FINAL REPORT WY2308F
Evaluating Wildlife Use of the South Jackson Project Highway Crossing Structures: Project Phase I

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WYDOT Project Champion:

Dr. R. Scott Gamo
Environmental Services Manager
5300 Bishop Blvd.
Cheyenne, WY 82009

Prepared by:

Dr. Hannah Specht, Research Scientist
Dr. Joshua J. Millspaugh, Boone and Crockett Professor
University of Montana
Missoula, MT

Submitted to:

Wyoming Department of Transportation
Programming Research Unit
5300 Bishop Blvd.
Cheyenne, WY 82009

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16. Abstract

Roadways have the potential to negatively impact wildlife populations directly through vehicle collision mortality and indirectly through habitat fragmentation. The Wyoming Department of Transportation installed wildlife crossing structures and wildlife on US 89 between along a 3.6 mile stretch between Jackson and Hoback Junction to mitigate these impacts. In the three years after construction was completed (Nov 2019-2022), there were 6,156 recorded, independent events representing 18,918 animals where wildlife approached and/or used the underpasses. The most common species using the underpasses were mule deer, white-tailed deer, elk and coyotes. Of these, elk exhibited the greatest seasonality in underpass use, primarily during the overwinter period. Vehicle collisions with large ungulates were reduced by an average of 75 percent annually within the project area. Collision reductions represent an annual estimated cost savings of $411,089. These findings provide evidence that the fencing and underpasses included in Phase 1 of the South Jackson Project improved highway safety for motorists while facilitating animal movement across the roadway.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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LIST OF ABBREVIATIONS

EIS	Environmental Impact Statement
NEPA	National Environmental Policy Act
WYDOT	Wyoming Department of Transportation

EXECUTIVE SUMMARY

Roadways have the potential to negatively impact wildlife populations directly through vehicle collision mortality and indirectly through habitat fragmentation. As a state with a substantial wildlife recreation economy, wildlife collisions and road-based wildlife habitat fragmentation bear particular costs to human communities, with costs associated with collisions amounting to thousands of dollars per incident and fragmentation affecting wildlife-based recreation opportunities. The Wyoming Department of Transportation (WYDOT) has installed wildlife fencing with wildlife crossing structures over recent years in association with highway construction projects in order to mitigate these impacts. The South Jackson project is a recent example of this continued effort, with fencing and eight crossing structures included in the design, determined through collaboration with Wyoming Game and Fish, interested Non-Governmental Organizations and the public. Phase I of the South Jackson Project encompassed US 89 mile posts 145.08 to 148.70, with crossing structures at mileposts 147.58 (hereafter “North Yard”) and 146.39 (hereafter “Flat Creek”).

This study evaluated wildlife use of the crossing structures over a three-year post-construction period using game cameras to validate the use of the placed structures. Cameras were mounted on both sides of underpasses, providing two opportunities to detect animals using the crossing structures and reducing the chances that crossing structures would go unmonitored if any single camera failed. Photo sequences of animal approaches were grouped within and across cameras based on the species and proximity in time into independent wildlife crossing events. The outcomes of each crossing event were tallied given the best available photo evidence. Timestamp data from the crossing events was used to examine species-specific temporal patterns of underpass activity using kernel density estimation. The study design feature wherein multiple cameras monitored the same underpass was used to evaluate the camera set up, revealing improvements in detecting animal crossing events when camera angle maximizes intersection of animal movement pathways and trigger zones and when at least 3 cameras are used on wide crossing structures. There were 6,156 recorded, independent events where wildlife approached and/or used the underpasses over the three years post-construction. These events represented 18,918 animals, 71 percent of which were assessed to have crossed through the underpasses, with outcomes for 23 percent undetermined. The most common species using the underpasses were mule deer, white-tailed deer, elk and coyotes. Of these, elk exhibited the greatest seasonality in underpass use with use constrained pretty strictly to the overwinter period.

Georeferenced collision data for the project area and adjacent, comparable highway segments were used to evaluate changes in reduction rates over the three-year post-construction monitoring period. In the three years post-construction, vehicle collisions with large ungulates (deer, pronghorn, elk and moose) were reduced by an average of 75 percent annually within the project area. Collision reductions represent an annual estimated cost savings of $411,089.

These findings provide evidence that the fencing and underpasses included in Phase 1 of the South Jackson Project improved highway safety for motorists while facilitating animal movement across the roadway. Additionally, this work demonstrated the utility of an underpass camera monitoring design where cameras are used at both ends of wildlife crossing structures, facilitating model-based estimation of conditions that result in wildlife crossings being undetected.

CHAPTER 1. INTRODUCTION

Roadways have the potential to negatively impact wildlife populations directly through vehicle collision mortality (Farrell et al. 2002, Litvaitis and Tash 2008) and indirectly through habitat fragmentation (Forman 2000, Lesbarrères and Fahrig 2012). To mitigate impacts to wildlife from roadways and to make potential roadway barriers more permeable, transportation planning authorities and wildlife manager have constructed underpasses, and overpasses with associated fencing to reduce habitat fragmentation and vehicle collisions. Evidence has shown that these wildlife crossing structures can help mitigate impacts to wildlife populations and improve safety for motorists (Mccollister and Van Manen 2010, Sawyer et al. 2012, Huijser et al. 2016). However, there is temporal and spatial variability in their success that necessitates site and species-specific work (Clevenger and Waltho 2000, Mccollister and Van Manen 2010). Furthermore, research has also shown that intended benefits of crossing structures will not be attained if structures are not constructed correctly, sited appropriately, or accompanied by adequate fencing (Reed et al. 1975, Clevenger and Waltho 2000, Clevenger et al. 2001).

