpass. No other elk activity was detected at the crossing structures from December through March in any of the study years.

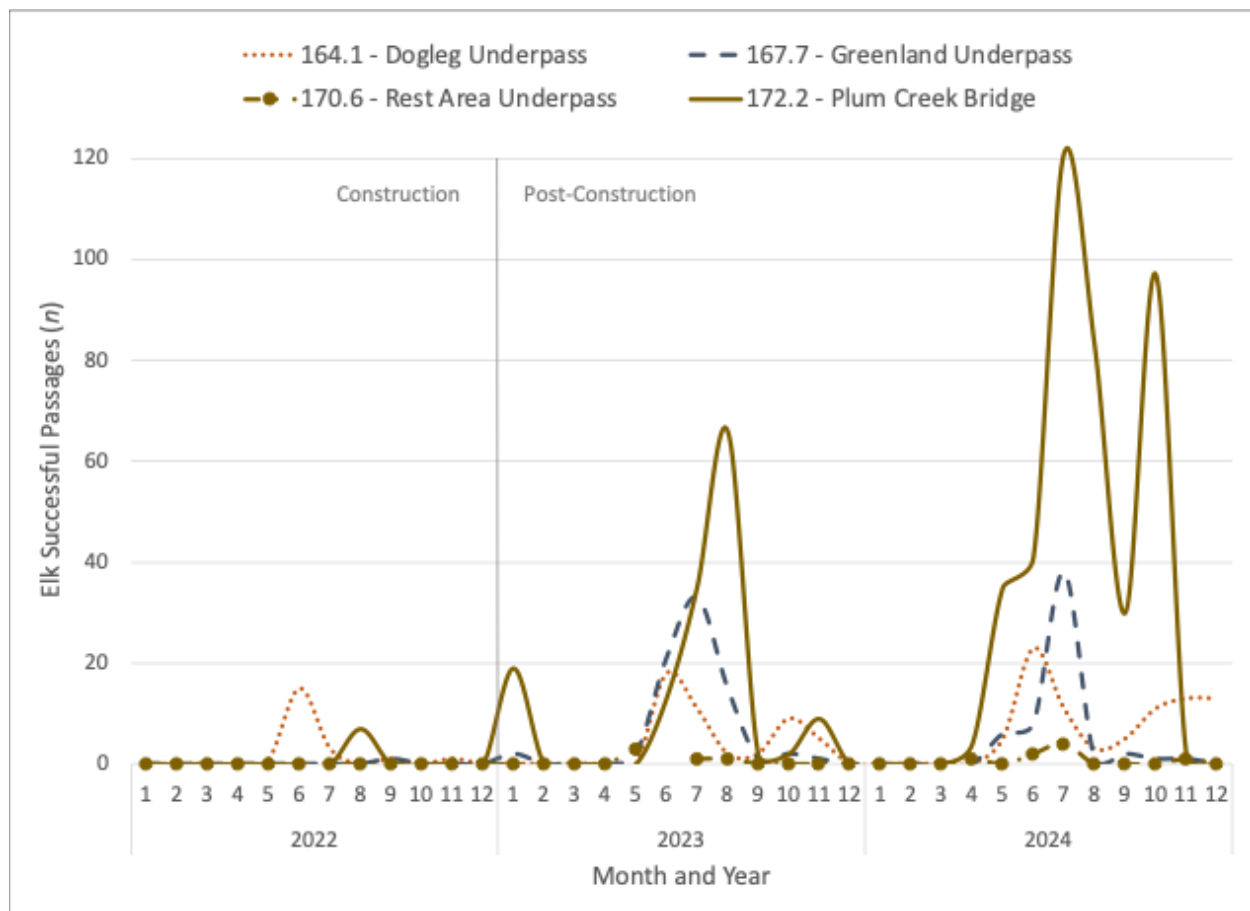


Figure 21. Elk successful passages by month and year at each of the wildlife crossing structures where they were detected over the three-year study period.

3.1.5. Direction of Origin

Movements through the crossing structures originated from both east or west. For the most part, movements originating from either side of the highway were nearly equal (Fig. 22). The greatest variation in direction of origin was observed in elk. In the months of December, January, and April more elk successful passages originated from the east and crossed through the structures to the west. Notably, elk activity was lowest during the winter and early spring months when this variation in directional movements was detected. Similarly, the greatest skew in white-tailed deer movements was observed in the month of April, when more animals moved from west to east than in the opposite direction; however, white-tailed deer activity in this time frame was generally low. In September and November, slightly more elk moved from the west to the east through the structures than in the

opposite direction. For all three ungulate species, east-west and west-east movements were roughly equivalent during the months of peak activity.

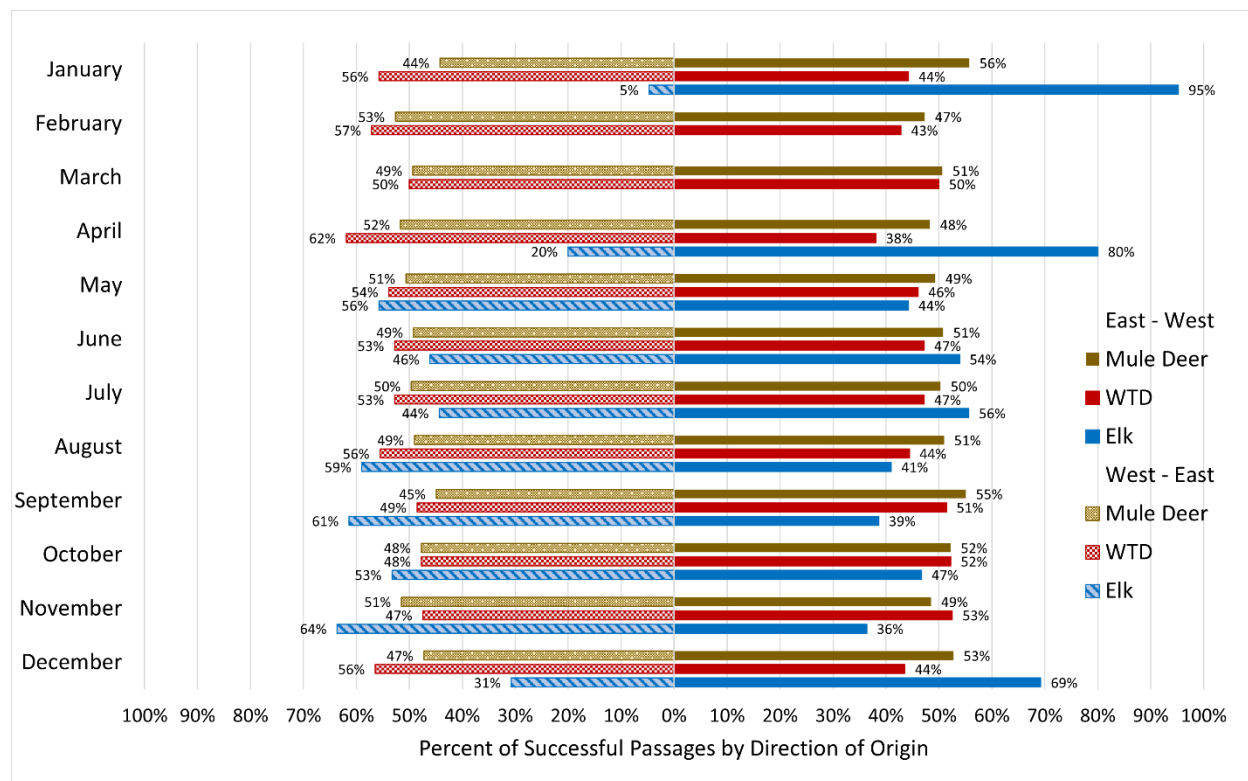


Figure 22. Direction of origin of mule deer, white-tailed deer and elk successful passages by month of the year (2022, 2023 and 2024 combined).

3.1.6. Demographics of Ungulates Using Crossing Structures

Overall, mule deer does accounted for 40% ($n=6714$) of successful mule deer passages through all five crossing structures and the existing box culvert over the three study years. Bucks accounted for 45% ($n=7493$), with young of the year/yearlings accounting for 12% ($n=1936$), and 4% of unknown age and gender ($n=606$). Demographic distributions varied among the crossing structures but were generally consistent from year to year at most structures (Fig. 23). Does accounted for most successful passages at the Monument Hill Underpass in all years, whereas bucks accounted for the most successful passages in all years at the 3-Chambered Box Culvert, the Rest Area Underpass and the Plum Creek Bridge. Activity at the Dogleg Underpass was nearly equal between does and bucks in all years, except 2024, which experienced very low levels of mule deer use. Annual gender distributions were most variable at the Greenland Underpass.

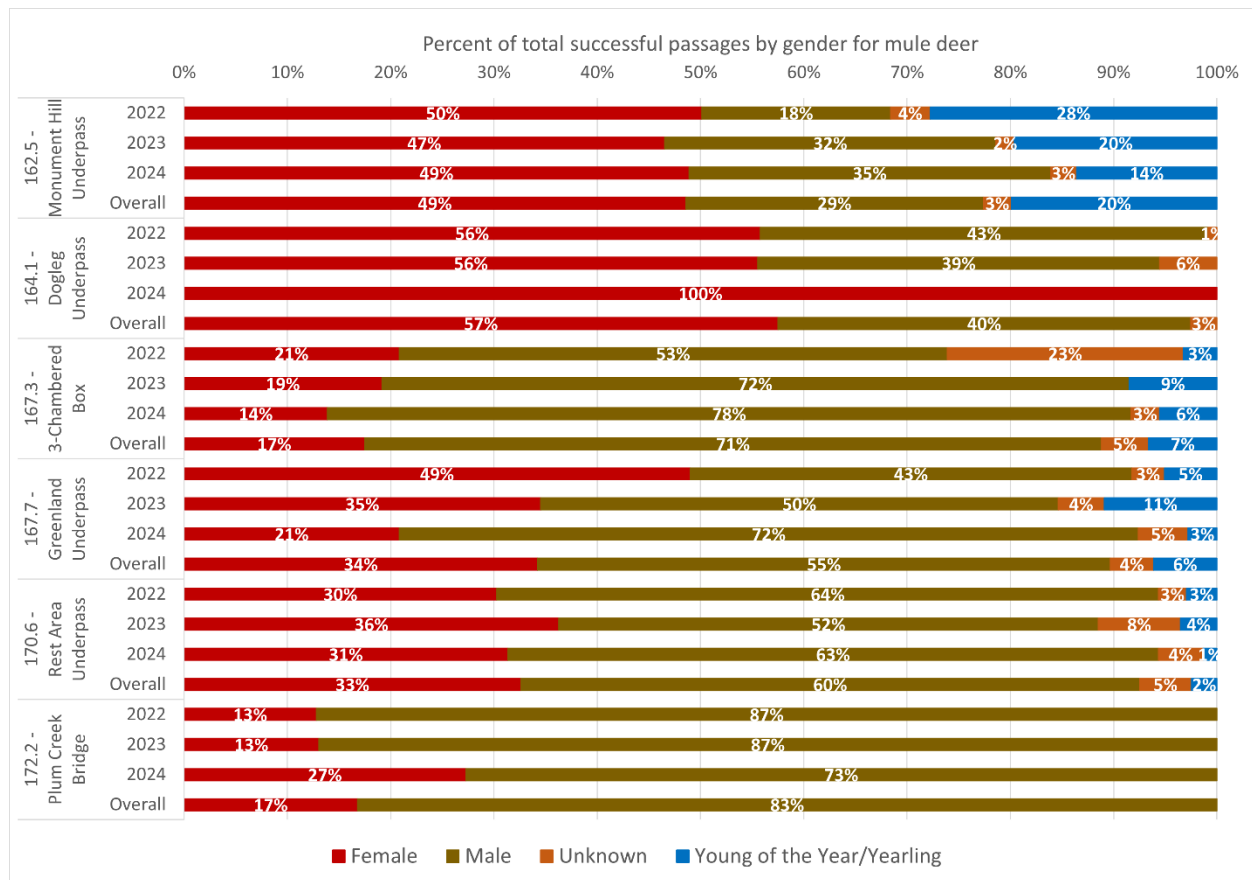


Figure 23. Demographic distribution of mule deer among the structures each year of the study.

For white-tailed deer, does accounted for 48% ($n=859$) of all successful passages, bucks 38% ($n=687$), young of the year/yearlings accounted for 11% ($n=188$), and unknown gender 3% ($n=57$). Compared to mule deer, there was much greater variation in demographic distributions among crossing structures and from year to year (Fig. 24). Most successful passages at the Plum Creek Bridge were made by white-tailed deer does, whereas bucks accounted for most successful passages at the Rest Area Underpass. White-tailed deer bucks also tallied more successful passages than does at the Dogleg Underpass, accounting for 71% of all through passage movements in 2022 and 67% in 2024; but in 2023 bucks accounted for just 14% of successful passages at this structure.

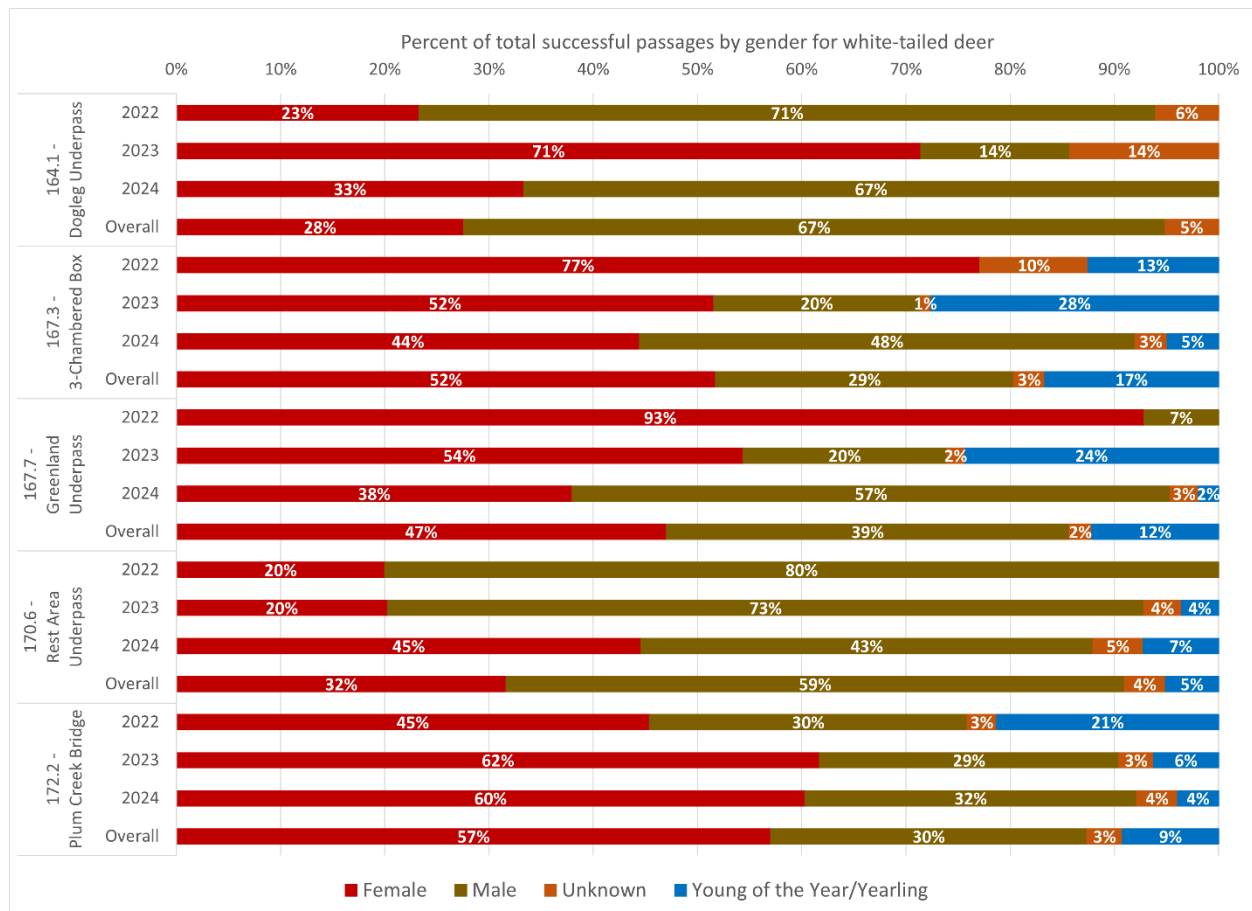


Figure 24. Demographic distribution of white-tailed deer among the structures each year of the study.

Overall, elk cows accounted for 54% of all successful passages ($n=467$) and bull elk accounted for 29% ($n=248$). Individuals that could not be gendered accounted for 5% ($n=44$) of successful passages, and young of the year/yearling elk accounted for 12% ($n=107$). Like white-tailed deer, there was high variability in the demographic distribution of elk among crossing structures and across years (Fig. 25). Bull elk accounted for most successful passages at the Rest Area Underpass each year (63-80%), but the number of successful passages each year was low, ranging from zero in 2022 to eight in 2024. The Plum Creek Bridge had the highest number of elk successful passages ($n=566$) but only seven of these occurred in the first year of the study – all cows. More bulls and young of the year/yearlings were detected in the subsequent two years. Similarly, there was only one successful passage at the Greenland Underpass in 2022 – made by a bull elk – although in the following years most successful passages at this location were by cows.

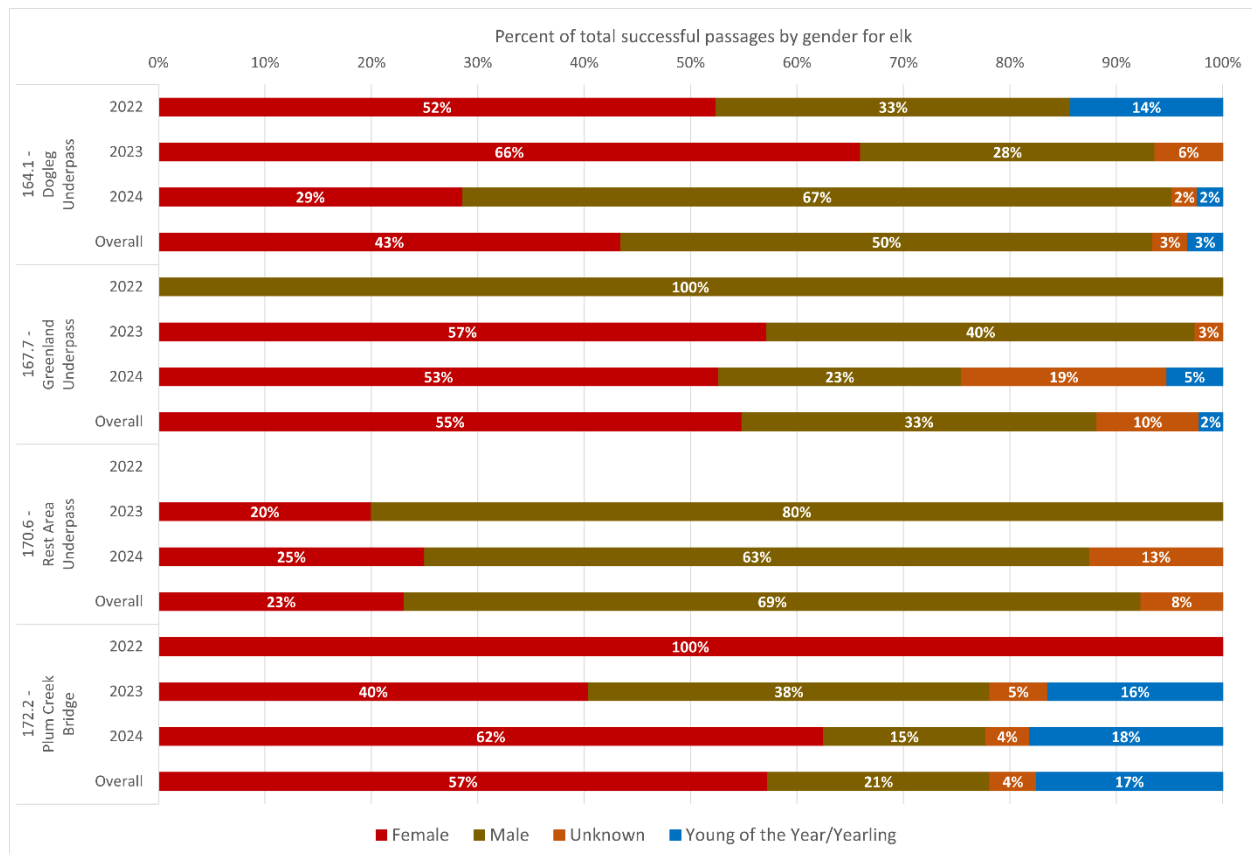


Figure 25. Demographic distribution of elk among the structures each year of the study.