Species specific differences in wildlife use of crossing structures is evident in the literature. For example, Gagnon et al. (Gagnon et al. 2011) monitored 6 wildlife underpasses in Arizona and found that structural attributes, placement, time of day, and months monitored were important to initially explain elk (*Cervus canadensis*) usage of underpasses. Four years later, only structural attributes and placement were important to explain successful elk usage, with the probability of successful usage increasing from 0.44 to 0.75 through the monitoring period. In contrast, successful usage of underpasses by white-tailed deer (*Odocoileus virginianus*) only depended on structural attributes and placement and the likelihood of successful usage did not increase through time. Along U.S. Highway 191 in Wyoming, 79 percent of mule deer (*Odocoileus hemionus*) crossings were under the highway, whereas 93 percent of pronghorn (*Antilocapra americana*) were over the highway (Sawyer et al. 2016). Also along U.S. Highway 191, researchers found that the benefits of crossing structures increased through time with pronghorn behavior gradually showing signs of acclimating to structure presence through increased use (Seidler et al. 2018). Recent literature has shown that variability among species, landscape attributes, and time that crossing structures have been present on the landscape create the need for individual, multi-year monitoring to assess the success of roadway mitigation projects to benefit wildlife.

1.1 Study Objectives

During Phase I of the South Jackson project along U.S. Highway 89, WYDOT installed wildlife crossing structures at two locations, accompanied by wildlife fencing. The entire South Jackson project will ultimately include 8 wildlife crossing structures, which, taken together, will provide insight into crossing structure use by different species that inhabit this landscape. Through the development of an Environmental Impact Statement (EIS) the South Jackson project evaluated impacts to vehicle traffic, municipal economics, and potential impacts to endemic wildlife. As part of the National Environmental Policy Act (NEPA) process with the EIS, wildlife use of the structures was to be evaluated for three years post construction to validate the actual use of the placed structures. To fulfill the obligations of monitoring provided within the EIS, this study associated with Phase I of the South Jackson Project examines use of the wildlife crossing structures and evaluates changes in collision rates.

Our objectives were to:

- Evaluate the functionality of the installed wildlife crossing features of the South Jackson project in facilitating wildlife crossing of the roadway
- Evaluate the level of use to better describe the success/failure with these structures
- Evaluate changes in collision rates in the project area to understand the relative success/failure of the combination of fencing and crossing structures.

Ultimately, these evaluations will meet the monitoring requirements as provided in the South Jackson EIS and will also help inform future wildlife crossing structure mitigation effort across Wyoming.

1.2 Study System

Phase I of the South Jackson Project included two crossing structures, placed at mileposts 147.58 (hereafter “North Yard”) and 146.39 (hereafter “Flat Creek”). The North Yard underpass was constructed as a dedicated wildlife passage, measuring 30.5 m wide (100 ft), 27.4m long (90 ft), and 1.5-3.9m tall (5-13 ft) (Figure 1, Figure 2-A) and occurred where a natural valley in the hills to the east of the highway met the road. The second underpass location, at Flat Creek, took advantage of an existing bridge over a creek, providing a passage on either side of the creek— these two passages are each 1.5-3m (5-10 ft) wide, 30.5m (100 ft) long and 3m (10 ft) tall (Figure 1, Figure 2-A. Wildlife fencing was placed from milepost 148.70 (South Park Loop Road) on the north end of the project to milepost 144.99 (Swinging Bridge Road) on the south end of the project (Figure 1). Average daily traffic volume on this segment of road increased steadily over the 20 year period in advance of construction (Route 10, mileposts 148.709-149.784, all vehicle daily traffic volume increase from 6,800 in 1998 to 13,121 in 2018; (Wyoming Department of Transportation 2021) and wildlife vehicle collisions, while exhibiting greater inter-annual variation, also increased over the same period (Jackson Hole Wildlife Foundation 2023). The combination of wildlife fencing and wildlife crossing structures has been shown to reduce collisions while retaining and facilitating animal movement across the road (Gagnon et al. 2015, Huijser et al. 2016).