3.1.7. Ungulate Responses to Crossing Structures

In addition to determining whether animals successfully passed through or repelled from a structure, the research team tallied behavioral responses to the structure on their approach. Response behaviors included hesitate, walk, run and startle. Behavioral responses offer insight into how comfortable the animals were using a crossing structure.

Walk was the most common response for all three species, accounting for 73% of all mule deer approach responses ($n=12,211$), 60% of all white-tailed deer approach responses ($n=1,075$), and 57% of all elk approach responses ($n=492$). Across all ungulate through passage movements, 71% walked, 18% ran, 10% hesitated, and less than 1% startled. Elk and white-tailed deer were more likely to hesitate or run through a crossing structure than mule deer. White-tailed deer were most likely to startle of all three species. No startle responses were reported for elk.

The proportion of mule deer passages with a walk response varied among the structures and by year. The number of mule deer walk responses decreased slightly from 2022 to 2023 and increased or remained constant in 2024. The exceptions were at the Monument Hill Underpass, where the walk responses decreased and hesitate responses increased in 2024; and the Plum Creek Bridge where the walk response type decreased each successive year while hesitate responses increased (Fig. 26).

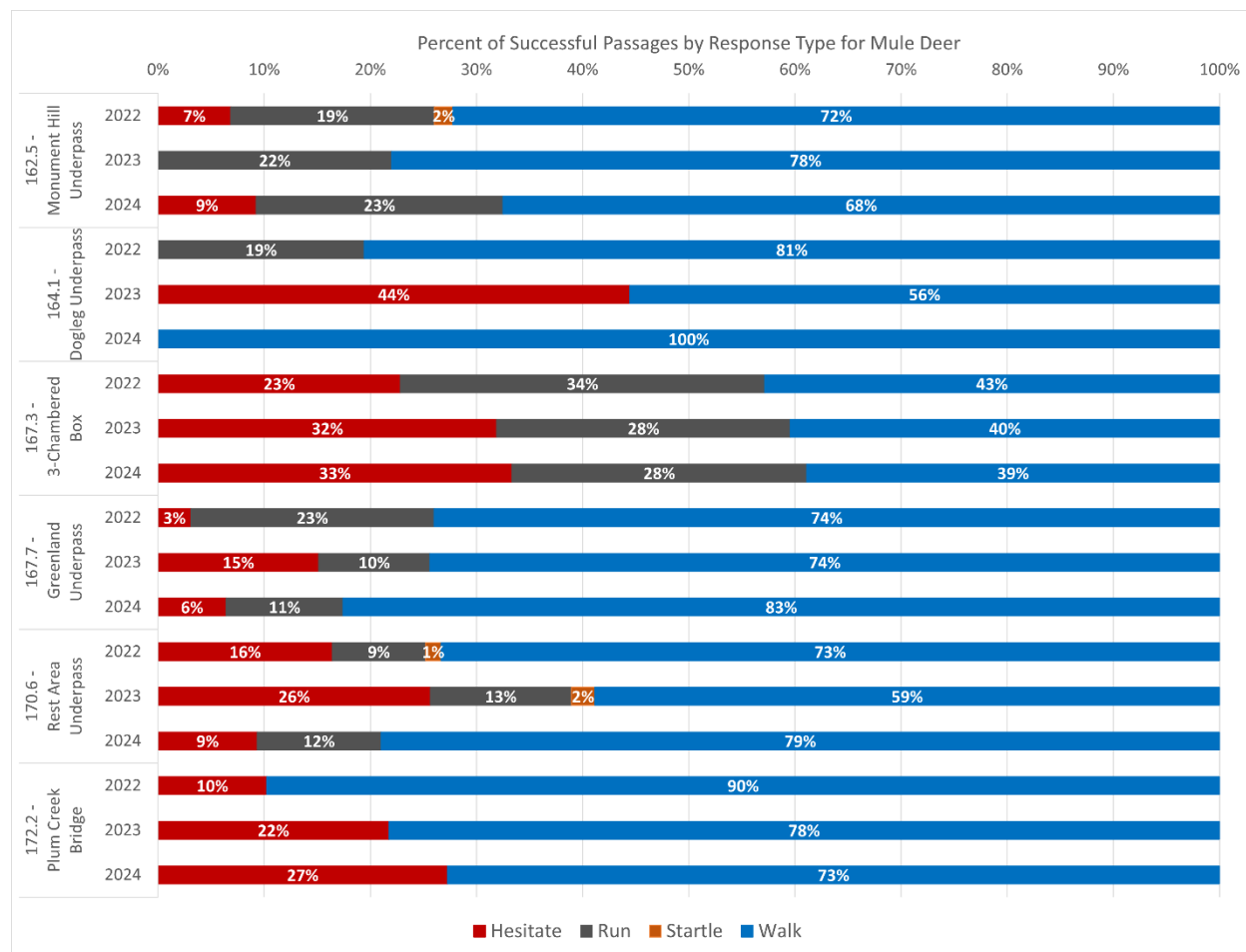


Figure 26. Percent of successful passages by response type for mule deer at each structure location and across all study years.

For white-tailed deer, the proportion of walk responses decreased in 2023 and then rebounded in 2024 at all structures except for the Plum Creek Bridge, where walk responses remained roughly stable with a small increase in 2023 (Fig. 27).

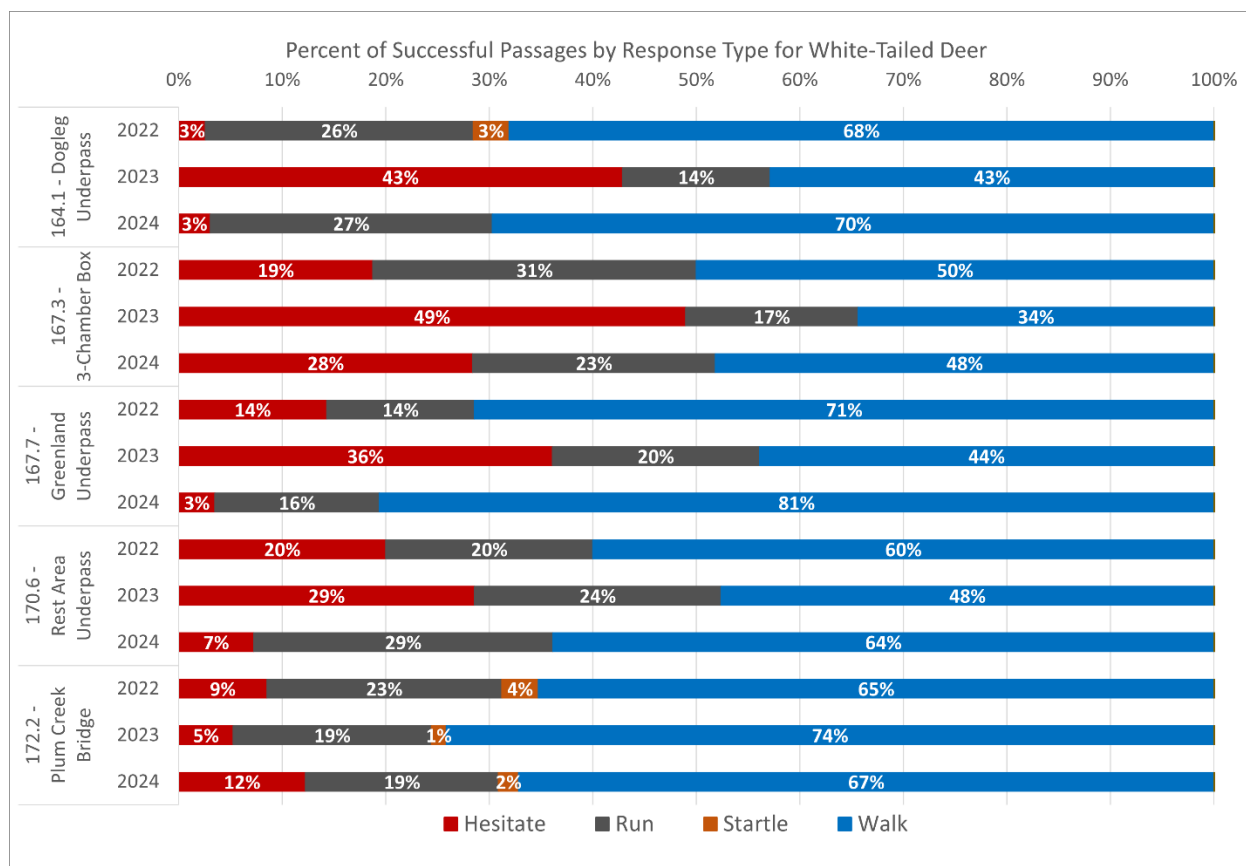


Figure 27. Percent of successful passages by response type for white-tailed deer at each structure location and across all study years.

The greatest variability in behavioral responses to the crossing structures by location and over time was observed in elk. At the Dogleg and the Greenland Underpasses, the proportion of walk responses decreased in 2023 and increased in 2024. The opposite occurred at the Plum Creek Bridge where the proportion of the response type walk increased in 2023 but decreased significantly in 2024. At the Rest Area Underpass, the proportion of this response type increased from 2023 to 2024 (Fig. 28).

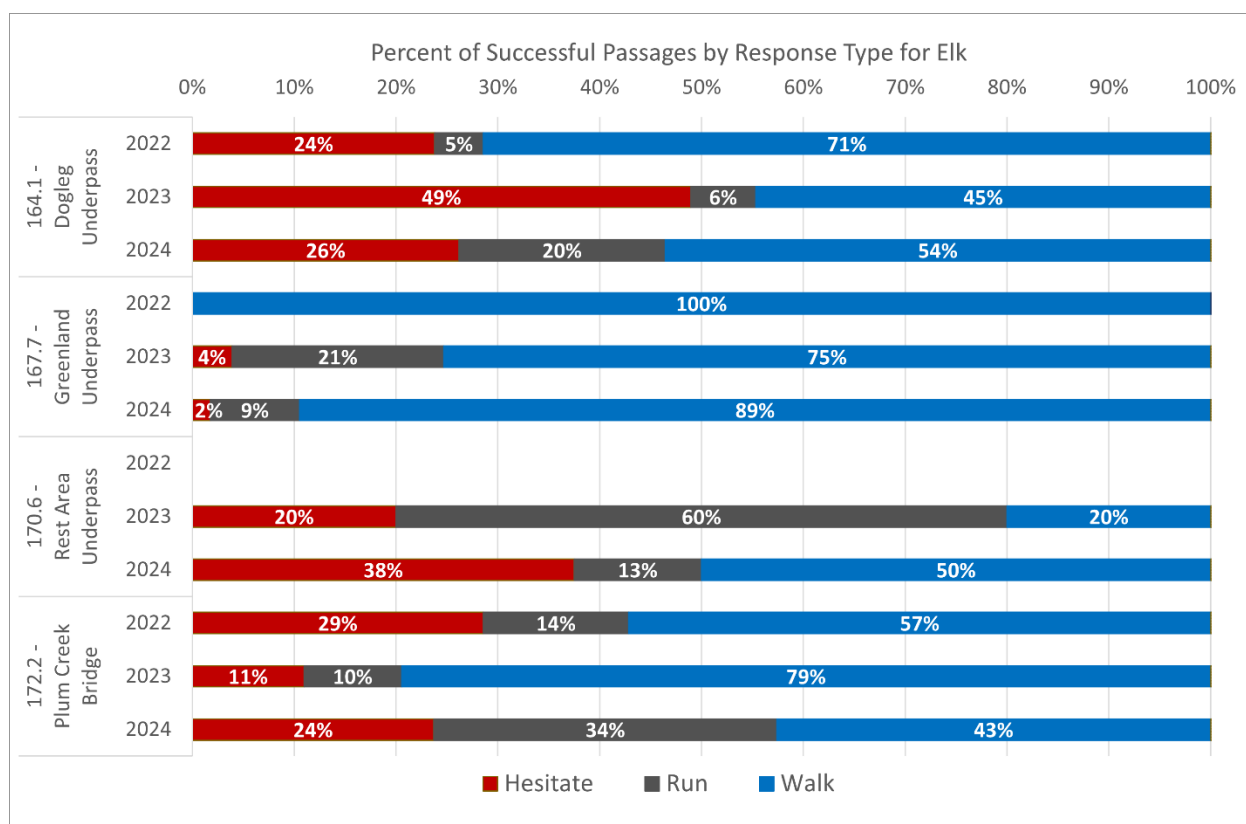


Figure 28. Percent of successful passages by response type for white-tailed deer at each structure location and across all study years.

3.1.8. Analysis of Factors Influencing Ungulate Use of Crossing Structures

3.1.8.1. Mule Deer Underpass Use

Statistical models indicated that most of the structure variables included in the analysis were not significantly associated with mule deer underpass use. Structure width had a small negative significant relationship with number of mule deer using underpasses ($p = 0.003$, $\alpha = 0.05$) (Table 8).

Table 8. Model coefficients for covariate relationships with usage counts by mule deer based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-30.97	-60.453	-1.487	15.043	-2.059	0.04

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
Direction of Origin (W)	0.82	-0.792	2.432	0.822	0.997	0.319
Structure Width	-0.029	-0.047	-0.01	0.01	-3.016	0.003
Structure Height	1.15	-0.396	2.696	0.789	1.458	0.145
Structure Length	-0.004	-0.023	0.014	0.009	-0.44	0.66
Grass/Forbs	0.031	-0.042	0.104	0.037	0.829	0.407
Brush	-0.04	-0.111	0.03	0.036	-1.129	0.259
Riparian Drainage (Some)	1.977	-0.77	4.724	1.401	1.411	0.158
Approach Slope (Flat)	-1.907	-6.378	2.564	2.281	-0.836	0.403
Approach Slope (Uphill)	-1.603	-4.965	1.76	1.716	-0.934	0.35
Season Start Date	0.001	0	0.001	0	2.916	0.004

3.1.8.2. Elk Underpass Use

None of the structure variables included were significantly associated with underpass crossing counts of elk (Table 9).

Table 9. Model coefficients for covariate relationships with usage counts by elk based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-112.969	-579.12	353.181	237.836	-0.475	0.635
Direction of Origin (W)	-0.158	-2.027	1.711	0.954	-0.166	0.868
Structure Width	0.076	-0.179	0.331	0.13	0.586	0.558
Structure Height	-2.398	-10.79	5.995	4.282	-0.56	0.576

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
Structure Length	0.971	-2.935	4.877	1.993	0.487	0.626
Grass/Forbs	-0.011	-0.086	0.065	0.039	-0.277	0.782
Brush	0.011	-0.084	0.107	0.049	0.236	0.814

3.1.8.3. White-tailed Deer Underpass Use

None of the structure variables included were significantly associated with underpass crossing counts of white-tailed deer (Table 10).

Table 10. Model coefficients for covariate relationships with usage counts by white-tailed deer based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-140.842	-532.044	250.36	199.597	-0.706	0.48
Direction of Origin (W)	0.231	-1.17	1.631	0.715	0.323	0.747
Structure Width	0.076	-0.139	0.292	0.11	0.694	0.488
Structure Height	-2.431	-9.613	4.751	3.664	-0.663	0.507
Structure Length	1.157	-2.142	4.457	1.684	0.687	0.492
Grass/Forbs	0.01	-0.04	0.059	0.025	0.387	0.699
Brush	-0.003	-0.065	0.06	0.032	-0.088	0.93

3.1.8.4. Ungulate Successful Passage Rate

Structure width and structure length had small negative significant relationships with successful passage rate ($p = <0.001$, $\alpha = 0.05$), while percentage grass/forbs ground cover and percentage bare ground cover had small positive significant relationships with successful passage rate ($p = 0.001$ and $p = <0.001$, respectively, $\alpha = 0.05$) (Table 11). Direction of origin, structure height and percentage tree ground cover had larger positive significant relationships with successful passage rate ($p = <0.001$, $\alpha = 0.05$).

Table 11. Model coefficients for covariate relationships with successful passage rate of all ungulates based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-3.323	-6.592	-0.053	1.668	-1.992	0.046
Direction of Origin (W)	1.627	1.089	2.166	0.275	5.921	<0.001
Structure Width	-0.009	-0.012	-0.006	0.002	-5.612	<0.001
Structure Height	0.264	0.163	0.366	0.052	5.114	<0.001
Structure Length	-0.031	-0.043	-0.019	0.006	-5.071	<0.001
Grass/Forbs	0.055	0.023	0.087	0.016	3.414	0.001
Brush	0.018	-0.003	0.039	0.011	1.674	0.094
Trees	0.128	0.078	0.179	0.026	4.968	<0.001
Bare Ground	0.063	0.036	0.09	0.014	4.499	<0.001
Riparian Drainage (Some)	0.269	-0.129	0.668	0.204	1.324	0.186

3.1.8.5. Ungulate Passage Use Over Time

Elk passage counts were significantly lower than the baseline species, mule deer ($p = 0.044$, $\alpha = 0.05$), and the interaction between time and elk had a small significant positive relationship ($p = 0.067$, $\alpha = 0.05$), indicating an increase in elk use over time (Table 12).

Table 12. Model coefficients for covariate relationships with successful passage use over time of all ungulates based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-4.618	-15.844	6.609	5.728	-0.806	0.42
MSD	<0.001	<0.001	0.001	<0.001	1.028	0.304
White-tailed Deer	8.029	-10.331	26.389	9.367	0.857	0.391

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
Elk	-23.304	-46.001	-0.606	11.581	-2.012	0.044
MSD: White-tailed Deer	-0.001	-0.001	<0.001	<0.001	-1.066	0.286
MSD: Elk	0.001	<0.001	0.002	0.001	1.832	0.067

3.1.8.6. Ungulate Passage Rate Over Time

Monthly elk passage rates were significantly lower than monthly deer passage rates and the interaction between time and elk had a small significant positive relationship ($p = <0.001$ and $p = 0.001$, respectively, $\alpha = 0.05$), indicating an increase in elk use over time (Table 13). Time (MSD) also had a very small significant positive relationship ($p = 0.026$, $\alpha = 0.05$), indicating a general increase in passage rate over time across ungulates.

Table 13. Model coefficients for covariate relationships with successful passage rate of all ungulates over time based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-4.711	-11.167	1.746	3.294	-1.43	0.153
Elk	-23.802	-36.49	-11.114	6.474	-3.677	<0.001*
MSD	0	0	0.001	0	2.23	0.026*
MSD: Elk	0.001	0	0.002	0	3.427	0.001*

3.1.8.7. Passage Rate Over Time by Demographic Groups

Elk passage rates were significantly lower than deer passage rates ($p = <0.001$, $\alpha = 0.05$), and male passage rates were significantly higher than female passage rates ($p = <0.001$, $\alpha = 0.05$). Time (MSD) also had a small significant positive relationship ($p = <0.001$, $\alpha = 0.05$), indicating a general increase in passage rate over time for all ungulate species (Table 14).

Table 14. Model coefficients for covariate relationships with changes in passage rate over time by demographic groups based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-9.686	-15.497	-3.874	2.965	-3.267	0.001
MSD	0.001	0	0.001	0	4.123	<0.001
Male	0.405	0.224	0.587	0.092	4.383	<0.001
Young/Yearling	0.009	-0.261	0.279	0.138	0.068	0.946
Elk	-1.652	-1.886	-1.419	0.119	-13.86	<0.001

3.1.8.8. Hesitation Rate Over Time

Elk hesitation rates were significantly lower than the model baseline, deer ($p = <0.001$, $\alpha = 0.05$). Overall hesitation rates had a small significant decrease over time ($p = <0.011$, $\alpha = 0.05$) (Table 15).

Table 15. Model coefficients for covariate relationships with changes in hesitation rate over time by ungulate species based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	9.845	4.074	15.616	2.944	3.344	0.001
MSD	0	0.001	0	0	-2.551	0.011
Elk	-0.861	-1.119	-0.602	0.132	-6.523	<0.001

3.1.9. Mule Deer Use of the Deer Bridge at the Monument Hill Underpass

In August 2022, a camera was set up at the small natural-surface bridge at the Monument Hill

Underpass ('deer bridge') that was installed over the riprap drainage to provide direct access to/from the east entrance of the crossing structure (Fig. 29).



Figure 29. A mule deer using the deer bridge after crossing through the Monument Hill Underpass.

During the period this structure was monitored, a total of 2,928 mule deer were documented crossing over the bridge. Of 6,379 successful through passage movements at the Monument Hill Underpass from August of 2022, when the deer bridge was installed, through December of 2024, 2,614 (41%) incorporated the deer bridge.

Forty-six percent of these movements involved mule deer approaching the deer bridge from the east (habitat side) while 54% approached it from the west (structure side) after having passed through the underpass (Table 16). Eighty-nine percent ($n=2,614$) of the deer that were detected approaching the bridge used it to cross over the riprap. Five percent ($n=132$) jumped or walked over the riprap while the remaining 6% ($n=182$) repelled from the bridge. Most repels at the deer bridge (91%; $n=166$) were by deer that approached it from the structure side and had already successfully passed through the crossing structures and instead walked around the riprap to access the habitat on the east side of I-25.

Table 16. Mule deer responses to the deer bridge at the Monument Hill Underpass, August 2022-December 2024.

Total Movements	Count	Percentage	Count	Percentage
	—	—	—	—
	Habitat to Structure	Habitat to Structure	Structure to Habitat	Structure to Habitat
Total Approaches	1305	45%	1623	55%
Cross over Bridge	1211	46%	1403	54%
Jump/Walk Over Riprap	78	59%	54	41%

Total Movements	Count	Percentage	Count	Percentage
	Habitat to Structure	Habitat to Structure	Structure to Habitat	Structure to Habitat
Repel from Bridge	16	9%	166	91%

Several addition species were documented using the deer bridge to cross over the riprap, including 35 black bears, 22 bobcats, 5 cottontails, 94 coyotes, 25 foxes, 53 raccoons, 20 squirrels, 1 turkey and 1 white-tailed deer.

3.1.10. Ungulate Activity at Habitat Cameras

At each of the new crossing structures, cameras were also set up facing away from the roadway to detect species in the habitat adjacent to a crossing structure that may or may not be approaching the structures. Most ungulate species captured on these cameras were also detected approaching, and in some cases using, the corresponding crossing structure (Table 17). Because the cameras only captured a small portion of the approach area to a crossing structure, white-tailed deer were documented in higher numbers successfully using the structure than what was documented on the habitat cameras at several locations. The exceptions were at Monument Hill where 11 white-tailed deer were detected on the habitat cameras compared to none successfully using the structure, and the Plum Creek Bridge where 1,369 animals were documented on the habitat cameras compared to 554 successfully using the structure.

At all crossing locations, elk was detected with greater frequency on the habitat cameras than successfully using the corresponding crossing structures. Notably, pronghorn was detected on the east side of the highway in the habitat adjacent to both the Dogleg and Greenland Underpasses but was not detected approaching any of the crossing structures (Fig. 30).



Figure 30. Image of pronghorn captured on the east side of the Greenland Underpass.

The only moose detected during the three years of this study was documented making a successful passage at the 3-Chambered Box Culvert; no moose detections occurred at the habitat cameras.

Table 17. Comparison of successful passages at wildlife crossing structures and presence at habitat camera locations adjacent to wildlife crossing structures.

Species and Monitoring Location	Monument Hill	Dogleg	Greenland	Rest Area	Plum Creek
Elk – Structure	0	152	135	13	566
Elk – Habitat	4	808	1,102	236	734
Pronghorn – Structure	0	0	0	0	0
Pronghorn – Habitat	0	244	253	0	0
White-tailed Deer – Structure	0	156	502	177	554
White-tailed Deer – Habitat	11	153	191	83	1,369

3.2. Discussion

3.2.1. Performance Measures Evaluation

Across all structures, the number of successful passages recorded for mule deer increased each year of this three-year study. From year to year, mule deer success rates remained above 80% at all structures except for one. Across all years combined, the success rate was over 90% at four of the five underpasses (Monument Hill, Greenland, Rest Area Underpasses and Plum Creek Bridge) and over 80% at the Dogleg Underpass. By the final year of the study, success movements at three of the crossing structures – Monument Hill Underpass, Greenland Underpass and the Plum Creek Bridge – met the goal of a success rate of at least 90% and four met the minimum goal of an 80% success rate. With the addition of wildlife fencing, the existing 3-Chambered Box Culvert achieved a 100% success rate with 145 mule deer successful passages in the final year of the study. The one exception was the Dogleg Underpass, where there was a decrease in both success movements and success rates between each year of the three-year study and was the only structure to never reach a success rate of 90% in any of the three years of this study. Therefore, the performance measure established at the outset of the study that mule deer success movements at each structure will increase over time with a minimum success rate of 80% and a goal of 90% was mostly but not fully met (Table 18).

Table 18. Mule deer success movements performance measures evaluation. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
Mule deer success movements at each structure will increase over time with a minimum of success rate of 80% and a goal of 90%.	(X)	

The number of successful elk passages compared to the number of elk movements captured at associated habitat cameras was 18% at the Dogleg Underpass, 12% at the Greenland Underpass, 6% at the Rest Area Underpass, and 76% at the Plum Creek Bridge. No elk were documented at the Monument Hill Underpass and just four at the associated habitat camera; however, elk are uncommon in this portion of the study area.

The elk performance measure was not met, as only one structure satisfied the criterion that successful elk passages at the crossing structures are at least 50% of elk movements recorded by the associated habitat cameras (Table 19).

Table 19. Elk success movements at structures compared to habitat cameras performance measures evaluation. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
The number of successful elk passages at all structures will be at least 50% of the number of elk movements captured at associated control (habitat) cameras.		(X)

Elk success movements increased year-over-year at all structures where elk were detected except for the Greenland Underpass where elk success movements decreased slightly from 2023 to 2024 ($n=77$ and 57, respectively). Statistical analysis also found a small significant positive relationship, indicating an increase in elk use of the crossing structures over time. Success rates for elk, however, varied from year to year. In the final year of the study, a success rate of 73% was documented at the Greenland Underpass and 87% at the Plum Creek Bridge. While the minimum success rate was met at the Dogleg Underpass in 2022 (70%), the elk success rate decreased in 2023 (68%) and 2024 (65%). The only structure that met neither the minimum or goal success rate was the Rest Area Underpass which had a success rate of 23% in 2023 and 19% in 2024. Therefore, the performance measure established at the outset of the study that elk success movements at each structure will increase over time with a minimum success rate of 70% and a goal of 80% was partially met (Table 20).

Table 20. Elk success movements performance measures evaluation. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
Elk success movements at each structure will increase over time with a minimum success rate of 70% and a goal of 80%.	(X)	

Mule deer movements east-west through the crossing structures accounted for 50% ($n=8,454$) of mule deer success movements over the three-year study. West-east movements accounted for the other 50% ($n=8,294$) of mule deer success movements. The performance measure that mule deer movements east-

west through the crossing structures will be roughly equivalent to west-east movements has been met (Table 21).

Table 21. Mule deer direction of origin performance measure evaluation.

Performance Measure	Met	Not Met
Mule deer movements east-west through the crossing structures will be roughly equivalent to west-east movements.	X	

Mule deer gender distribution varied between crossing structures but was consistent from year to year at most structures. By the final year of the study, successful passages by mule deer does accounted for 36% of all mule deer successful passages across all structures. Bucks accounted for 53% and young of the year/yearlings accounted for 7%. This represents an overall downward trend from year-to-year for mule deer does (46% in 2022, 39% in 2023 and 36% in 2024) and an upward year-to-year trend for bucks (35% in 2022, 44% in 2023 and 53% in 2024). With all years combined, mule deer does accounted for 40% of all successful passages ($n=6,714$), bucks accounted for 45% ($n=7,493$) and young of the year/yearling accounted for 12% ($n=1,936$).

Elk passages saw variation in the gender distribution between crossing structures and across years. In the final year of the study, elk cows accounted for 56% of all successful passages across all structures while bull elk only accounted for 24% and young of the year/yearling elk accounted for 14%. Both cow and bull elk percentages were down from construction phase (2022) percentages (62% and 28%, respectively), and show an opposite trend to mule deer: the percentage of elk cows increased (49% to 54%) and bull elk decreased (37% to 29%) between the final two years of the study. Across all years, elk cows accounted for 54% of all successful passages ($n= 467$) while bull elk only accounted for 29% ($n=248$).

Overall, success movements through the crossing structures were represented by males, females and juveniles for both mule deer and elk; therefore, this performance measure has been met (Table 22).

Table 22. Mule deer and elk demographics performance measure evaluation.

Performance Measure	Met	Not Met
Over time, mule deer and elk movements through the crossing structures will be represented by males, females, and juveniles.	X	

White-tailed deer made successful passages at all but one of the five underpasses and existing box culvert. In most years and at most structures, successful passages by white-tailed deer remained constant or increased. At several of the crossing structures successful passages by white-tailed deer accounted for more than the number of white-tailed deer movements captured at the associated habitat cameras.

Pronghorn were detected in the vicinity of two crossing structures – the Greenland and Rest Area Underpasses – but were never documented attempting to use a structure. Thus, the performance measure that approaches by less common ungulate species will remain constant or increase over time has been partially met (Table 23).

Table 23. Other ungulate species performance measure evaluation.

Performance Measure	Met	Not Met
Successful passages through the crossing structures by less common species will remain constant or increase over time (e.g., pronghorn, white-tailed deer).	(X)	

3.2.2. Effectiveness of the Wildlife Crossing Structures for Ungulate Species

The research documented 16,749 mule deer, 1,791 white-tailed deer, and 866 elk successful passages through the five wildlife underpasses and existing box culvert. The number of successful passages at each structure location for all three species increased annually, with post-construction success rates of 93%, 91%, and 76%, respectively. With only two years of post-construction data captured in this study, these findings suggest the crossings are highly effective for these species, with elk likely to increase their use over time due to longer habituation periods. While pronghorn was not observed using the crossings, they were captured near two structures on the east side of I-25. Whether pronghorn ultimately seek to

expand into the grassland habitats on the west side of the interstate via either the underpasses or the future Greenland Overpass remains unknown.

Mule deer success rates remained above 80% each year of the study at all structure except for the Dogleg Underpass, where cameras documented a decrease in both the number of successful passages and the success rate from one year to the next. White-tailed deer passages also decreased at this location during post-construction relative to levels documented during the construction phase. This study was unable to definitively determine the reason for the decrease in deer use of the Dogleg Underpass. This structure was one of the first built and the initial activity documented in 2022, the final construction year, may have dispersed to other structures as they were completed. Other environmental or population-level factors may have also played a role.

White-tailed deer are less common than mule deer in the study area, but were documented making successful passages in numbers similar to or greater than elk at several locations – most notably, the Plum Creek Bridge, which is situated squarely within white-tailed deer habitat. Only one white-tailed deer was documented approaching the Monument Hill Underpass, although 11 were documented on the habitat cameras, but this location is on the periphery of white-tailed deer habitat. The underpass structures and existing box culvert located within white-tailed deer habitat are effectively providing habitat connectivity for this species.

That elk use of the underpasses may further increase over time is supported by observations from previous studies in other locations (Gagnon et al. 2011; Kintsch et al. 2021) and by the statistical analysis, which found a small significant positive relationship between time and elk use of the underpasses. While not all structures where elk were detected were able to meet the minimum success rate goal of 70%, elk success movements increased year-over-year at most structures where elk were detected. Elk were not detected approaching the 3-Chambered Box Culvert, which was originally installed without consideration for elk passage. However, elk did successfully use the nearby Greenland Underpass, which was specifically designed to facilitate elk movements in the design of the I-25 South Gap project. Elk movements across I-25 are also expected to increase with the construction of the Greenland Overpass in 2025.

The 3-Chambered Box Culvert is an existing culvert that was included in the monitoring study to evaluate wildlife use of the structure once it was connected into the wildlife exclusion fencing. Limited pre-construction camera monitoring (Pinyon 2017) recorded just two instances of deer using this culvert. Once included in the mitigation system, this study documented a total of 395 mule deer and 354

white-tailed deer passages, in addition to badger, bobcat, coyote, and raccoon. This finding underscores the value of adding wildlife exclusion fencing to existing structures (Donaldson and Elliott 2020).

3.2.3. Factors Influencing Ungulate Use of Crossing Structures

Structural and environmental factors were analyzed to investigate potential influences on ungulate use of crossing structures. Most of the variables included in the models were not found to be significantly associated with ungulates making successful passages through the underpasses. Three of the five crossings have the same dimensions. Structure width was found to have a small negative relationship on the number of mule deer using a structure; however, the magnitude of the covariate was small, and the finding contradicts extensive research across western North America indicating a strong positive relationship between structure width and mule deer through passage success (Clevenger and Barrueto 2014, Gordon and Anderson 2003, Sawyer et al. 2012). The findings in this study were likely influenced by the Monument Hill Underpass – despite being the narrowest and longest of the crossings, this structure is sited in an area with a high density of mule deer between the Pike National Forest to the west and the Black Forest to the east. Accordingly, the highest number of mule deer successful passages was tallied at this crossing. Across ungulate species, time was the biggest factor impacting passage counts and success rates with more animals using the structures with greater success and less hesitation over time.

Chapter 4. Other Species Use of Wildlife Underpasses

4.1. Results

In addition to the three primary ungulate species, many other wildlife species were detected in this research study, representing most of the meso and large mammal species known to be present in this landscape.

4.1.1. Overview of Non-Ungulate Species Use of Wildlife Crossings

Over the three years of this study, eleven non-ungulate species were documented successfully using the crossing structures and the existing box culvert during the three-year study: badger, black bear, bobcat, coyote, fox, mountain lion, porcupine, raccoon, squirrel, striped skunk and turkey. Four additional species were detected at or near the crossing structures, but either repelled or were documented foraging/resting or moving parallel/ignoring the structure: beaver (Fig. 31), cottontail rabbit, mallards, and weasel.



Figure 31. A beaver captured on camera at the Monument Hill Underpass.

While most of these species were documented approaching, and either using or repelling from at least one structure in all three years of the study, several were documented at only one location, including beaver at the Monument Hill Underpass, cottontail rabbit at the Plum Creek Bridge, mallards at the 3-Chambered Box Culvert, mountain lion at the Plum Creek Bridge, and striped skunk at the Rest Area Underpass (Table 24). The beaver detected at the Monument Hill Underpass may be a resident of a pond at a nearby RV campground.

The greatest species richness was observed at the Rest Area Underpass and Plum Creek Bridge, where eight non-ungulate species approached and successfully passed through each crossing structure.

Elsewhere, seven species were documented successfully using the Dogleg and Greenland Underpasses and five successfully used the Monument Hill Underpass. The lowest species richness was at 3-Chambered Box Culvert where only four non-ungulate species were documented successfully using the structure.

Table 24. Species with successful passages at each structure and overall success rates.

Species	162.5 Monument Hill	164.1 Dogleg	167.3 3-Chambered Box	167.7 Greenland	170.6 Rest Area	172.2 Plum Creek	Overall Success Rate
Badger	0	1	1	1	0	0	100%
Black Bear	52	14	0	3	43	38	97%
Bobcat	68	1	3	6	140	18	98%
Coyote	88	405	109	214	355	113	91%
Fox	25	2	0	5	2	1	90%
Mountain Lion	0	0	0	0	0	2	100%
Porcupine	0	0	0	0	0	1	50%
Raccoon	38	5	24	114	92	34	92%
Squirrel	0	0	0	0	6	4	100%
Striped Skunk	0	0	0	0	5	0	100%
Turkey	0	1	0	3	378	0	88%

Coyotes, bobcats and raccoons were documented successfully using all five wildlife crossing structures and the existing box culvert. Black bears and fox used five out of six of the structures with neither species recorded at the 3-Chambered Box Culvert. Turkeys – including females with chicks – were most often documented successfully using the Rest Area Underpass ($n=378$) with only one to three successful passages captured at the other locations where it was detected (Fig. 32).



Figure 32. A female turkey with chicks using the Rest Area Underpass.

Porcupine and striped skunk were only documented successfully using a structure in 2022 ($n=1$ and 5, respectively).

4.1.2. Bears, Felids, and Canids Use of Wildlife Underpasses

Black bears and foxes were most frequently documented successfully using the Monument Hill Underpass ($n=52$ and 25, respectively), coyotes at the Dogleg Underpass ($n=405$), and bobcats at the Rest Area Underpass ($n=140$). Two mountain lion successful passages were documented at the Plum Creek Bridge in the final year of the study, but the species was not detected at any of the other crossings except on the approach cameras (Fig. 33). For most species, the number of successful passages remained steady or increased each year of this study. Black bear successful passages increased by 234% between the first and second year post-construction (2023 and 2024). Similarly, coyote successful passages increased 123% from the construction phase (2022) and 137% from the first to the second year post-construction. The only species to see a decrease was fox, whose successful passages decreased in 2024 ($n=2$).

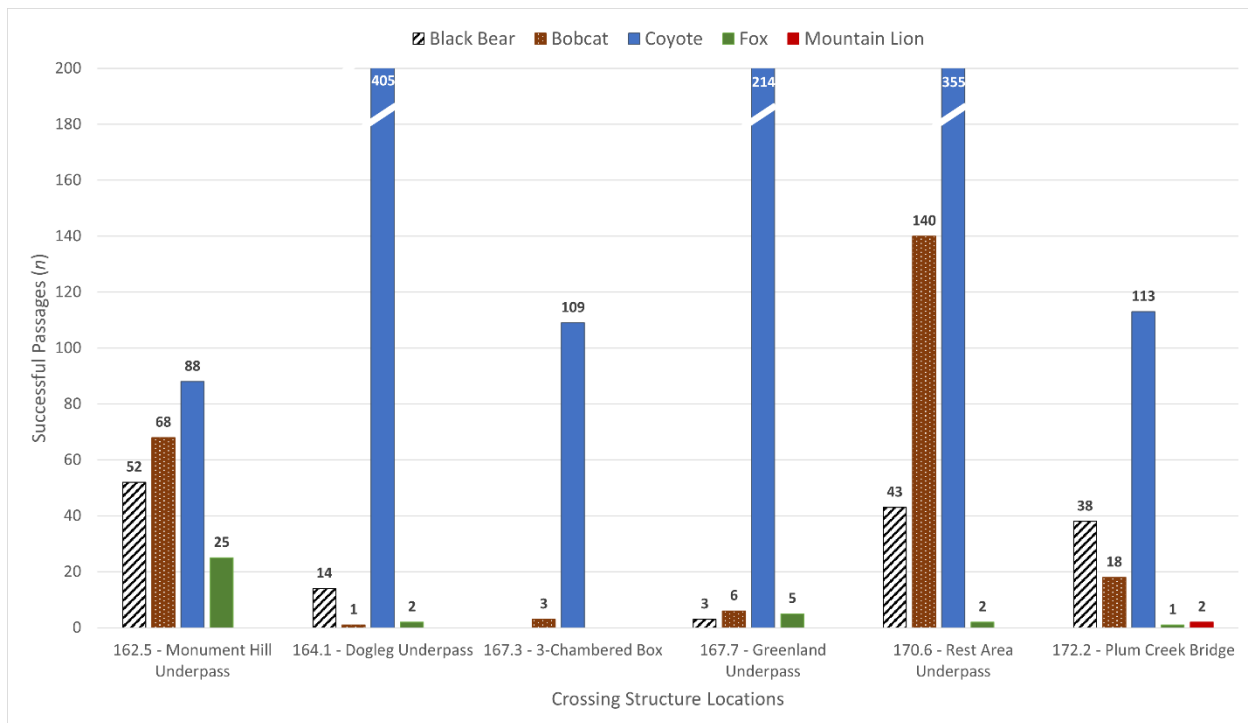


Figure 33. Successful passages by non-ungulate species with more than 5 successful passages at a minimum of one structure over the three years of study period.

Success rates for these species varied by species and location but remained high ($\geq 90\%$) for most species across all years (Table 25).