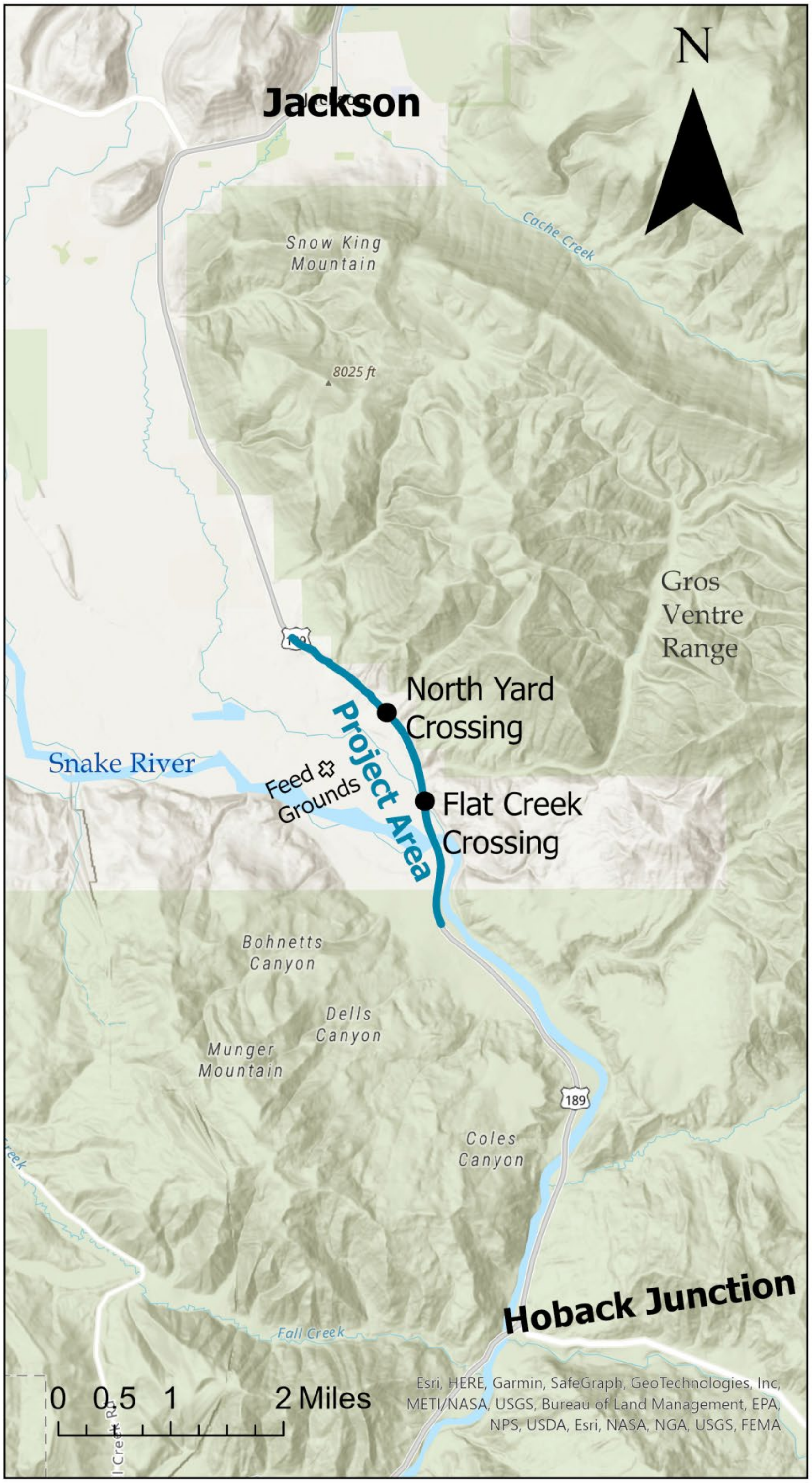


Figure 1. Map of the Phase I project area on Highway 89 between the town of Jackson to the North and Hoback Junction to the South. The crossing structure locations are marked with dark circles. Many ungulates use the South Park feed grounds (X) overwinter.

CHAPTER 2. DATA COLLECTION AND ANALYSIS METHODS

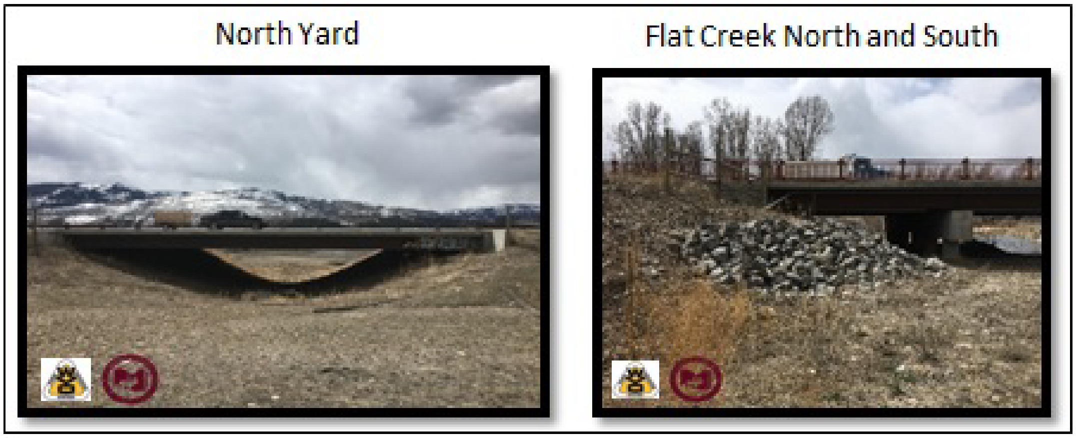
2.1 Part 1: Wildlife Crossing Structure Monitoring