Table 25. The number of total success passages, repel movements, and success rates for bear, canid and felid species at each wildlife underpass and existing box culvert during three-year study. Total detections include parallel/ignore and forage/rest movements.

Mile Post	Structure Name	Movements and Success Rates	Black Bear	Bobcat	Coyote	Fox	Mountain Lion
162.5	Monument Hill	Total Detections	55	78	101	38	0
-	-	Success Passages	52	68	88	25	-
-	-	Repels	3	4	8	3	-
-	-	Success Rate	95%	94%	92%	89%	-
164.1	Dogleg	Total Detections	15	5	691	3	0
-	-	Success Passages	14	1	405	2	-

Mile Post	Structure Name	Movements and Success Rates	Black Bear	Bobcat	Coyote	Fox	Mountain Lion
-	-	Repels	0	0	50	0	-
-	-	Success Rate	100%	100%	89%	100%	-
167.3	3-Chambered Box	Total Detections	0	4	158	0	0
-	-	Success Passages	-	3	109	-	-
-	-	Repels	-	0	28	-	-
-	-	Success Rate	-	100%	80%	-	-
167.7	Greenland	Total Detections	3	19	246	12	0
-	-	Success Passages	3	6	214	5	-
-	-	Repels	-	1	11	1	-
-	-	Success Rate	100%	86%	95%	83%	-
170.6	Rest Area	Total Detections	45	162	416	5	0
-	-	Success Passages	43	140	355	2	-
-	-	Repel	1	1	24	0	-
-	-	Success Rate	98%	99%	94%	100%	-
172.2	Plum Creek	Total Detections	41	23	143	2	2
-	-	Success Passages	38	18	113	1	2
-	-	Repels	1	0	11	0	0
-	-	Success Rate	97%	100%	91%	100%	100%
-	-	Total Successful Passages	150	236	1,284	35	2
-	-	Overall Success Rate	97%	98%	91%	90%	100%

Bobcats and coyotes made successful passages at all five wildlife crossing structures and the existing box culvert. Bobcats had overall success rates of greater than 90% at all structures except for the Greenland Underpass (86%). Coyotes also had overall success rates of greater than 90% at all structures except for two – the Dogleg Underpass (89%) and the 3-Chambered Box Culvert (80%). Black bears and fox were documented successfully using five of the six structures; both species were missing only from the 3-Chambered Box Culvert. Black bears had an overall success rate of 90% or greater at every structure they were documented using. Fox also had success rates of 90% or greater at all structures they used except for at the Monument Hill and Greenland Underpasses (89% and 83%, respectively). Mountain lions were only detected using the Plum Creek Bridge ($n=2$) but had a 100% success rate at this structure. Overall success rates for all bear, canid and felid species were above 90%.

At each crossing structure, cameras were also set up facing away from the roadway to detect species presence in the habitat adjacent to a crossing structure that may or may not be approaching the structures. Most species captured on these cameras were also detected using the corresponding crossing structure (Table 26). Most species were documented using a crossing in similar and often higher numbers than what was documented on the habitat cameras. Species documented in higher numbers on the habitat cameras included fox and mountain lion at the Greenland and Rest Area Underpasses, and bobcat and coyote at the Plum Creek Bridge.

Table 26. Comparison of successful passages at wildlife crossing structures and presence at habitat camera locations adjacent to wildlife crossing structures.

Species	162.5 Monument Hill	164.1 Dogleg	167.7 Greenland	170.6 Rest Area	172.2 Plum Creek
Black Bear – Structure	52	14	3	43	38
Black Bear – Habitat	13	2	0	31	7
Bobcat – Structure	68	1	6	140	18
Bobcat – Habitat	12	1	3	10	20
Coyote – Structure	88	405	214	355	113
Coyote – Habitat	59	218	99	80	144

Species	162.5 Monument Hill	164.1 Dogleg	167.7 Greenland	170.6 Rest Area	172.2 Plum Creek
Fox – Structure	25	2	5	2	1
Fox – Habitat	6	0	34	5	0
Mountain Lion – Structure	0	0	0	0	2
Mountain Lion – Habitat	0	0	1	2	0

4.2. Discussion

4.2.1. Performance Measures Evaluation

Of the eleven non-ungulate species documented successfully using the crossing structures, all but three (fox, porcupine and striped skunk) saw their numbers increase or remain steady year-over-year.

Mountain lion was only documented making successful passages in the final year of the study but based on previous research (Kintsch et al. 2021), this species may have a longer habituation period than could be fully captured in this study timeframe. Overall success rates for species documented successfully using the structures were 90% or greater, except for porcupine (50%) and turkey (88%). The performance measure that successful passages by less common species will remain constant or increase over time was met for all bear, canid, and felid species except fox (Table 27).

Table 27. Other species performance measure evaluation. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
Successful passages through the crossing structures by less common species will remain constant or increase over time (e.g., mountain lion, black bear, bobcat).	(X)	

4.2.2. Other Species Use of Wildlife Crossings

4.2.2.1. Black Bear

Black bear was documented making successful passages at all structures except for the 3-Chambered Box Culvert. Most successful passages occurred at the Monument Hill Underpass, which is located in an area with forested habitat and known high levels of black bear activity. While the Monument Hill Underpass is smaller than the other new wildlife underpasses, these findings are consistent with findings in other areas that black bear will use of a variety of underpass types (Huijser et al. 2016) but prefer crossing structures that are more confined (Clevenger and Waltho 2005, Clevenger and Barrueto 2014, Kintsch et al. 2021).

Black bear use of the five underpass structures remained stable from the construction to the post-construction phase ($n=29$ both years) and then increased in the final year of the study ($n=97$). These results are consistent with research in other locations that documented an increase in black bear use of crossing structures over time (Huijser et al. 2016, Clevenger and Barrueto 2014). Although these previous studies reported an increase over five or more years, the upward trend of black bear use documented in this study suggests that black bear movements will remain steady or continue grow over a longer timeframe.

4.2.2.2. Bobcat

Bobcat used all five underpass structures and the existing box culvert, with the highest use documented at the Rest Area Underpass. These results are consistent with studies in other locations, which have documented bobcats using a variety of structure types (Cramer 2014, Huijser 2016, Kintsch et al. 2021), including a sediment-filled drainage culvert to cross under a highway (Singer et al. 2011).

4.2.2.3. Coyote

Coyote used all five underpasses and the existing box culvert each year of this study. This species was the third most frequent visitor to the crossing structures behind mule deer and white-tailed deer, averaging 1.2 successful passages per monitoring day. Most coyote activity occurred at the Dogleg Underpass, followed by the Rest Area Underpass. In each year of the study, coyote passages increased by over 100% from the year before, peaking at 879 successful passages in the final year of the study. Although not confirmed, it is likely that these increases were due to habituation and regular passages made by the same individuals for which a given structure is located within their home ranges.

4.2.2.4. Fox

Like black bear, fox made successful passages at all five underpass locations but did not use the existing 3-Chambered Box Culvert. Research elsewhere indicates that fox use a variety of structure types and sizes with good visibility (Cramer et al. 2014, Singer et al. 2011). This may explain the absence of fox using the 3-Chambered Box Culvert, which has limited visibility through the structure. Overall, fox use of the crossing structures was low, with successful passages ranging from one at the Plum Creek Bridge to 25 at the Monument Hill Underpass.

4.2.2.5. Mountain lion

Mountain lion successfully used the Plum Creek Bridge and was detected at two additional nearby structures, the Rest Area Underpass and the Greenland Underpass. This small sample size makes it difficult to ascertain structural or locational preferences. However, the upward trend of mountain lion detections and use of the structures over time create the expectation that mountain lion use of the underpasses will remain steady or grow incrementally in the coming years.

4.2.3. Effectiveness of the Wildlife Crossings for Bear, Felid and Canid Species

All bear, felid and canid species (black bear, bobcat, coyote, mountain lion, and fox) present in the study area used the crossing structures each year of the study except for mountain lion. Each of these species was documented successfully using the crossing structures every year of the study with success rates exceeding 90% by the final year of the study. Mountain lions were documented on the habitat cameras at two locations in the first two years of the study but did not successfully use a crossing structure until the final year of the study.

In general, the number of bears, felids and canids was lower than the ungulate species, although the tally of coyote successful passages surpassed those for elk. This pattern is to be expected given their smaller population sizes relative to ungulate populations. As these species regularly used the crossing structures with consistently high success rates, it is likely that the mitigation provides, at a minimum, a base level of genetic connectivity for these species. Visually differentiation between males and females of these species was not possible except where a female was documented with her young. While it was not possible to ascertain demographic connectivity for these species through camera monitoring, it may be assumed that the crossings provide some population connectivity for bobcat and black bear as young of those two species were documented successfully using structures.

Black bear and bobcat successful passages were greatest at the Monument Hill and Rest Area Underpasses – both upland sites with adjacent forest cover – followed by the Plum Creek Bridge, an

important riparian corridor in the project area. These habitat conditions influence both the distribution of bears, felids and canids in the study area and their use of the individual crossing structures.

4.2.4. In Summary

While the total number of successful passages by these bear, felid and canid species were lower than for deer, overall success rates were high (90% or greater) for each species, and most species showed stable or increasing crossing structure use during the three-year study period. Ongoing variability and increasing use by many species suggests that this group of species is still adapting to the mitigation, and patterns in wildlife use of the crossing structures may continue to evolve over time. 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, Kintsch et al. 2021). This study only captured wildlife use for just two years following the construction of the wildlife mitigation infrastructure; nevertheless, the trends observed during this time frame indicate that the infrastructure is effectively providing safe passage and improved connectivity for these species.

Chapter 5. Small Fauna Cover Features

Five small fauna cover features were monitored at four underpass locations, including the Dogleg Underpass, the Rest Area underpass and Plum Creek Bridge. At the Greenland Underpass, where there are two cover features on either side of the small tributary to Carpenter Creek, both features were monitored. The connectivity feature at the Monument Hill Underpass was not monitored as part of this study. Both the Greenland Underpass and the Plum Creek Bridge are adjacent to riparian habitat with documented use by Preble's meadow jumping mouse.

The onset of monitoring at each of these locations depended on the construction completion date of the small fauna cover features. Monitoring did not commence until August 2022 and May 2023 at the small fauna cover features at the Plum Creek Bridge and the Rest Area Underpass, respectively. Findings at the small fauna cover features were restricted to the summer and early fall months when species diversity was greatest (see *Methods*). Monitoring days were calculated based on the days cameras were active from June 1 through September 30 each year of the study. Differences in the number of monitoring days at each location were due to differing set up dates, battery depletions and SD card storage capacity being reached.

The monitoring objective at the small fauna cover features was to detect species and relative abundance and evaluate the effectiveness of the mitigation in providing safe passage for small fauna to move through the crossing structures. Species presence was tallied based on daily rather than actual counts because small mammals often made multiple back and forth movements in front of a camera in a short time frame.

5.1. Results

A total of twenty-three different wildlife species were documented at the small fauna cover features; however, several species that were detected were not using the cover feature but were instead exploiting the gap created by the photo booth, likely to investigate for potential prey (e.g., bobcat, mink, raccoon, domestic cat) or, in some cases, out of curiosity (e.g., bird, ungulate). Species detected included small mammals (chipmunk, cottontail, deer mouse, other mouse species, 13-lined ground squirrel, pocket gopher, shrew species, other squirrel species, striped skunk, vole species, weasel, and woodrat) and herpetofauna (bull snake, lizard, northern leopard frog, racer, toad).

Preble's meadow jumping mouse was positively identified on two occasions. The number of species detected at the small fauna photo booths increased each year of the three-year study: sixteen were detected in 2022, nineteen in 2023 and twenty in 2024.

The greatest species richness was at the Plum Creek Bridge with 18 species documented at this structure over the three years of the study (Fig 34). The Greenland Underpass had the second most with 16 species detected at the two photo booths at that structure. Species richness was lowest at the Dogleg and Rest Area Underpasses, which tallied 10 and 13 species, respectively, over the course of the study.

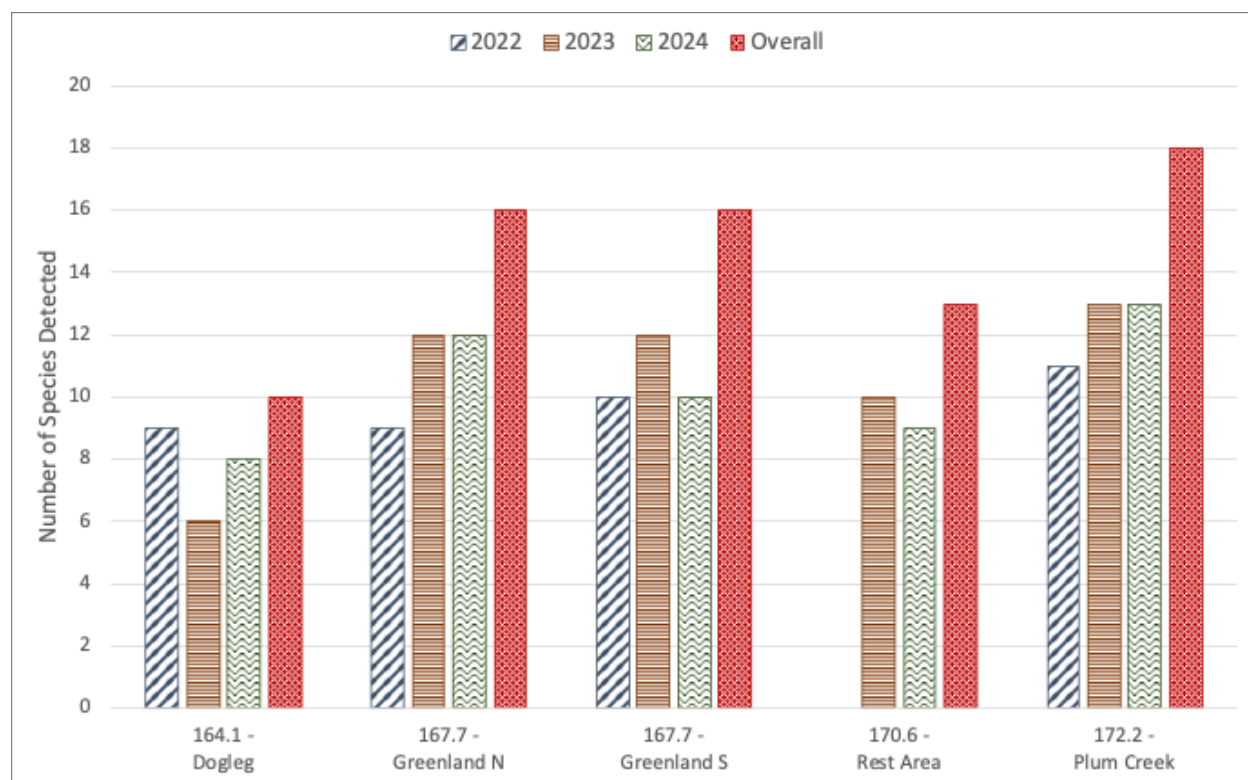


Figure 34. Species richness by year and overall at the small fauna photo booths. Note that the cameras at Plum Creek Bridge and the Rest Area Underpass were not deployed until August 1, 2022, and May 1, 2023, respectively.

Deer mouse had the most daily detections ($n=2,184$) and was frequently detected at all cover features. Other commonly detected species included, mouse species ($n=641$), shrew species ($n=380$), woodrat ($n=376$) and vole species ($n=369$). Figure 35 compares the total number of daily detections at each photo booth for non-predator species with at least 10 daily detections and excluding deer mouse. Note that daily detections for ground squirrel, 13-lined ground squirrel, and other squirrel species were combined. Shrew species were the most frequently observed species at the Dogleg cover feature

($n=302$) but had far fewer detections at all other locations. Vole species were most frequently observed at the Dogleg and Plum Creek Bridge cover features, whereas other mouse species were most common at the Greenland south cover feature. Squirrel species were most common at the Plum Creek Bridge and Rest Area cover features.

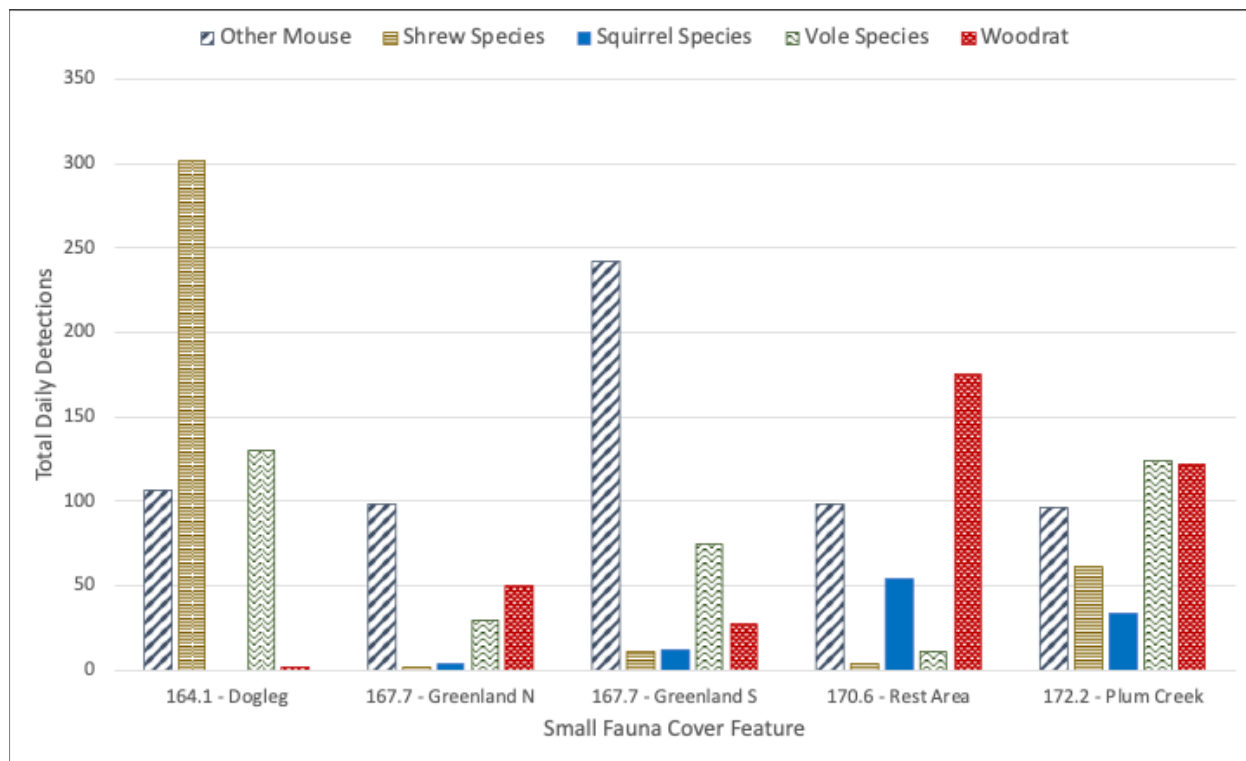


Figure 35. Total number of daily detections by location of species with at least 10 daily detections between June 1 and September 30 across all years. Deer mouse is not shown due to the high number of daily detections. Daily detections for squirrel species were combined. Due to construction time frames, photo booths at the Plum Creek Bridge and the Rest Area Underpass were not deployed until August 1, 2022, and May 1, 2023, respectively.

Table 28 lists species detections by year at each location. Deer mouse was the only species to be detected at every structure during every month of the monitoring period through each year of the study. There were two confirmed detections of Preble’s meadow jumping mouse, both at the Plum Creek Bridge, the first in June 2023 and the second in August 2024 (Fig. 36). Reptiles and amphibians were also detected at the cover features, including bull snake ($n=1$), lizard ($n=1$), racer ($n=1$) and Woodhouse’s toad ($n=1$) at the Greenland Underpass; bullsnake ($n=1$), lizard ($n=4$) and northern leopard frog ($n=1$) at the Plum Creek Bridge; and lizard ($n=6$) at the Rest Area Underpass.



Figure 36. Preble's meadow jumping mouse at the Plum Creek Bridge photo booth in August 2024.

Table 28. Number of daily detections between June 1 and September 30 in 2022, 2023 and 2024 by species with at least 5 daily detections. Cameras at the Plum Creek Bridge and the Rest Area Underpass were not deployed until August 1, 2022 and May 1, 2023, respectively.

Species	Year	164.1 – Dogleg	167.7 – Greenland North	167.7 – Greenland South	170.6 – Rest Area	172.2 – Plum Creek	Total Daily Detections
Deer Mouse	2022	211	106	159	-	70	546
-	2023	136	160	205	175	157	833
-	2024	148	131	211	140	175	805
-	Overall	495	397	575	315	402	2,184
Ground Squirrel	2022	0	0	2	-	27	29
-	2023	0	2	3	0	4	9
-	2024	0	1	2	8	1	12
-	Overall	0	3	7	8	32	50
Mouse - other	2022	37	1	5	-	1	44
-	2023	49	54	139	90	65	397
-	2024	21	43	98	8	30	200

Species	Year	164.1 – Dogleg	167.7 – Greenland North	167.7 – Greenland South	170.6 – Rest Area	172.2 – Plum Creek	Total Daily Detections
-	Overall	107	98	242	98	96	641
Shrew Species	2022	158	1	1	-	2	162
-	2023	88	1	1	2	9	101
-	2024	56	0	9	2	50	117
-	Overall	302	2	11	4	61	380
Squirrel	2022	0	0	0	-	0	0
-	2023	0	1	5	31	1	38
-	2024	0	0	0	15	1	16
-	Overall	0	1	5	46	2	54
Vole Species	2022	113	3	8	-	5	129
-	2023	8	10	13	6	1	38
-	2024	9	16	54	5	118	202
-	Overall	130	29	75	11	124	369
Woodrat	2022	1	36	23	-	19	79
-	2023	0	7	3	41	30	81
-	2024	1	7	1	134	73	216
-	Overall	2	50	27	175	122	376
Species Richness	All	10	16	16	13	18	-

Species richness was consistent through the summer monitoring period, with a slight drop in species detections observed in September, and a peak in species richness at the Plum Creek Bridge in August.

Figure 37 displays the monthly average number of species detections by location.

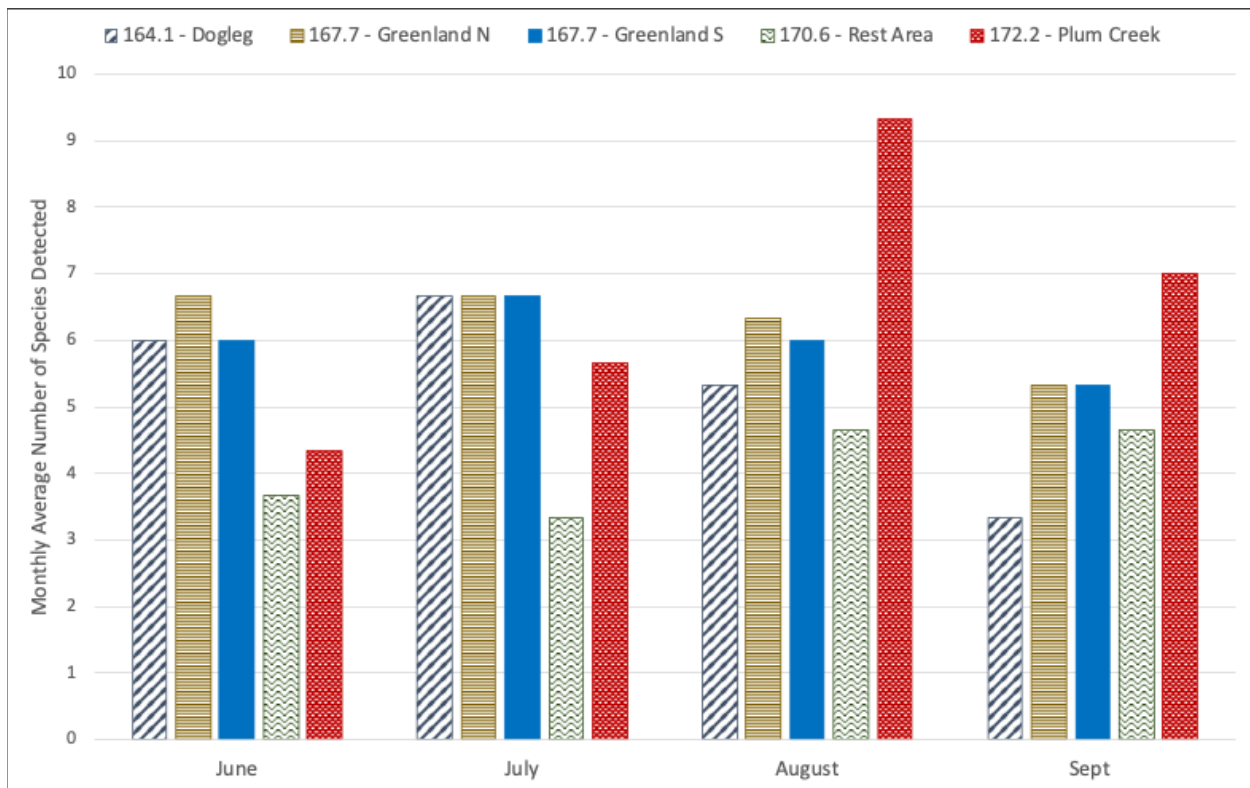


Figure 37. Average species richness by month at each monitored cover feature location.

5.2. Discussion

The research performance measures did not establish a specific target for small fauna use of the cover features. Nevertheless, the novel use of small fauna photo booths supported the evaluation of this type of mitigation feature in providing connectivity for small fauna at large wildlife underpasses. A variety of wildlife not otherwise detected at the wildlife underpasses were documented using the cover features. Most notably this study confirmed that Preble’s meadow jumping mouse – a federally threatened species – used the cover feature at the Plum Creek Bridge on two occasions. The cover features supported use by frogs, toads, snakes, and a variety of small mammals. These high levels of use by diverse small fauna highlight the value of these low-cost mitigation features in restoring and enhancing connectivity for a broader array of wildlife than would otherwise be served by the large wildlife crossings alone.

Chapter 6. Wildlife Guards

6.1. Results

Cameras recorded a total of 193 approaches at the four monitored wildlife guards by both ungulate and carnivore species (Fig. 38). The wildlife guards all had the same design but varied in width, ranging from 32-feet wide at the Upper Lake Gulch Road-East location to 58-feet wide at the Greenland Road-East location. 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.

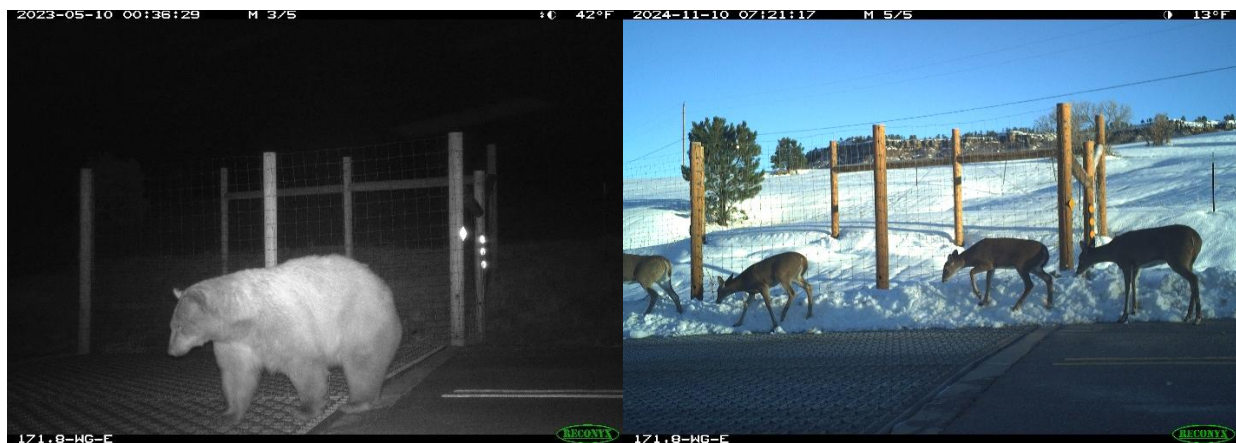


Figure 38. A black bear (left) and white-tailed deer (right) successfully breaching the Upper Lake Gulch Road - East Wildlife Guard.

6.1.1. Activity by Species and Location

The wildlife guards deterred ungulates from crossing 58% of the time ($n=158$ approach movements) over the course of the study. Animals with padded feet, including bears, canids, and felids, were deterred 49% of the time ($n=35$). Mule deer ($n=64$) and elk ($n=58$) were the most detected species to approach the guards. Mule deer, white-tailed deer, coyote, and fox approached all four guard locations. Notably, the monitored guards were all located in the northern half of the study area, which corresponds with white-tailed deer distribution on the landscape, along the Plum Creek drainage. There are more breaks in the fence and, thus, wildlife guards in the northern portion of the study area. In addition, a camera placed at Misty Acres (MP 162.8) in the southern portion of the study area was stolen shortly after it was deployed and was not replaced.

Most approaches to a wildlife guard occurred at Upper Lake Gulch Road on the east side of I-25, primarily by elk and white-tailed deer (Table 29). Monitoring cameras were placed at Upper Lake Gulch Road on either side of I-25 and while there were 29 approaches by white-tailed deer to the guard on the east side of the interstate, there were just 2 approaches to the guard on the west side. The fewest approaches to a wildlife guard were at Greenland Road on the east side of I-25.

Table 29. Total number of approaches to wildlife guards by large and medium-sized mammals.

Guard Location	Mule Deer	White-tailed Deer	Elk	Black Bear	Bobcat	Coyote	Fox	Total
Greenland East	5	2	0	0	0	1	5	13
Upper Lake Gulch East	14	29	39	6	3	3	10	104
Upper Lake Gulch West	22	2	19	1	1	2	1	48
West Frontage Road	23	3	0	0	0	1	1	28
Total	64	36	58	7	4	7	17	193

The location with the highest breach rate (51%) was the Upper Lake Gulch Road - West Wildlife Guard (Table 30), which accounted for 33% of all breaches to the monitored guards. The corresponding guard on Upper Lake Gulch Road on the east side of the interstate had almost twice as many ungulate approach movements and a breach rate of 40%. Bears, canids, and felids were most commonly documented at the Upper Lake Gulch Road - East Wildlife Guard, which also had the highest breach rate for this group of species.

Over half of all ungulate movements on the habitat side of the fence (54%) ignored the guard and did not approach, whereas only 10% of ungulate movements on the right-of-way side of the fence were parallel/ignore movements. Among bears, canids, and felids, coyote was the only species to ignore the guards and was slightly more likely to make a parallel movement (53%) than to approach a guard.

Table 30. Approach movements and breach rates for ungulates, bears, felids, and canids by location.

Guard Location	Ungulate Approaches	Ungulate Breach Rate	Bear, Canid, Felid Approaches	Bear, Canid, Felid Breach Rate
Greenland East	7	29%	6	17%
Upper Lake Gulch East	82	40%	22	68%
Upper Lake Gulch West	43	51%	5	40%
West Frontage Road	26	35%	2	0%

6.1.2. Activity at Wildlife Guards Over Time

Overall ungulate approaches to the wildlife guards increased in 2023, following the completion of construction activities, although it should be noted that the monitoring camera at Upper Lake Gulch Road - West was not deployed until May 2023 and there were no construction phase data for this location. Post-construction, ungulate approaches decreased at each of the monitored guard locations (Table 31).

Table 31. Ungulate approaches to the wildlife guards by location each year of the study.

Guard Location	2022 Construction	2023 Post-Construction	2024 Post-Construction
Greenland East	2	5	0
Upper Lake Gulch East	18	42	22
Upper Lake Gulch West	n/a	33	10
West Frontage Road	2	16	8

Overall ungulate approaches to the wildlife guards decreased in the second year post-construction – from 96 approaches in 2023 to 40 in 2024, a 58% decrease. In 2023, the first year post-construction, the total number of ungulate approaches to the guards peaked and the repel rate was at its lowest (48%) resulting in 50 ungulate breaches over the guards (Fig. 39).



Figure 39. Bull elk successfully breaching the Upper Lake Gulch Road - West Wildlife Guard.

In 2024, the total number of approaches dropped while the repel rate increased to 73%, such that there were only 11 breach movements that year. Meanwhile, the number of ungulate movements parallel to the guards increased each year of the study. These animals were captured by the cameras in the vicinity of a wildlife guard but did not approach the guard (Fig. 40).

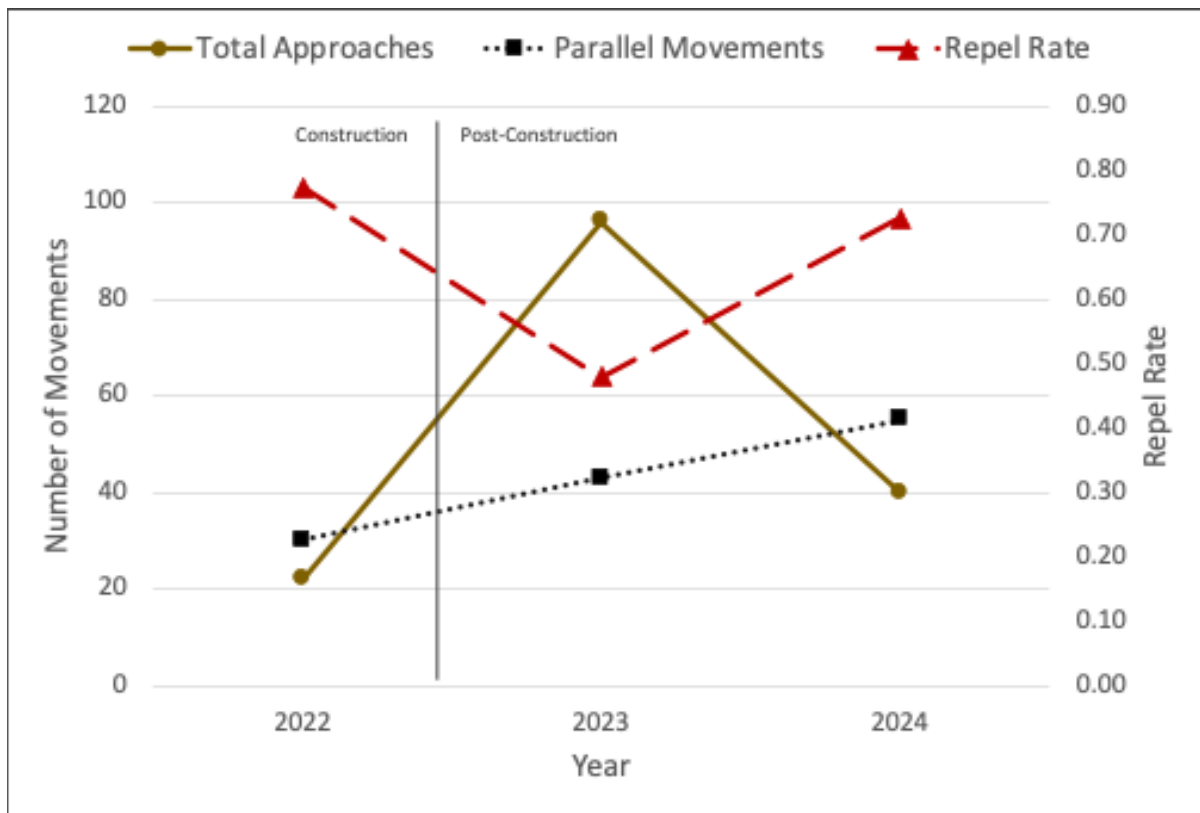


Figure 40. Ungulate approach and parallel movements and repel rates each year of the study.

6.1.3. Habitat Side versus Right-of-Way Side Movements

Most ungulate approaches to the guards were from the habitat side of the fence (65%) and accounted for 55% of all ungulate breach movements, although, deer or elk trapped inside the fencing also breached guards to return to the habitat side of the fencing. Bears, canids, and felids breach the guards equally in both directions, although two-thirds of all approach movements were from the habitat side.

While the breach rate for mule deer was approximately the same regardless of whether the animal approached the guard from the habitat side or the highway side of the fence (30% and 33%, respectively), the breach rates for white-tailed deer and elk were higher for animals seeking to escape from the highway right-of-way back to the habitat side of the fence (70% and 71%, respectively) than for those on the habitat side attempting to breach the fenced highway right-of-way (38% each).

6.1.4. Analysis of Factors Influencing Ungulate Breaches

Statistical models did not find that either guard width or crossing distance were significantly associated with breach events ($p = 0.724$ and $p = 0.759$, respectively, $\alpha = 0.05$) (Table 32). However, increases in distance from the nearest building were approaching a significant association with increased breach events ($p = 0.083$, $\alpha = 0.05$).

Table 32. Model coefficients for covariate relationships with breach events based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-1.496	-4.077	1.085	1.317	-1.136	0.256
Building Distance	0.001	<0.001	0.002	<0.001	1.733	0.083
Guard Width	-0.012	-0.08	0.055	0.035	-0.354	0.724
Crossing Distance	<0.001	<0.001	<0.001	<0.001	-0.307	0.759

None of the covariates included in the model evaluating were significantly associated with repel behavior (Table 33).

Table 33. Model coefficients for covariate relationships with repel events based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-1.793	-4.353	0.767	1.306	-1.373	0.17
Guard Width	0.039	-0.029	0.107	0.035	1.124	0.261
Crossing Distance	<0.001	<0.001	<0.001	<0.001	0.454	0.65
Building Distance	<0.001	-0.001	0.001	<0.001	0.696	0.486

6.2. Discussion

6.2.1. Performance Measures Evaluation

In the final year of the study, the wildlife guards successfully deterred ungulates from entering the fenced highway right-of-way 73% percent of the time, nearly meeting the goal of an 80% repel rate. The total number of approaches to the guards decreased 58% and the breach rate decreased from 52% in 2023 to 28% in 2024. While the performance measure established at the outset of the study was not fully met and the number of animal approaches to the wildlife guards is likely to vary from year to year due to environmental conditions and population fluctuations, these findings suggest a promising trend towards meeting these goals (Table 34).

Table 34. Wildlife guards performance measures evaluation. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
Over time, detections of ungulates attempting to breach wildlife guards to enter the road right-of-way will decrease and ungulates will be deterred from entering the road right-of-way at least 80% of the time.	(X)	

6.2.2. Effectiveness of the Wildlife Guards in Preventing Ungulate Breaches

At the outset of this study, the research team was concerned about the wildlife guard design, which included an extra crosshatch across the grate openings, creating a more stable surface for hooved animals to attempt breaching into the fenced highway right-of-way (Fig. 41).



Figure 41. Surface of the wildlife guards in the I-25 South Gap Project.

The number of wildlife approaches to the monitored guards was low compared to other projects, such as the State Highway 9 Wildlife Crossings Project in Grand County, resulting in fewer attempted breaches into the fenced right-of-way. The overall ungulate repel rate was 58% over the course of the study, but in the final year, a repel rate of 73% was achieved. Still, this rate is lower compared to State Highway 9, which documented repel rates of 94% for round bar guards and 90% for flat bar guards (Kintsch et al. 2021). The lower repel rate is likely due to the incorrect wildlife grates installed on the I-25 South Gap Project, as wildlife grates with open cells have proven effective in other locations (e.g., Allen et al. 2013, Peterson et al. 2003). Nevertheless, due to the low number of ungulate approaches to the guards, the number of wildlife incursions into the fenced right-of-way was limited.

As has been observed elsewhere (e.g., Kintsch et al. 2021), the number of ungulate approaches to a guard decreased over time while the number of parallel/ignore movement increased, suggesting that as animals learn the migration system, including the locations of the wildlife underpasses, they are less likely to attempt breaching the guards.

6.2.3. Factors Influencing Ungulate Breaches of Wildlife Guards

Statistical analyses of structural and environmental factors influencing ungulate breach rates were limited by a small sample size and other compounding factors. Despite the limitations of a real-world study in teasing out these influences, this study offers indications of the factors influencing ungulate breaches at wildlife guards. Among the influences discussed here are motivation, distance to a wildlife crossing structure, habituation, and guard width.