2.1.1 Camera trap set up

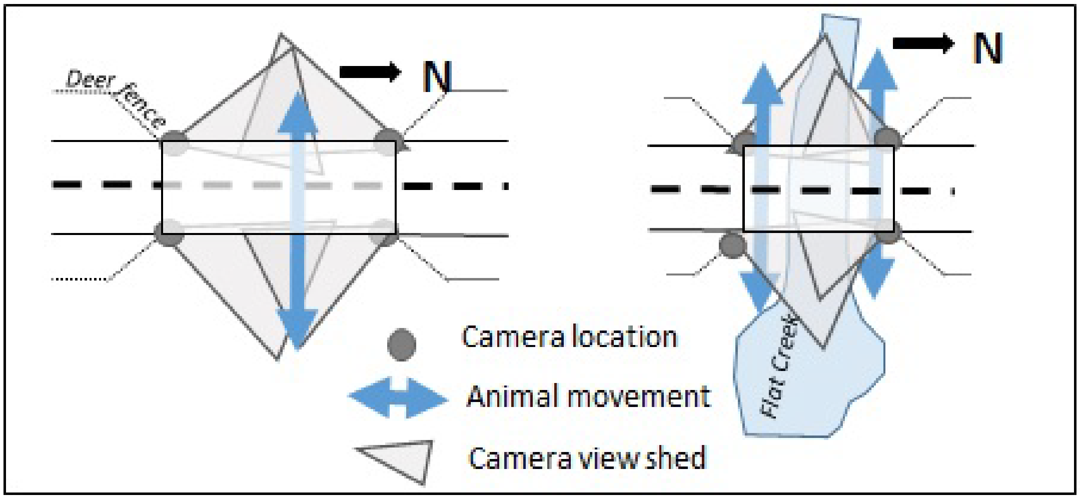
We placed Reconyx Hyperfire 2 (Reconyx, Holmen, WI) at both ends of each crossing structure to assess wildlife movements and use of the crossing structures. Cameras were mounted and secured to bridge girders or adjacent wildlife fencing (Figure 2-B). Cameras were angled such that the trigger zones intersected the movement pathways of crossing animals to maximize the chances that the cameras would trigger (Figure 2-A). Cameras were set to take 10 rapid-fire photos when motion-triggered with no break period between successive trigger events and to take a single photo every 12 hours to verify camera function. Cameras were checked every two to six months to swap SD cards and replace batteries. Cameras were deployed from November, 15 2019 to November 15, 2022. Cameras, attached to bridge girders (Figure 2-C) were initially angled perpendicular to the direction of movement. This arrangement was adjusted in April 2021 (half way through the study period) to maximize the intersection of the trigger zone and animal movement pathways. At this time, the camera arrangement at North Yard underpass was increased from cameras on the southwest and southeast corners to cameras at all four corners, again, to improve detection of animal movement.

2.1.2 Photo processing

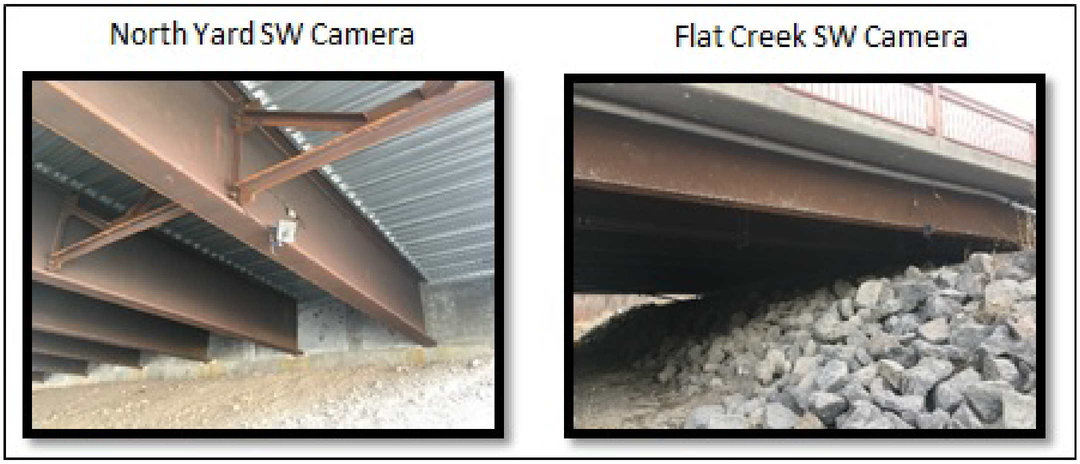
We processed photos from triggered sequences using Timelapse software (version 2.3.0.6; Greenberg et al. 2019), recording species, number present and predominant behavior in each photo. We were not interested in nor did we obtain research authorization to study human use; as such, photos of humans captured on cameras were excluded from analyses.



A. Subfigure depicting underpasses at North Yard and Flat Creek locations.



B. Subfigure diagram depicting camera locations at North Yard and Flat Creek underpasses.



C. Subfigure of photos depicting cameras mounted to bridge girders at North Yard and Flat Creek underpasses.

Figure 2. Camera traps used to monitor the North Yard and Flat Creek wildlife crossings were placed at both sides of the crossing structures (a). Cameras were mounted to bridge girders (b, c) and angled so that movement would reliable trigger them (b,c).