While difficult to measure directly, motivation is a powerful driver influencing wildlife behaviors, such as breach attempts at the wildlife guards. In particular, the motivation for animals on the habitat side of the fence is different than for those that are inside the fenced right-of-way that may be more pressured to breach a guard to escape from vehicle traffic. This was observed among white-tailed deer and elk, which were almost twice as likely to breach a wildlife guard from the highway to the habitat side of the fence than from the habitat side into the fenced highway right-of-way. Mule deer were equally likely to breach a guard regardless of which side of the fence they were on. In addition, the number of parallel/ignore movements was greater (54% of all movements) among ungulates on the habitat side of the fence than those inside of the highway right-of-way (10% of all movements) even though there were far more ungulates documented on the habitat side than the highway side, suggesting that the motivation to breach a guard was higher for animals trapped on the highway side of the fence.

Distance to a wildlife crossing structure also appeared to influence wildlife guard breach attempts, particularly where there is a longer stretch of wildlife exclusion fencing with no suitable safe passage opportunities. Notably, the northernmost portion of the study area, from Sky View Lane / Jellystone (MP 173.8) to the north fence end (MP 176.2) has multiple potential breach points at wildlife guards across access roads and driveways and the closest safe crossing opportunity is at the Plum Creek Bridge Underpass at milepost 172.2. Abundant wildlife in this portion of the study area combined with multiple potential breach points and no safe passage opportunities may lead to more wildlife approaches to the wildlife guards and attempted breaches into the fenced right-of-way, increasing the potential for ongoing WVCs (see Chapter 9). In contrast, the fewest attempted breaches at a wildlife guard were at Greenland Road on the east side of I-25. This guard is located 0.3-miles from the Greenland Underpass and the availability of a nearby safe passage may have been a factor in reducing the likelihood of a breach attempts at this location, as has also been documented in Montana (Allen et al. 2013).

Habituation to the wildlife guards and other mitigation infrastructure is evident in this study as well as previous studies from other locations, depending on the guard type (Cramer and Flower 2017, Gagnon et al. 2020, Kintsch et al. 2021). Although this study included only two years of post-construction monitoring, both the total number of ungulate approaches to the guards and the breach rate decreased in the final year of the study, by 58% and 47%, respectively.

The potential influence of guard width on breach rates was not discernable in this or previous studies. A metaanalysis across multiple studies with comparable methods in Colorado or other western states is recommended to determine this and other influences.

Chapter 7. Escape Ramps

Escape ramps provide an escape route for animals that become trapped inside a fence highway right-of-way. Camera monitoring at the escape ramps was designed to evaluate how well ungulates that become trapped in the fenced right-of-way were able to use the escape ramps to exit the highway right-of-way and return to the habitat side of the fence. Seven escape ramps were monitored for the duration of this study: four standard escape ramps and three 2-sided ramps (Fig. 42). The design height for all the ramps was 66 inches; constructed ramp heights ranged from 60 to 70 inches (see Appendix B).



Figure 42. Young mule deer using standard ramp (right) and buck mule deer using 2-sided ramp (left) to successfully escape to the habitat side of the fencing.

7.1. Results

Cameras recorded a total of 172 approaches by mule deer in the highway right-of-way at the seven escape ramps, 21 white-tailed deer, and 12 elk. Bears, felids, and canids were also documented. When an individual animal encountered an escape ramp inside the fenced right-of-way, 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, the ungulate intercept rate was 81% and the escape rate was 40%.

Black bear, bobcat, coyote, fox, and mountain lion were also detected inside the highway right-of-way at the escape ramps. Most individuals of these species ignored the ramps, but coyote, fox, and black bear were all observed successfully using the ramps to jump back to the habitat side of the fence.

All ungulate species were detected in greater numbers on the habitat side of the fence adjacent to the escape ramp than they were on the highway side of the fence (Table 35). The only moose detection was on the habitat side of the fence.

Table 35. Total number of detections of each ungulate species inside of the highway right-of-way compared to on the habitat side of the fence.

	Mule Deer	White-tailed Deer	Elk	Moose
Inside ROW	172	21	12	0
Habitat Side	626	121	100	1

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 elk attempted to jump up from the habitat side of a ramp into the fenced right-of-way. The only species documented jumping or climbing up from the backside of the ramp to enter the right-of-way was bobcat ($n=1$). One mule deer attempted to jump up but was not successful (Fig. 43).



Figure 43. Mule deer attempting to jump up from the habitat side of the escape ramp.

7.1.1. Spatial and Temporal Distribution of Ungulate Activity at Escape Ramps

Ungulate activity at the escape ramps varied over each year of the study and with respect to the ramp locations on the landscape. Mule deer approaches to the escape ramps were highest in the first year post-construction (2023) – a 131% increase over the construction phase – and then decreased by 11% in the second year post-construction. White-tailed deer and elk approaches to the ramps inside the

fenced right-of-way remained low (less than 10 approaches each year) and relatively steady year-over-year (Fig. 44). While there was some variation in escape rates from year to year, rates for all ungulate species were between 20-30% in Year 3.

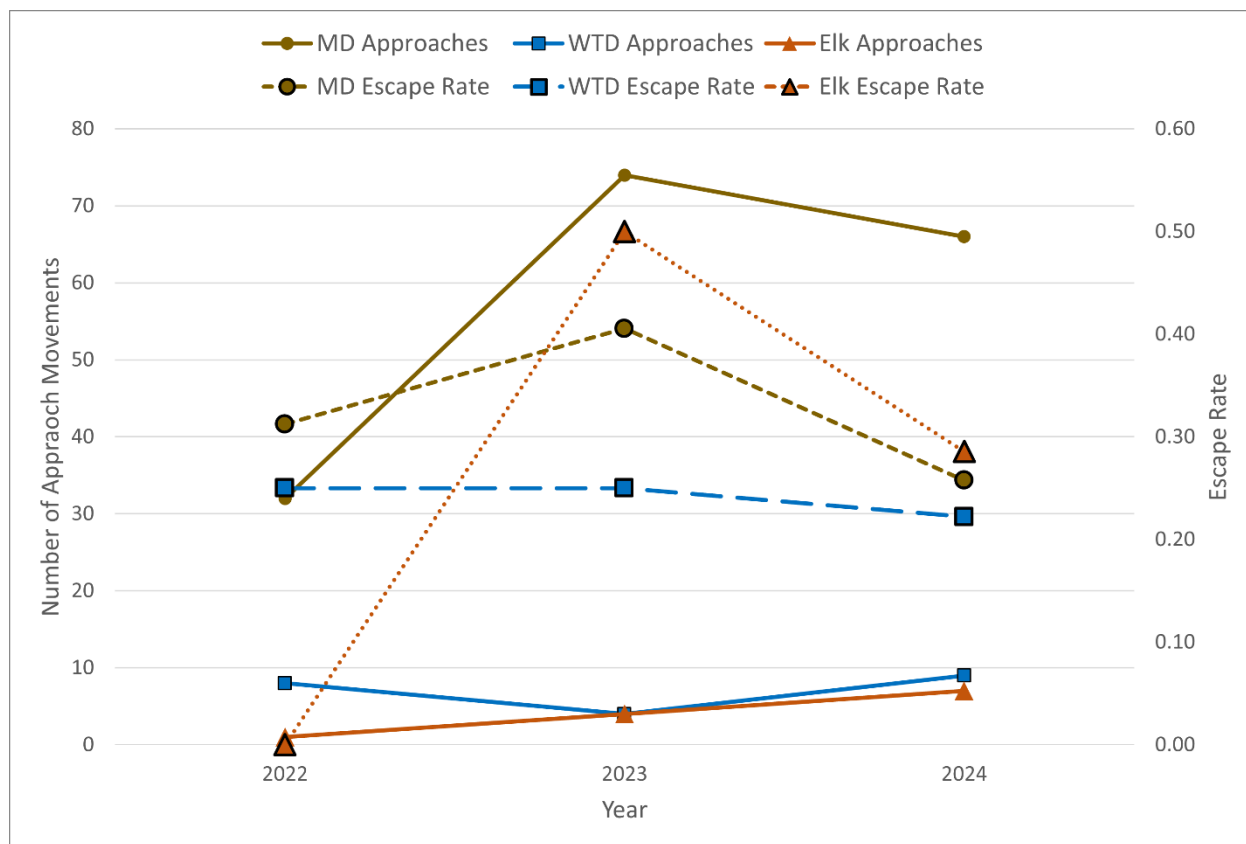


Figure 44. Number of approach movements and escape rates by species for mule deer (MD), white-tailed deer (WTD), and elk.

Mule deer approached all the monitored ramp locations but 66% of all approaches to a ramp and 37% of all escapes were at the standard escape ramp adjacent to Jellystone on the southbound side of I-25 (MP 173.8). Overall, mule deer ($n=172$) had an intercept rate of 83% and an escape rate of 40%.

White-tailed deer were detected only at the four northernmost ramps in the study area, corresponding with their distribution on the landscape, along the Plum Creek drainage. The intercept rate for white-tailed deer ($n=21$) was 57% and the escape rate was 42%. Elk were also observed only in the northern portion of the study area, at three of the four ramps monitored north of Plum Creek Bridge. The intercept rate for elk ($n=12$) was 100% and the escape rate was 12%. Moose was not detected inside of

the highway right-of-way but was observed on one occasion at the escape ramp adjacent to Jellystone on the southbound side of I-25 (MP 173.8).

7.1.2. Intercept and Escape Rates by Ramp Type

The intercept rates for mule deer and white-tailed deer were higher at the 2-sided ramps than at the standard ramps, yet the escape rate for both species were approximately double at the standard ramps for both species (Table 36). For elk, the intercept rate was 100% at both ramp types but the escape rate was higher at the 2-sided ramps (40%) than at the standard ramps (29%).

Table 36. Intercept and escape rates by ramp type for ungulate species (mule deer = MD; white-tailed deer = WTD)

Ramp Type	MD Intercept Rate	MD Escape Rate	WTD Intercept Rate	WTD Escape Rate	Elk Intercept Rate	Elk Escape Rate
Standard Escape Ramp						
<i>n</i> =150 mule deer	81%	44%	38%	67%	100%	29%
<i>n</i> =8 white-tailed deer						
<i>n</i> =7 elk						
2-Sided Escape Ramp						
<i>n</i> =22 mule deer	95%	14%	69%	33%	100%	40%
<i>n</i> =13 white-tailed deer						
<i>n</i> =5 elk						

7.1.3. Factors that Influence Intercept and Escape Rates

Statistical analyses determined that neither ramp type nor road distance were significantly associated with intercept ($p = 0.551$, $p = 0.25$, respectively, $\alpha = 0.05$). Crossing distance had a small positive significant ($p = 0.036$, $\alpha = 0.05$) relationship with intercept events (Table 37).

Table 37. Model coefficients for covariate relationships with intercept based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-0.543	-2.25	1.163	0.871	-0.624	0.532
RampType: Standard	-0.537	-2.303	1.23	0.901	-0.596	0.551
RoadDistance	0.01	-0.007	0.026	0.008	1.15	0.25
CrossingDistance	<0.001	<0.001	<0.001	<0.001	2.093	0.036*

No significant associations were detected for ramp type, distance to road, and crossing distance with the response variable of escape ($p = 0.928$, $p = 0.282$, and $p = 0.839$, respectively, $\alpha = 0.05$) (Table 38).

Table 38. Model coefficients for covariate relationships to escape events based on a generalized linear mixed effects model.

	Estimate	Lower 95% CI	Upper 95% CI	Standard Error	Z value	p-value
(Intercept)	-2.405	-4.587	-0.223	1.113	-2.16	0.031
RampType:Standard	-0.092	-2.111	1.927	1.03	-0.09	0.928
Road Distance	0.014	-0.011	0.039	0.013	1.077	0.282
Crossing Distance	<0.001	<0.001	<0.001	<0.001	0.203	0.839

Relationships between intercept or escape rates and structural and landscape variables were hard to infer due to a limited sample size and a high variability in the landscape characteristics of the monitoring locations.

7.2. Discussion

7.2.1. Performance Measures

Ungulate approaches to the escape ramps remained steady through both post-construction years of the study and the escape rate decreased from a high of 40% in 2023 to 26% in 2024 (Table 39). The goal of no ungulates jumping up onto the ramp from the habitat side of the fence was met.

Table 39. Escape ramp performance measures evaluation. Parentheses indicate that the performance measure was partially met.

Performance Measure	Met	Not Met
Over time, ungulate detections at escape ramps will decrease; of ungulates that ascend an escape ramp the proportion that successful escape to the habitat side will increase; and no ungulates will jump up onto the ramp from the habitat side.		(X)

7.2.2. Effectiveness of the Escape Ramps in Allowing Ungulates to Escape out of the Fenced Right-of-way

Despite the escape ramp performance measure not being fully met, the overall mule deer and elk escape rates of 40% and 33%, respectively, was higher than the rates document in the State Highway 9 monitoring study in Grand County, Colorado, where the mule deer escape rate was 10% and the elk escape rate was 23% (Kintsch et al. 2021). The standard escape ramp design on the I-25 South Gap Project was informed by this previous study in several ways: 1) a 5'6"-high ramp height and more careful construction management to ensure consistency in ramp height across all locations; and 2) a 3:1 ramp slope. The documented improvement in escape rates for both species indicates the success of these adjustments to the standard ramp design.

7.2.3. Effect of Ramp Type on Intercept and Escape Rates

Ungulate intercept rates were higher at the 2-sided ramps (88%) than at the standard ramps (80%) and, conversely, escape rates were higher at the standard ramps (44%) than at the 2-sided ramps (23%). This trend was particularly true for mule deer and white-tailed deer, although the sample size for mule deer was much smaller at the 2-sided ramps ($n=22$) than at the standard ramps ($n=150$). Elk had an intercept rate of 100% at both ramp types and an escape rate of 40% at the two-sided ramps and 29% at the standard ramps, although the total number of elk documented at the escape ramps was small ($n=12$).

Nevertheless, high ungulate intercept rates at 2-sided ramps and lower escape rates may suggest that ramp orientation parallel to the roadway may be more beneficial to intercepting animals inside a fenced right-of-way than the standard ramp orientation perpendicular to a roadway. As escape rates are a function of intercept rates – an animal must first ascend a ramp to attempt jumping off the ramp – successfully drawing animals to a ramp is a critical element of escape ramp success. The 2-sided ramp design may not always be necessary, though it may be desirable in some situations, such as where the

right-of-way is narrow between the pavement edge and the wildlife fence. The standard ramp design may also be reoriented parallel to the roadway at a jog in the fence such that animals following a fence line are more likely to intercept the ramp. Based on these limited findings, the research team recommends further testing of ramp orientation to determine its effect on intercept rates.

7.2.4. Factors Influencing Ungulate Intercept and Escape Rates

Due to the nature of the wildlife mitigation infrastructure, i.e., wildlife fencing that is specifically designed to keep animals out of a highway right-of-way, the greatest factor influencing intercept and escape rates is the presence of ungulates in the fenced right-of-way. Animals in the right-of-way are a function of their distribution on the landscape and opportunities for breaching the fence, for example at holes in the fence, wildlife guards, or by walking around the fence ends. When animals enter a fenced right-of-way, they need to seek out opportunities for escaping back to the habitat side of the fence or they may be subject to a WVC. Where the wildlife fence is tight, preventing intrusions into the fenced right-of-way, wildlife activity at escape ramps remains low, resulting in little data. Consequently, statistical analyses were unable to discern major influences on intercept and escape rates based on ramp type or landscape characteristics, although the analysis did suggest that intercept events increased as the distance to the nearest crossing structure increased.

Nevertheless, ramp height is known to be an important variable in escape ramp design: for all the target species in a project area, ramp height must find the right balance between being low enough for animals – including cows or does with their young – to jump off the ramp while also preventing animals from jumping up onto the ramp into the fenced right-of-way. Both ramp types on the I-25 South Gap project specified a 5'6" (66") height in the engineering design plans. The actual heights measured in the field of the monitoring ramp locations ranged from 52" to 70" with an average height of 65" (5'5") across the seven locations.

The effect of ramp height on escape events could not be evaluated through statistical analysis because there was little variation in ramp heights among the monitored ramp locations – while this is a positive outcome from a construction standpoint, the lack of variation limits the power of analysis from the standpoint of experimental research. The design height of 5'6" resulted in few attempted jump ups and no successful jump ups by deer or elk; however, a lower ramp height be necessary to encourage more successful escapes.

Chapter 8. Wildlife Fence End and Fence End Treatment

Only one fence end was monitored on the I-25 South Gap project – the northeast fence end, which included a 16-foot-wide stretch of Geocell erosion mesh in the clear zone, extending from the pavement edge to the wildlife fence. The research objective was to determine the effectiveness of this fence end design in deterring wildlife – primarily ungulates – from entering the fenced highway corridor.

Wildlife movements at the fence end were categorized in three ways:

- 1) Movements that occurred beyond the fence end, perpendicular to the fenced road corridor with animals moving either from the habitat side of the fence towards the frontage road and I-25, or from the highway side of the fence towards the habitat side of the fence. These animals did not interact with the fence end.
- 2) Movements into the fenced right-of-way.
- 3) Movements out of the fenced right-of-way by animals that were already inside the fenced road corridor, having previously entered either at the fence end or another location, such as by breaching a wildlife guard.

In addition, some animals were detected on the habitat side of the fence but did not cross the barbed wire right-of-way fence that extends from north from the terminus of the wildlife exclusion fence. These movements were not included in the analysis.

8.1. Results

Small herds of mule deer, white-tailed deer, and elk were documented at the northeast fence end. In total, 251 ungulate movements were documented at the northeast fence end, the majority of which were mule deer (58%). White-tailed deer and elk each comprised 21% of all fence end movements. Across all three years of the study, most wildlife movements at the fence end were made by animals moving beyond the fence end that did not interact with or approach the fence end or Geocell treatment (79%) (Fig. 45).



Figure 45. Bachelor elk herd moving beyond the northeast fence end.

Anecdotally, some of these animals were observed looking in the direction of the opening between the fence end and the pavement edge, but did not approach.

The greatest number of ungulate movements at the fence end occurred during the construction phase ($n=130$). All three fence end movement types decreased in number from the construction phase and remained stable post-construction. In the final year of the study, ungulate movements decreased by 57% relative to construction phase (2022) levels, although fluctuations in the total number of movements by each species were observed in the two post-construction years (Fig. 46). The number of white-tailed deer movements declined each year of the study, whereas mule deer movements increased somewhat in the final year of the study following an initial decrease of 80% during the first post-construction year. Elk movements at the north fence end peaked during the first post construction year and then decreased to their lowest level in the final year of the study.

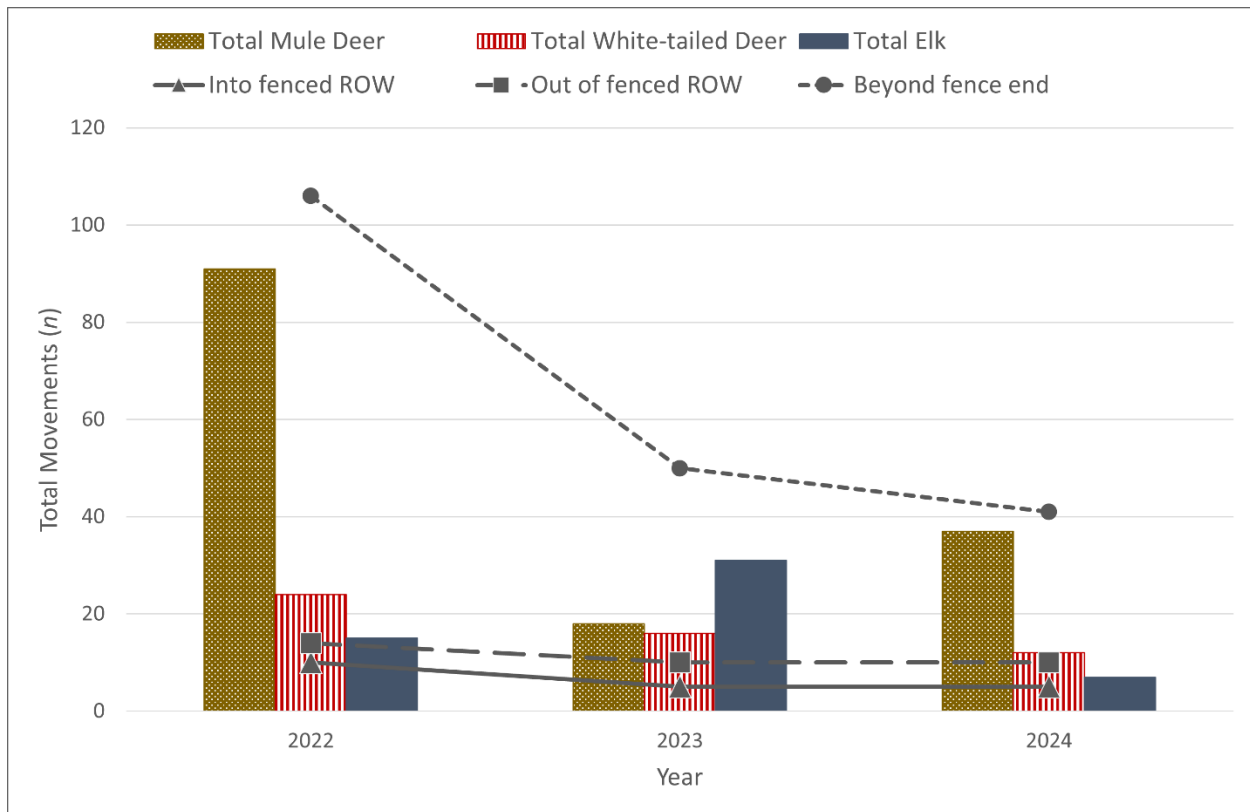


Figure 46. Total number of movements by mule deer, white-tailed deer, and elk each year of the study overlaid with the total number of each fence end movement type over the three-year study period.

Post-construction, most movements by all three ungulate species occurred beyond the fence end (annual average 75%); however, the post-construction annual average number of movements decreased by 56% relative to the construction phase. Ungulate movements into the fenced right-of-way similarly decreased by 60% and only three such movements were recorded in the final year of the study. Ungulate movements out of the fenced right-of-way decreased on average by 29% post-construction relative to the construction phase.

Ungulates that approached the Geocell fence end treatment ($n=54$) were more likely to walk around the treatment (58%) than to breach (33%) or repel (19%) (Table 40). While the overall breach rates for mule deer and elk were the same (42%), mule deer were equally likely to breach the Geocell treatment moving in either direction (Fig. 47), whereas elk breached the Geocell 100% of the time when moving out of the fenced right-of-way compared to 13% when moving into the fenced right-of-way. White-tailed deer made no breach attempts into the fenced right-of-way but had a breach rate of 27% moving

out of the fenced right-of-way. On one occasion a white-tailed deer was recorded jumping over the Geocell to exit from the fenced right-of-way (Fig. 48).



Figure 48. Mule deer breaching the Geocell to exit the fenced right-of-way.



Figure 48. White-tailed deer jumping over the Geocell fence end treatment.

Table 40. Ungulate movements at the fence end, including movements beyond the fenced right-of-way (ROW), into the fenced ROW, and out of the fenced ROW, and responses to the Geocell treatment.

Movement Direction	Total Ungulate Count	Geocell Breach (n)	Breach Rate	Geocell Walk Around (n)	Walk Around Rate	Geocell Repel (n)	Repel Rate
Beyond Fenced ROW	197	n/a	n/a	n/a	n/a	n/a	n/a
Into Fenced ROW	20	4	20%	10	50%	6	30%
Out of Fenced ROW	34	14	41%	16	47%	4	12%
Into and out of ROW Combined	54	18	33%	26	48%	10	19%

8.2. Discussion

8.2.1. Performance Measures Evaluation

The proportion of ungulate movements that attempted moving into the fenced right-of-way remained steady throughout the three-year study, accounting for between 8-9% of all fence end movements. Of these, a total of five movements resulted in deer or elk successfully entering the fenced right-of-way during the two post construction years, averaging 2.5 breach movements per year. These movements into the fenced right-of-way included one elk and three mule deer breaches of the Geocell and one elk that walked around the Geocell. The goal of the fence end performance measure established at the outset of this study was met (Table 41).

Table 41. Fence end performance measure evaluation.

Performance Measure	Met	Not Met
The proportion of ungulate movements at the northeast fence end that enter the fenced right-of-way will decrease to 20% or less.	X	

8.2.2. Effectiveness of the Northeast Fence End and Geocell Treatment

Ungulates and other wildlife continue to attempt crossing the interstate at-grade beyond the mitigated project area, as documented by the monitoring camera at the northeast fence end and as documented by ongoing incidents of wildlife-vehicle collisions (WVCs) to the north. These findings are consistent with previous studies in Colorado (e.g., Kintsch et al. 2021). There are no safe passage opportunities from Sky View Lane / Jellystone (MP173.8) to the north fence end (MP 176.2). Motivated animals are, thus, likely to attempt an at-grade crossing beyond the north fence end. Accordingly, most ungulate movements at the north fence end resulted in animals moving beyond the fence without regard for the fence end itself or Geocell treatment.

Few fence end movements resulted in ungulates entering the fenced road corridor, either by breaching or walking around the Geocell. Notably, given that the fence end runs parallel to the frontage road, it is likely that some animals detected moving beyond the fence end towards the frontage road and I-25 were ultimately deterred from attempting an at-grade crossing of I-25 and may have turned back inside of the fenced road corridor. This type of movement pattern is a likely explanation for there being more ungulate movements out of the fenced road corridor than were detected entering it at the fence end.

The Geocell treatment at the fence end was largely ineffective at deterring ungulate movements into the fenced road corridor. Seventy percent of ungulates that attempted to enter the fenced right-of-way breached the Geocell (20%) or simply walked around it on the pavement side (50%), potentially increasing the safety hazard for drivers on the frontage road. To the extent that the Geocell did serve as a deterrent for 19% of ungulates approaching it in either direction, it also prevented some animals from readily exiting the fenced road corridor. Regardless, ungulates appeared to be more motivated to exit the fenced area than to enter it, with 89% of all approaches to the Geocell from inside the fenced right-of-way resulting in either a breach (41%) or walk around movement (47%).

Few wildlife-highway mitigation projects have implemented Geocell as a fence end treatment and fewer still have evaluated the effectiveness of this fence end treatment, including this study and a previous study on US 160 in southwest Colorado (Cramer and Hamlin 2021). A key difference between this test site and the one on US 160 was the presence of guard rail. This study found that most of the wildlife that interacted with the Geocell simply walked around it on the pavement whereas no such movements were documented in the US 160 study. Both studies found that most wildlife at the fence end moved beyond the fence end without interacting with the Geocell.

Chapter 9. Wildlife-Vehicle Collisions

9.1. Results

Analyses of pre- and post-construction WVC crashes and carcasses in the study area were used to evaluate how effectively the mitigation reduced WVCs. Two independent datasets were available for analyzing wildlife-vehicle collisions in the study area: crash data compiled by CDOT Traffic and Safety; and carcass reports recorded by CDOT Maintenance patrols and CPW wildlife managers.

9.1.1. Before-After Analysis of Wildlife-Vehicle Collision Crashes

While most crash datasets only capture a small portion of WVC (Olson 2013, Kintsch et al. 2021), crash reporting is consistent over time and provides a consistent barometer for assessing mitigation effectiveness through a comparison of the data during the pre- and post-construction time frames. In the five years prior to the start of construction on the I-25 South Gap project (2013-2017), WVCs were the third most common crash type on this segment of highway, after rear end and sideswipe crashes, accounting for nine percent of all reported crashes. On average, there were 32.2 WVC crashes each year during the five years prior to the construction of the mitigation (2013-2017). In 2024, the second year following the completion of construction activities, there were three WVCs inside the fenced project area. Overall, the annual average number of all crash types combined decreased 20% relative to the pre-construction annual average, while WVC crashes decreased by 85%. Figure 49 depicts the total number of WVC crashes during five years prior to the onset of construction, during the five-year construction period, and during the first two years post-construction relative to the five-year pre-construction annual average.

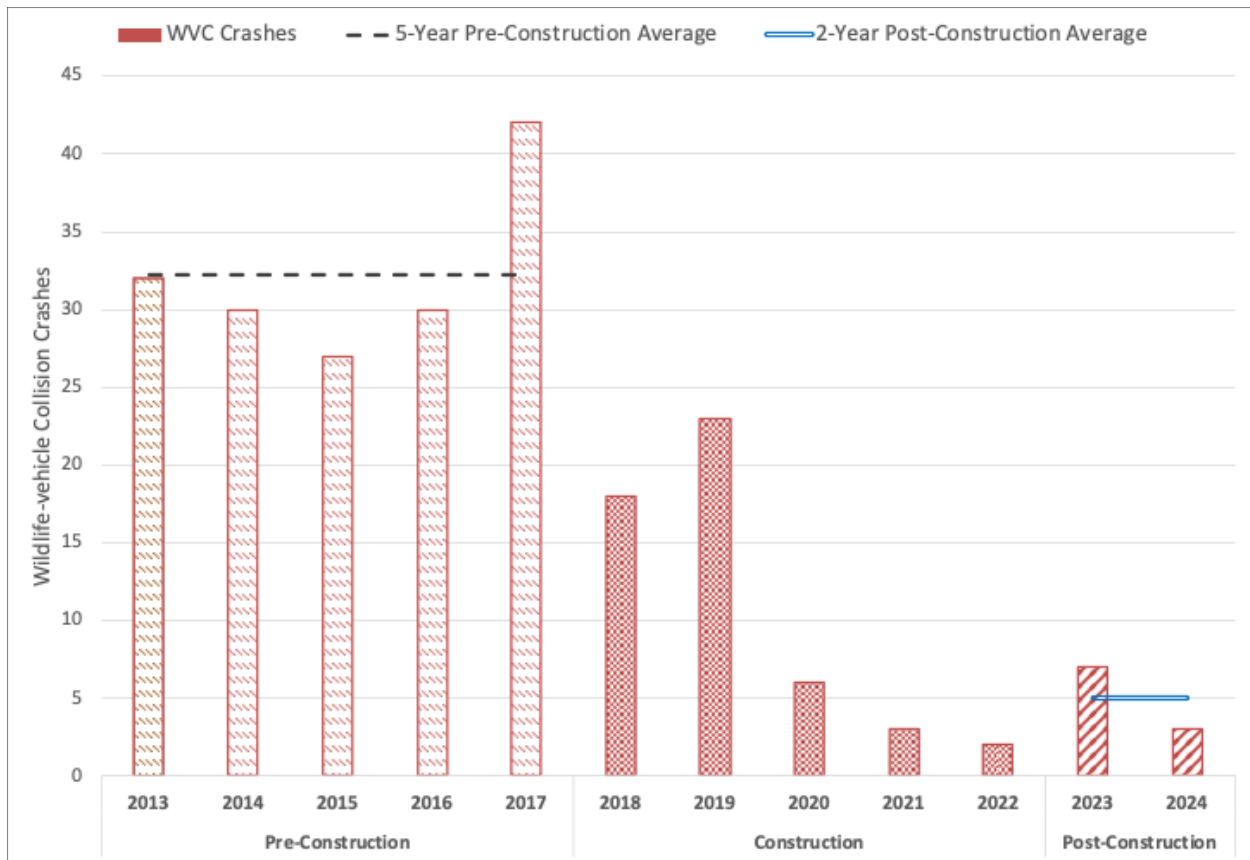


Figure 49. Wildlife-vehicle collision crashes in the project area during the five years pre-construction, five-year construction period, and two years post construction, relative to the five-year pre-construction annual average and two-year post-construction average.

Most post-construction WVCs involved mule deer ($n=7$), while the remainder involved elk ($n=2$) and black bear (1). Post-construction, most WVCs were recorded in May and June (50%) with the remainder occurring between March through November. Two crashes resulted in human injury and remainder resulted in property damage only.

While the WVC carcass dataset does not include pre-construction data, comprehensive reporting initiated at the onset of construction is useful for observing WVC trends during the construction and post-construction phases. Carcass reports document a 74% reduction in WVCs from construction through post-construction – from an annual average of 46.2 WVCs during the construction phase to an annual average of 12 WVCs post-construction (Fig. 50).

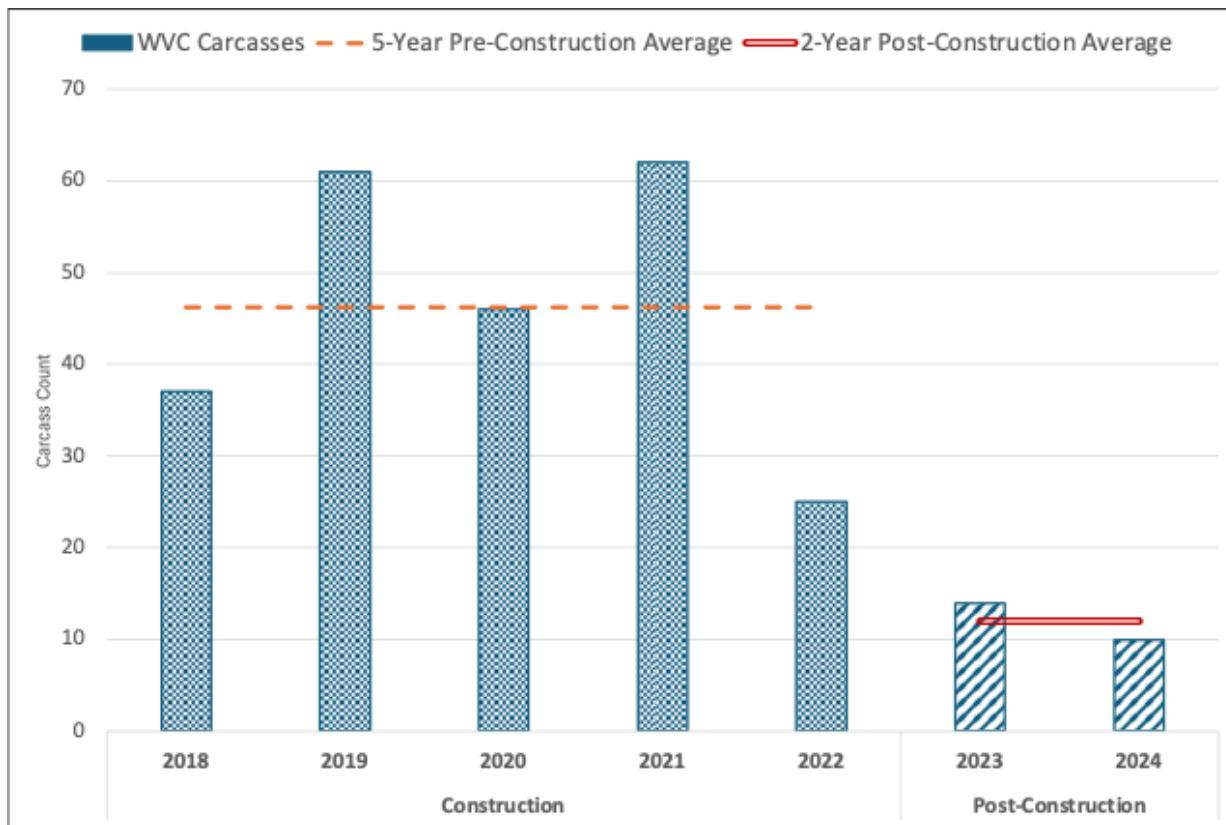


Figure 50. Wildlife-vehicle collision carcass reports in the project area during the five years pre-construction, five-year construction period, and two years post construction, relative to the five-year pre-construction annual average and two-year post-construction average

9.1.2. Spatial Distribution of Wildlife-Vehicle Collision Crashes Pre- and Post-Construction

Figure 51 depicts the distribution of post-construction WVC crashes (2-year annual average, 2023-2024) relative to the five-year pre-construction average (2013-2017) by milepost. WVCs were distributed throughout the project area prior to the construction of the mitigation, with peaks around mileposts 162 and 172-174. Post-construction, WVC crashes were highest at and beyond the south fence end (MPs 161-162), at milepost 172, and milepost 174.

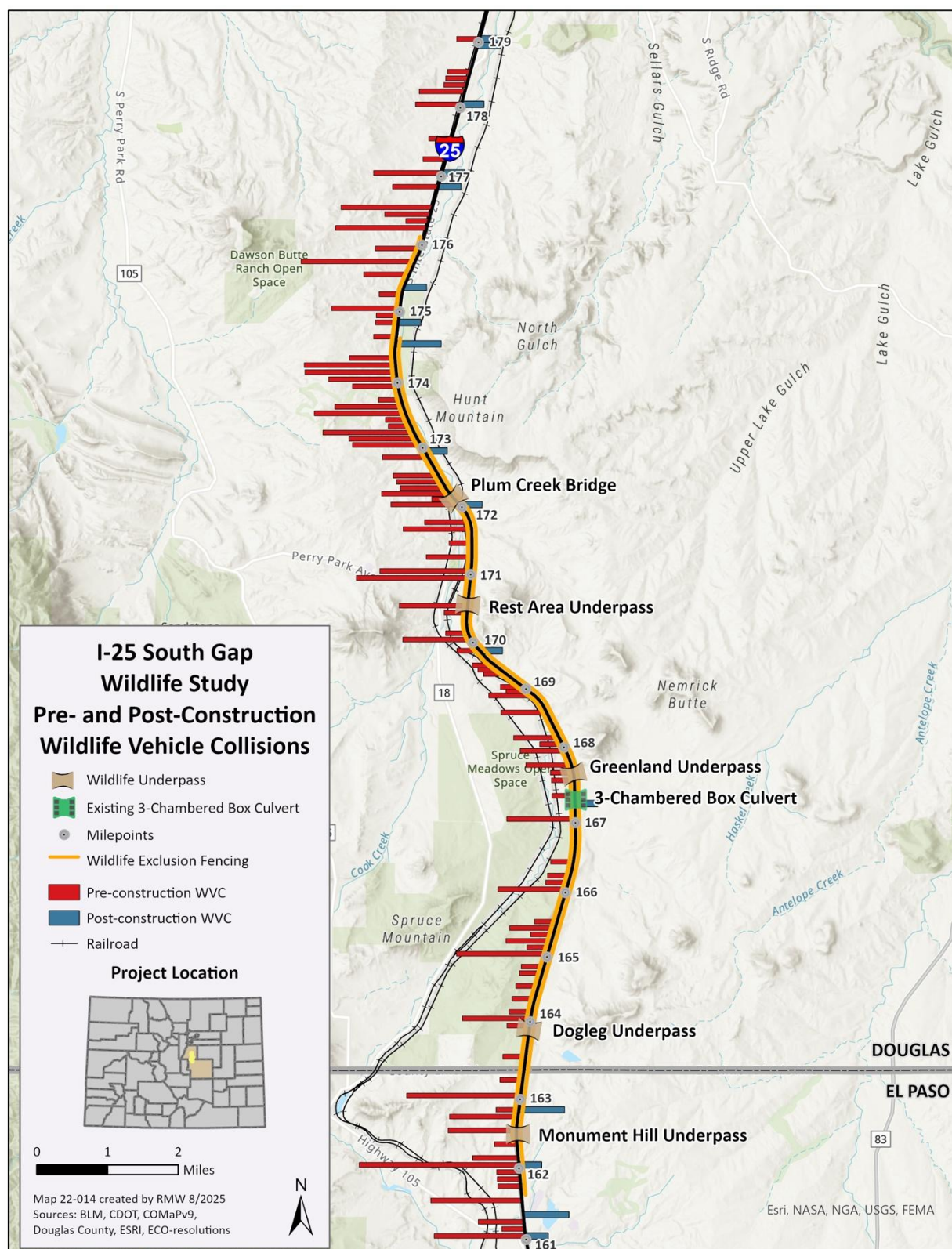


Figure 51. Map of the spatial distribution of pre- and post-construction WVCs.

Due to the increased carcass reporting effort that was initiated by this project and the rolling out of statewide carcass reporting apps by both CDOT and CPW, carcass data are useful for augmenting WVC crash data in identifying problem areas within the mitigated project area, such as at potential breach locations through the wildlife fencing. The combined crash and carcass data highlights several peaks in post-construction WVCs (Fig. 52):

- Around and beyond the south fence end, where the fence ends are offset. On the east side of I-25, the fence ends at milepost 162.1, whereas on the west side of I-25 the fence runs farther south to milepost 161.4 and ties into a short section of sound wall.
- In the northern portion of the project area from milepost 171 to milepost 176. The combined WVC crash and carcass data documented 12 mule deer, six bear and five elk carcasses inside the fenced project area. Additional carcasses were recorded beyond the north fence end.