Species such as elk, mule deer, and white-tailed deer that cause upwards of one hundred collisions annually on this stretch of Interstate 89 (mean 93.5 from 2013-2019; Teton County Wildlife-Vehicle Collision Database (2022) 2023), and were anticipated to make up the majority of wildlife crossing structure users. These species often move in groups, meaning that individual animal use of the crossing structures would not be behaviorally independent. We therefore sought to identify independent wildlife crossing events by a group of animals; in the case of a lone animal, a crossing event would be defined by the movement of that individual. This would allow us to provide information about wildlife crossing structure use about both groups and individual animals. We defined the time beyond which photos from the same underpass and species should be considered as independent crossing events based on the absence of temporal autocorrelation as indicated by lorelograms built from the first photos from each 10-photo sequence (Iannarilli et al. 2019, R Core Team 2023). We conducted lorelogram analyses for elk, mule deer, and white-tailed deer (the three species for which there were frequent enough crossings to conduct these analyses) using the first 6 months and year of data, finding that the time to independence was between 10-15 minutes for each. As such, we grouped photos of the same species from all cameras associated with an underpass that were separated in time by less than the species-specific time to independence into one event. Across all photos associated with an event (including across multiple cameras), we evaluated the directionality of the animals associated (east vs. westbound), the number of individual animals in a group (based on the maximum number of unique individuals detected as part of the event from the perspective of a single camera), and the event outcome(s). We did this first within cameras and then across cameras, where outcomes were informed from the best information across cameras, where potential outcomes are “transmission” (successful crossing), “reflection” (an animal turned around before crossing) or unknown (Figure 3). For example, we derived the total number of animals from the maximum seen on one camera as part of a given event; if the east camera detected five unique westbound individuals entering the underpass and the west camera detected three individual westbound animals exiting the underpass, we characterized that event as having five animals and five transmissions (three of which were detected on both sides); the remaining two animals were not counted as reflections because they were not observed turning around or exiting the same side of the underpass. If a photo sequence of animals ended before animals finished entering an underpass, the outcomes for those animals were assigned as “unknown” but could be changed to “transmission” if they were detected exiting on the other side of the underpass

Estimating time-to-independence allowed us to associate photo data across cameras monitoring the same animal crossing structure so as to not double-count groups of animals captured on both cameras, as well as providing a means by which to estimate the proportion of missed crossing events (via considering cameras on each end as independent observers and using capture-recapture based analyses).

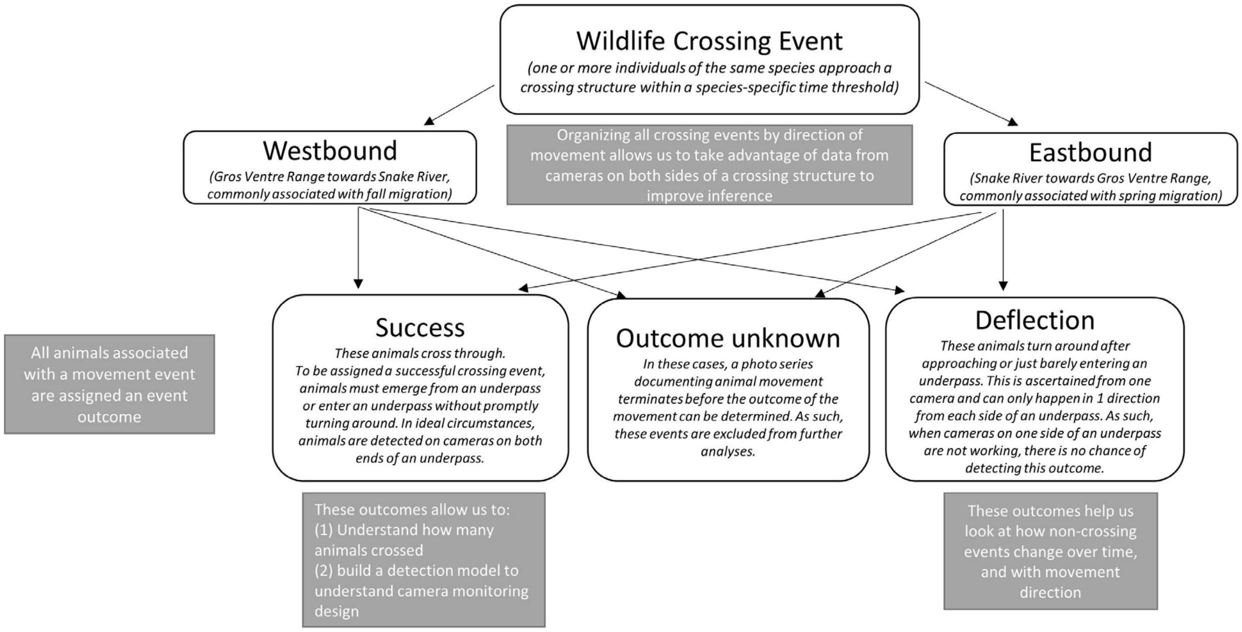


Figure 3. Data organization framework for understanding wildlife crossing events from photos derived from cameras mounted on both sides of underpasses.

2.1.3 Photo Data Analyses

All data analyses were performed in R software (version 4.3.1; R Core Team 2023). We used summarized camera event data to identify the date of first crossing event for each species at each underpass, the total number of crossings and reflections by each species in each year and variation in these parameters relative to site, movement direction and year since construction.

We used a Bayesian implementation of a closed population model with individual covariates on detection (Royle 2009) to evaluate the probability of detecting wildlife crossing events for the most common species, mule deer, and assess camera set up at each underpass. For this model we included covariates on detection probability, including animal group size, direction of movement, and ambient temperature. We hypothesized that larger groups would have more opportunities to trigger cameras, that animals moving different directions might follow different paths through underpasses with different trigger probabilities, and that warm blooded animals would be more likely to trigger infrared sensors in colder ambient temperatures. Covariates were scaled by the mean and standard deviation and devoid of concerning correlation (correlation coefficients <0.5). We were not able to include covariates on the state variable (crossing event occurrence) in this model, such as time since construction, because we could not supply covariate values for undetected events.

We used univariate kernel density estimation to characterize temporal patterns of annual underpass use for species with more than 50 underpass events (Taylor 2008, Ridout and Linkie 2009, Lashley et al. 2018).

2.2 Part II: Wildlife Vehicle Collisions

2.2.1 Data Analyses

We used collision data from Jackson Hole Wildlife Foundation’s Teton County Wildlife Vehicle Collision dataset to conduct collision analyses (Jackson Hole Wildlife Foundation 2023). This dataset combines data from Wyoming Department of Transportation (Crash and Carcass Pick-up Data), Jackson Hole Wildlife Foundation’s Roadkill Hotline and Nature Mapping, and Wyoming Game and Fish Department’s Wildlife Observation System. This georeferenced, compiled dataset has been screened for replicate observations and information from such replicated observations is combined into a single record. In this way, this dataset provides a more complete representation of collisions (and thus collision mitigation) in the project area than any single dataset.

To identify changes in collisions associated with the South Jackson Phase 1 project, we used data from 2013 through 2022, providing data for five years pre-construction and three years post construction. While wildlife fencing and crossing structures facilitate safe movement of all manner of animals across roads, collision datasets predominantly reflect species large enough to cause economic harm to humans, namely ungulates—as such, collision analyses focused on deer, elk, moose (*Alces alces*), and pronghorn. To provide spatial and temporal references for evaluating changes in collisions from the project area, we replicated analyses for similar-length stretches of road to the north (to the intersection with Hwy 22) and south (to Hoback Junction). Dataset releases run through spring of each year, corresponding to the end of the ungulate overwintering and peak collision season (December through April); however this is offset from the three-year post construction monitoring timeline (November through November). As such, we were able to assess post-construction changes in collisions for two and one half years.

To evaluate mitigation of wildlife vehicle collisions associated with the South Jackson Project, we calculated the difference in collisions in the project area post-construction relative to a six-year average pre-construction. Wildlife are known to follow wildlife fencing to fence ends; where there are not crossing structures at fence ends, this results in spatially concentrated collisions near fence ends (Clevenger et al. 2001). In our calculation of mitigated collisions, we considered any collisions occurring within 500m of fence ends to be associated with the project area (Clevenger et al. 2001). We calculated the mitigated costs associated with collisions following methods of Huijser et al. (2009), adjusted for inflation to 2023 dollars; for these analyses, we estimated the total number of collisions for the 12-month period running from November 2021 through November 2022 based by dividing the 6-month data (November 2021 through April 2022) by the proportion of annual collision that occur in November to April over a 10-year period (this proportion was 0.65). To assess whether observed changes in collisions within the project area reflected inter-annual variation in collision rates or changes likely driven by the South Jackson Project, we compared the temporal changes in collision rates (collisions per km) from the project area to the sections of road to the north and south.

CHAPTER 3. RESULTS

3.1 Part I: Wildlife Crossing Structure Use

3.1.1 Characterization of Camera Monitoring Data

We processed 544,508 photos taken between November 15, 2019 (when cameras were deployed at all underpass sides) and November 15, 2022 (three years later). Camera data collection was interrupted in 2020, when the corona virus pandemic travel restrictions resulted in a prolonged period where SD cards and batteries could not be replaced, and several cameras died or SD cards were filled. Operation of individual cameras was interrupted in several other circumstances when SD cards were filled, batteries died, or camera angle was tampered with (Figure 4). As such, all underpasses had periods where they were monitored by only 1 camera, or not at all. Due to time and budget constraints on photo processing, there were some stretches of photo data from the North Yard underpass that were not processed when adequate data were provided by other cameras at the same crossing structure.

3.1.2 Crossing event characterization

There were 6,156 recorded events where wildlife approached and/or used the underpasses over the three years post-construction, representing 18,918 animals. Transmission events of at least one animal occurred in association with 85% (5,243) of events, reflections of at least one animal in association with 11% and 37% of events included an unknown outcome for at least one animal. The transmission rate across all animals was 71.0% with the majority of remaining outcomes undermined (22.6%).

Of the recorded events, 43% (2,649) were captured by cameras on both sides of an underpass. The proportion of events with associated reflections decreased across years for westbound movements (from 16 percent to 10 percent, chi-squared= 16.528, $p<0.01$) but remained constant for eastbound movement across years (7.5 to 6.4 percent, chi-squared=0.666, $p=0.41$). A greater proportion of unknown individual outcomes occurred at Flat Creek than North Yard. Additionally, the rates of undetermined outcomes were much higher for smaller animals than larger animals.

Closed population models for mule deer crossings at each underpass provided estimates specific to each underpass of the probability of detecting an ungulate crossing event before and after changes to camera set up. Estimates of the probability of detection of mule deer crossing events at the underpass scale averaged across all days in the study period were 0.77, 0.64 and 0.54 at North Yard, Flat Creek North and Flat Creek South respectively (Figure 5). Across all three locations, the probability of detecting a mule deer crossing event on at least one camera when all cameras were running improved after changes were made to the camera arrangement (Figure 6). Across all sites, the probability of detecting a crossing event increased when there were more animals in the group (100 percent of posterior distribution of coefficient > 0 across all sites).