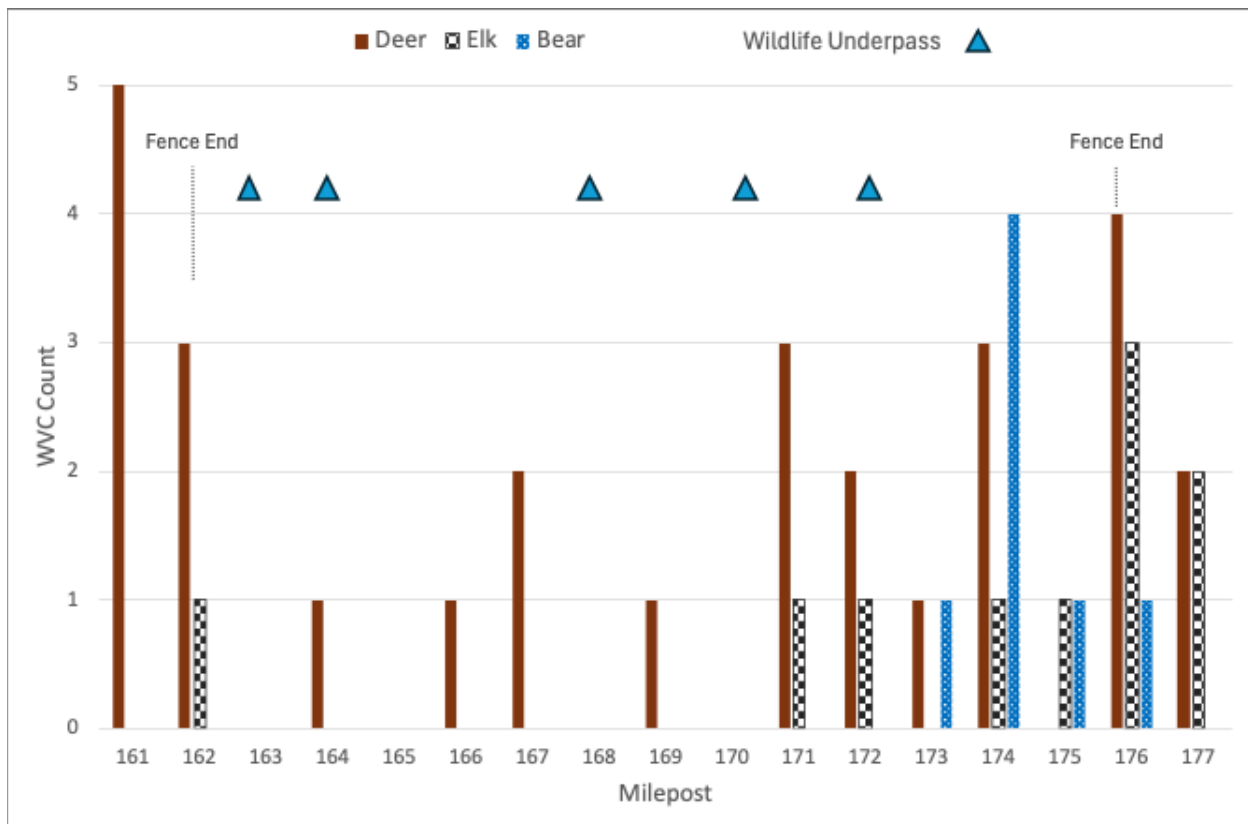


Figure 52. Post-construction WVC reported crash and carcass counts by species and milepost, relative to the approximate locations of the wildlife underpasses and the wildlife fence extent.

9.2. Discussion

9.2.1. Performance Measures Evaluation

In the final year of the study, WVC crashes were 91% lower than the 5-year pre-construction average. On average, WVC crashes decreased on average by 85% during the post-construction monitoring time frame, meeting the goal of a minimum 80% reduction in WVCs (Table 42).

Table 42. Motorist 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 will decrease over time by a minimum of 80% and with a goal of a 90% reduction compared to the five-year preconstruction average.	X	

9.2.2. Effectiveness of the Wildlife Crossings Infrastructure in Reducing Wildlife-Vehicle Collisions

In two years of post-construction monitoring, this study confirmed an average decrease in WVCs of 85%. An initial sharp reduction in WVCs was documented during the 5-year-long construction phase of the project, before all the wildlife underpasses were fully constructed and the wildlife fence was fully installed. Some of this initial decrease may have been due to the construction activities themselves. The carcass dataset, which provides a more robust account of the actual tally of wildlife-vehicle conflict during construction and post-construction, documents a 74% reduction in WVCs from the construction phase to post-construction. Given that the crash dataset documented a 67% decrease from pre-construction to the construction phase, it is extremely likely that a significant decrease would have been evident in the carcass data, had they been available for the pre-construction phase. While WVC rates fluctuate year to year due to environmental conditions and fluctuations in wildlife population, the annual average number of WVCs in the project area is expected to stabilize (e.g., Kintsch et al. 2021).

From a safety standpoint, the WVC mitigation and wildlife connectivity investments were one of the most effective components of the I-25 South Gap project, which was designed to reduce congestion and improve safety through the reduction of all crash types. While WVC crashes decrease an average of 85% post-construction, only overturning crashes were reduced by a comparable amount (87% decline) for collisions with no wildlife involved. Other common crash types declined to a lesser extent, with rear end

and guard rail crashes decreasing by an average of 43% and 30%, respectively. However, sideswipe crashes increased on average by 7%, while concrete barrier crashes increased by over 3,000% post-construction. Overall, the average annual number of all crash types combined decreased 20% relative to the pre-construction annual average.

Ongoing maintenance of the mitigation infrastructure, in particular, the fence, guards and escape ramps, is essential to minimizing wildlife incursions into the fenced highway right-of-way to continue keeping the interstate safe for motorists and wildlife over time.

9.2.3. Factors Influencing Post-Construction Wildlife-Vehicle Collisions

The highest concentration of post-construction WVCs occurred around the fence end in the northern portion of the project area from milepost 171 to milepost 176. There are no wildlife crossings in the northern portion of the project area, from Sky View Lane / Jellystone (MP 173.8) to the north fence end (MP 176.2). Challenging terrain combined with frontage roads on either side of I-25 and the railroad line running adjacent to the west side frontage road hindered efforts to install a suitable wildlife underpass in this section of the project area. The closest safe passage opportunity is at the Plum Creek Bridge Underpass at milepost 172.2. In addition, there are multiple wildlife guards across access roads and driveways in this stretch. With an average ungulate repel rate of 58%, the wildlife guards and the north fence end were likely the primary points of entry for animals in the fenced right-of-way. Abundant wildlife combined with multiple potential breach points and no safe passage opportunities may have led to more attempted breaches into the fenced right-of-way, increasing the potential for WVCs in this stretch of I-25.

At the south end of the project, the fence ends on either side of I-25 are offset, with the west side fence extending seven-tenths of a mile farther than the east side fence. This offset prevents animals traveling from the west from accessing the interstate, but it also creates a potential trap for animals that enter the highway from the east and are forced to turn back due to the west side barrier fence, thus doubling the time they are exposed to a potential WVC. Extending the east side fence to match the west side fence end would help to further reduce collisions in this area.

Chapter 10. Recommendations

Multiple recommendations were derived from the I-25 South Gap monitoring study. These recommendations were developed for maintenance, adaptive management, informing 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.

10.1. Maintenance Recommendations

- Promptly repair broken posts and holes in the fence, especially during peak wildlife activity seasons, to reduce wildlife incursions into the fenced right-of-way and help ensure motorist safety (Fig. 53).



Figure 53. Broken fence post at the Greenland Rd East Wildlife Guard that was down for several months.

- There is evidence of the fill settling on several of the escape ramps such that the fill level is lower than the wood ramp backing. Periodically monitor conditions at every escape ramp and consider adding additional soil to ramps with a height difference greater than 6" between the top of soil ramp and the wood backing

10.2. Adaptive Management Recommendations

- Extend the south fence end on the east side of I-25 to match the west side fence end at milepost 161.4.

- The installation of the wildlife guard on County Line Road on the west side of I-25 was postponed during the construction of the I-25 Gap project and delegated to the County for inclusion with other anticipated roadway projects. This study recommends that the wildlife guard be installed without further delay as a part of upcoming transportation and development projects in this area to eliminate this hole in the wildlife fencing.
- The 2-sided escape ramp on the southbound (west) side of I-25 at milepost 169.4 is only 4'4" high. Determine the best way to increase the height of this ramp to prevent jump ups from the habitat side into the fenced highway right-of-way. Add a bar or board to the top/backside of the ramp to increase the effective ramp height and minimize jump-up attempts.
- While the wildlife guard design with the small grate openings is not optimal, it does not appear to be worth the cost of replacement provided that the total number of ungulate approaches to the guards remains low and the breach rate does not increase.
- Remove the old fence in disrepair that runs perpendicular to the Greenland Underpass on the east side of I-25 to minimize barriers to wildlife movement in the approach to this crossing structure.

10.3. Recommendations to Inform Future Wildlife Mitigation Projects

10.3.1. Crossing Structures

- The small benches on either side of the underpasses provide a slightly raised pathway as an alternative to walking down the middle of the underpass for ungulates and other wildlife. While not specifically tallied, anecdotally, the benches were used by many animals to cross through the structure. Adding small benches to the side slopes of an underpass is recommended for future projects.

10.3.2. Small Fauna Cover Features

- The addition of small fauna cover features in large fauna crossing structures is recommended on all future projects to boost the effectiveness of crossing structures for a much larger diversity of species with the addition of this low-cost mitigation feature.
- Linear small fauna cover features should extend all the way through a crossing structure into the habitat on either side of the crossing and should provide sufficient interstitial space for animals to move between the sticks and branches. The features should measure approximately two-feet

wide by one to one-and-a-half feet tall. Arrange or trim branches so that they are not sticking far out of the cover feature so that large fauna can easily jump over.

10.3.3. Wildlife Guards

- Where wildlife guards with a grate design are employed, the recommended cell size opening is a minimum of 2" x 4", which has been used elsewhere in Colorado, and up to 5" x 5", which is the standard used by the Wyoming Department of Transportation. A grate design is suitable in areas with high bicycle or pedestrian traffic and is most suitable in landscapes without a continuous winter snowpack where snow can become packed in the grate.
- The installation of the incorrect wildlife grates with a small cell size opening was an unfortunate circumstance on the I-25 South Gap project. Despite extensive collaboration between the engineering team and the biology team through project development and design, the incorrect grates were purchased. Additional validation and oversight prior to ordering the grate manufacturing could have prevented this error, which provides a lesson for future projects.

10.3.4. Escape Ramps

- The research team recommends considering a ramp height of 5' with the addition of a bar (see Huijser and Getty 2023) to encourage more successful escapes while continuing to deter ungulates from jumping up into the fenced right-of-way. As a 5' ramp height may not be sufficient for deterring elk jump ups (*pers. comm.* J. Gagnon, 8/28/25), at this time, the 5'-high ramp with a bar is recommended only for projects with mule deer or white-tailed deer.
- In addition, strict adherence to ramp height specifications during construction is necessary with adjustments made as needed to ensure that all escape ramps are built to specifications prior to closing out a project.
- The 2-sided escape ramp design on the I-25 South Gap project was derived from the Utah Department of Transportation and included a 100' length of fencing leading animals up to the ramp. While these 'corral' areas were not specifically monitored as a part of this study, the research team was able to anecdotally observe wildlife activity in the corrals and recommends shortening this fence length to 10' – 25'. There are no apparent benefits to such a long fence corral leading up to a ramp.

10.3.5. Wildlife Fence

- The Geocell fence end treatment was mostly ineffective at deterring ungulate movements into the fenced road corridor and many animals simply walked around the fence end treatment. The combination of guard rail along the pavement edge in addition to the Geocell treatment may provide some added benefit in deterring ungulates from walking around the fence end treatment (see Cramer and Hamlin 2021). Given the low cost of Geocell, a partial deterrent effect may be more beneficial than not having any type of fence end treatment through the clear zone. Erosion control mesh with a smaller opening size may offer a more effective treatment – elk, which have larger hooves, were repelled from the Geocell more often than deer.
- Alternatively, place riprap between the fence end and the edge of pavement, as was done on the State Highway 9 Fortification Creek and high-low fence project north of Craig; or bring the fence end up to the edge of pavement and use break-away posts in the clear zone.

10.4. Recommendations for Future Wildlife Monitoring Research Studies

- Initiate future research studies at the end of construction so that the monitoring period focuses on post-construction data collection. Extended post-construction monitoring periods are necessary to better understand structural preferences and tolerances of species with longer habituation time frames or those whose crossing structure needs remain poorly studied.
- Statistical analyses were unable to discern significant influences on breach rates at the wildlife guards or on intercept and escape rates at the escape ramps. A metanalysis across multiple studies with comparable methods in Colorado and other western states is recommended to reveal more significant associations.
- The use of machine learning computer vision models was very helpful in filtering out false positive photo events that were not triggered by animals. These models are highly recommended to reduce the photo processing workload. Model options should be investigated at the beginning of each study given the constant advancement of computer vision capabilities (e.g. future models may be able to accurately classify certain wildlife species, discern age or sex, or recognize individual animals to reduce double counting individuals).
- Automated data processing increased photo processing efficiency by capturing metadata for each photo event, reducing the workload for data entry technicians.

- As much as conditions allow, individual data technicians should be consistent across years to assure uniform data entry.
- Enterprise database platforms (e.g. SQL Server, PostgreSQL, etc.) with centralized storage are recommended over cloud or locally stored personal databases (e.g. Microsoft Access databases).
- The photo booths at the small fauna cover features were a novel design that proved effective at capturing wildlife use of the cover features. However, the photo booths also captured animals not using the cover features, such as bobcat and birds that were investigating the photo booths themselves. Future monitoring of small fauna cover features should seek to improve the design of the photo booths to minimize these incursions by potential predators.
- Cameras placed at ground level for monitoring at the small fauna photo booths subject to weather events including flooding and icing; however, none of the cameras were damaged by these events.

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Appendix A. Species List

Species detected via camera monitoring. Starred species were observed only at the small fauna photo booths.

Common Name	Scientific Name
13-lined Ground Squirrel*	<i>Ictidomys tridecemlineatus</i>
Badger	<i>Taxidea taxus</i>
Bighorn Sheep	<i>Ovis canadensis</i>
Black Bear	<i>Ursus americanus</i>
Bobcat	<i>Lynx rufus</i>
Bullsnake*	<i>Pituophis catenifer sayi</i>
Chipmunk*	<i>Neotamias quadrivittatus</i>
Cottontail Rabbit	<i>Sylvilagus spp.</i>
Coyote	<i>Canis latrans</i>
Deer Mouse*	<i>Peromyscus maniculatus</i>
Elk	<i>Cervus canadensis</i>
Fox Species	<i>Vulpes spp.</i>
Lizard*	<i>Sceloporus and Phrynosoma spp.</i>
Mallard	<i>Anas platyrhynchos</i>
Mink*	<i>Neogale vision</i>
Moose	<i>Alces alces</i>
Mountain Lion	<i>Puma concolor</i>
Mouse Species*	<i>Onychomys, Perognathus, Peromyscus and Reithrodontomys spp.</i>

Mule Deer	<i>Odocoileus hemionus</i>
Northern Leopard Frog*	<i>Lithobates pipiens</i>
Pocket Gopher*	<i>Geomyidae spp.</i>
Porcupine	<i>Erethizon dorsatum</i>
Preble's Meadow Jumping Mouse*	<i>Zapus hudsonius preblei</i>
Pronghorn	<i>Antilocapra americana</i>
Raccoon	<i>Procyon lotor</i>
Racer*	<i>Coluber constrictor</i>
Shrew Species*	<i>Sorex spp.</i>
Squirrel Species*	<i>Sciurus spp.</i>
Striped Skunk	<i>Mephitis mephitis</i>
Turkey	<i>Meleagris gallopavo</i>
Vole Species*	<i>Microtus spp.</i>
Weasel Species*	<i>Mustela and Neogale spp.</i>
White-tailed Deer	<i>Odocoileus virginianus</i>
Woodhouse's Toad*	<i>Anaxyrus woodhousii</i>
Woodrat*	<i>Neotoma cinerea</i>

Appendix B. Monitoring Locations

Monitoring locations and mitigation specifications are listed in the table below from south to north. For wildlife underpasses, the total structure length includes the median gaps between the bridges supporting the opposing traffic lanes and, where applicable, the adjacent frontage road.

Milepost	Monitoring Location	Mitigation Type	Specifications
162.5	Monument Hill	Wildlife Underpass	59'W x 20'H x 209'L
162.5	Monument Hill	Deer Bridge	Walkway over riprap drainage
163.1	Misty Acres	Wildlife Guard	*Camera stolen, not replaced
164.1	Dogleg	Wildlife Underpass	106'W x 15'H x 144'L
164.1	Dogleg	Cover Feature	
167.3	Andrews Road; northbound	Escape Ramp	Standard ramp, 70"H
167.3	3-Chambered Box	Existing Culvert	12-16'W (each box) x 13.5'H x 183'L (+ adjacent frontage road)
167.4	Greenland Road East	Wildlife Guard	58'W
167.7	Greenland	Wildlife Underpass	107'W x 20' H x 155'L
167.7	Greenland	Cover Feature	
169.4	169.4 southbound	Escape Ramp	2-sided ramp, 52"H
170.6	Rest Area	Wildlife Underpass	107'W x 20'H x 154'L
170.6	Rest Area	Cover Feature	
171.8	Upper Lake Gulch Road East	Wildlife Guard	32'W
171.8	Upper Lake Gulch Road West	Wildlife Guard	30'W
172.0	172 northbound	Escape Ramp	Standard Ramp, 68"H
172.2	Plum Creek	Bridge Underpass	322'W x 20-25'H x 146'L
172.2	Plum Creek	Cover Feature	
173.8	Jellystone southbound	Escape Ramp	Standard ramp, 69"H

Milepost	Monitoring Location	Mitigation Type	Specifications
174.1	174.1 northbound	Escape Ramp	2-sided ramp, 69”H
175.5	175.5 southbound	Escape Ramp	Standard ramp, 60”H
175.6	175.6 northbound	Escape Ramp	2-sided ramp, 68”H
175.7	West Frontage Road	Wildlife Guard	42’W
176.2	North Fence End – East	Fence End	Geocell end treatment

Appendix C. Performance Measures Evaluation

The following table provides a summary of the performance measures evaluation. Parentheses indicate that the measure had been partially met at the time of this reporting.

Performance Measure		Met	Not Met	Chapter Reference
1	Mule deer success movements at each structure will increase over time with a minimum of success rate of 80% and a goal of 90%.	(X)		Chapter 3
2	The number of successful elk passages at all structures will be at least 50% of the number of elk movements captured at associated control (habitat) cameras.		(X)	Chapter 3
3	Elk success movements at each structure will increase over time with a minimum success rate of 70% and a goal of 80%.	(X)		Chapter 3
4	Mule deer movements east-west through the crossing structures will be roughly equivalent to west-east movements.	X		Chapter 3
5	Over time, mule deer and elk movements through the crossing structures will be represented by males, females, and juveniles.	X		Chapter 3
6	Successful passages through the crossing structures by less common species will remain constant or increase over time (e.g., pronghorn, white-tailed deer, mountain lion, black bear, bobcat).	(X)		Chapter 3 Chapter 4

7	The proportion of ungulate movements at the northeast fence end that enter the fenced right-of-way will decrease to 20% or less.	X		Chapter 8
8	Over time, detections of ungulates attempting to breach wildlife guards to enter the road right-of-way will decrease and ungulates will be deterred from entering the road right-of-way at least 80% of the time.	(X)		Chapter 6
9	Over time, ungulate detections at escape ramps will decrease;		X	Chapter 7
	of ungulates that ascend an escape ramp the proportion that successful escape to the habitat side will increase;		X	Chapter 7
	and no ungulates will jump up onto the ramp from the habitat side.	X		Chapter 7
10	The annual average number of reported WVC crashes (CDOT Traffic and Safety data) within the mitigated area will decrease over time by a minimum of 80% and with a goal of a 90% reduction compared to the five-year preconstruction average.	X		Chapter 9