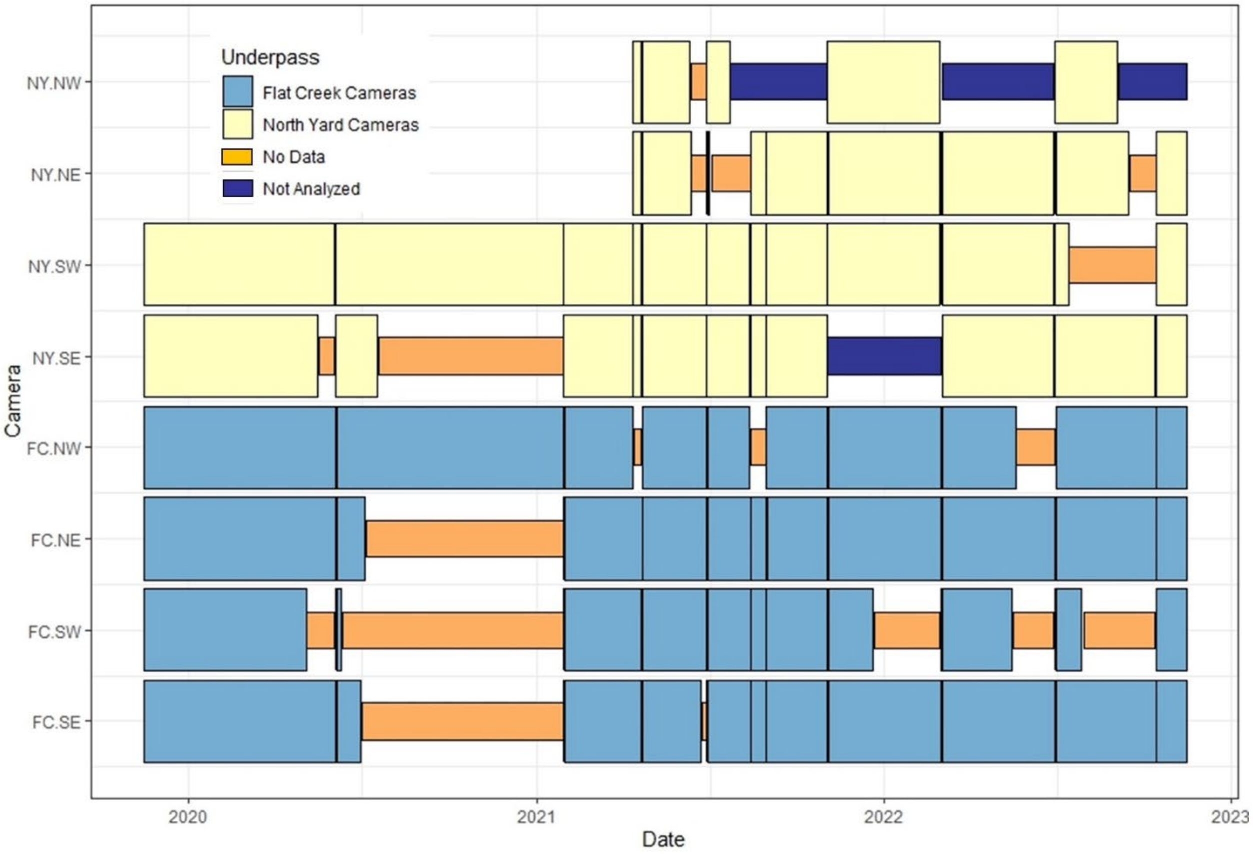


Figure 4. The three underpasses were monitored with six cameras (two each) from Nov 2019-Apr 2021, and with two additional at North Yard until Nov 2022. During some periods, data were unavailable (narrow bars with light shading), or not analyzed (narrow bars with dark shading). Camera names are designated using a four-character code, wherein the first two characters communicate location (FC= Flat Creek and NY= North Yard) and the second two characters communicate the cardinal direction at which the camera was mounted on the underpass (e.g. SE= Southeast).

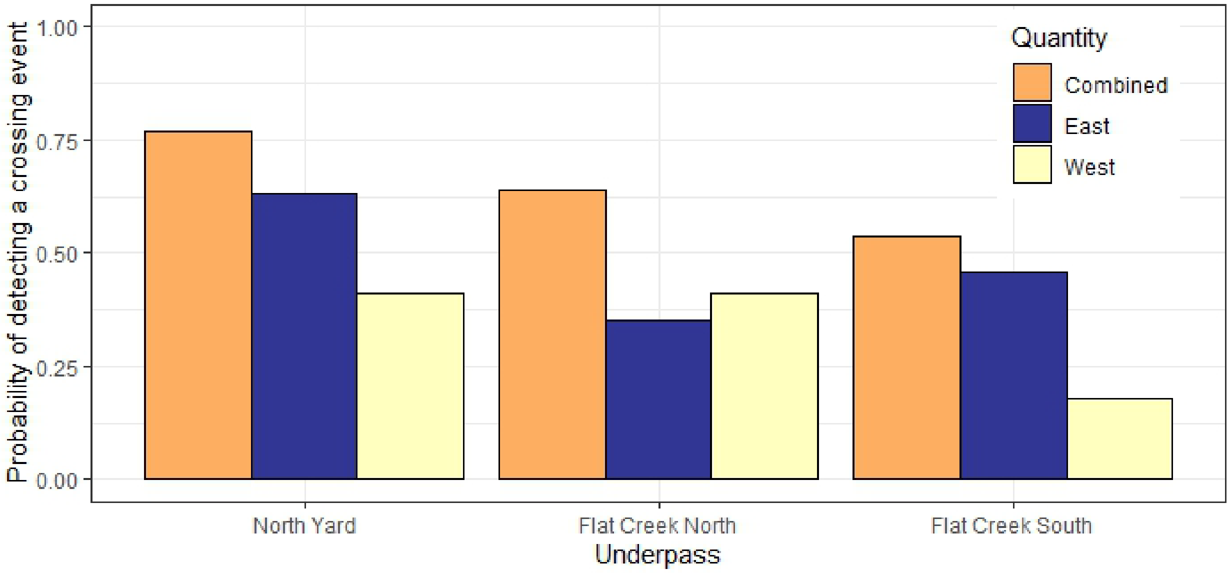


Figure 5. The mean daily probability of detecting a mule deer crossing events for east-side cameras, west-side cameras and their combined probability. Probabilities are higher where cameras were operational for more of the study.

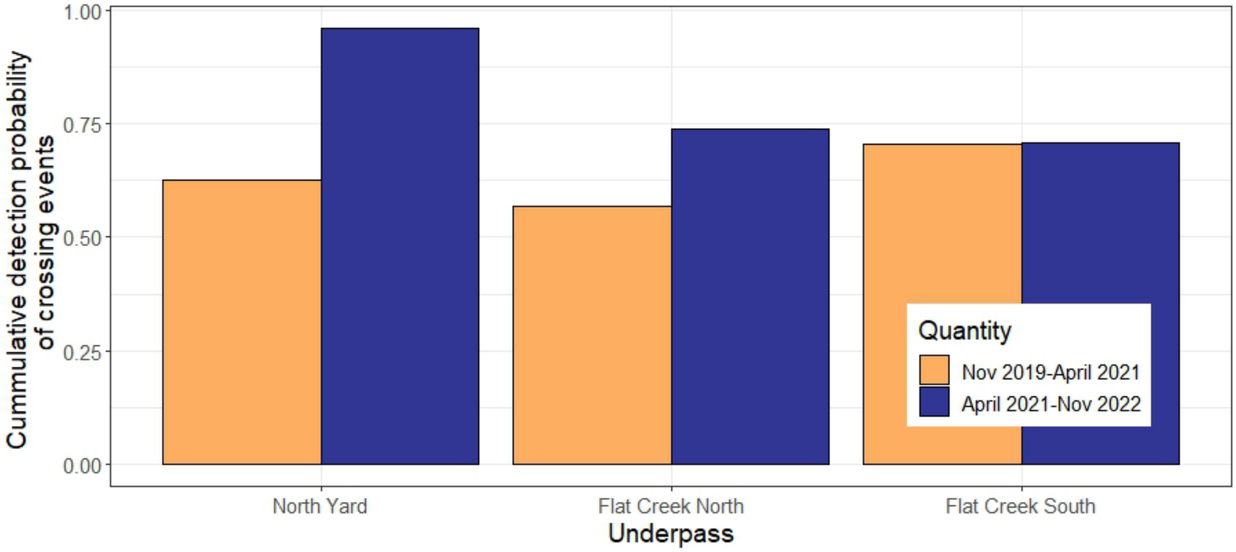


Figure 6. The probability of detecting a mule deer crossing event on at least one camera at an underpass before and after camera set up was changed in April 2021. At all three underpasses, changes to camera arrangement improved detection probability.

3.1.3 Species composition

Eight wildlife species were observed using the North Yard underpass, and twelve were observed using the Flat Creek underpass (Table 1). Notable absences to the wildlife community of underpass users included black bears (*Ursus americanus*) and pronghorn. Bears were observed to cross US 89 along Flat Creek before the crossing structure was constructed while pronghorn were observed to approach US 89 at the location of the North Yard underpass prior to construction (based on camera-trap monitoring conducted by the Greater Yellowstone Coalition prior to construction).

Table 1. First crossing dates by species at each underpass.

Species (Common Name)	Species (Scientific Name)	North Yard	Flat Creek North	Flat Creek South
American badger	*Taxidea taxus*	15-Apr-2021	NA	NA
Coyote	*Canis latrans*	28-Jun-2021	7-Oct-2020	31-Jan-2020
Elk	*Cervus canadensis*	30-Dec-2019	12-Jan-2020	28-Dec-2019
American mink	*Neogale vison*	NA	14-Jun-2021	NA
Moose	*Alces*	28-Dec-2019	11-Jan-2021	NA
Mountain lion	*Puma concolor*	NA	24-Jan-2020	28-Jan-2020
Mule deer	*Odocoileus hemionus*	16-Nov-2019	18-Nov-2019	16-Nov-2019
Muskrat	*Ondatra zibethicus*	NA	NA	7-Mar-2020
Raccoon	*Procyon lotor*	NA	24-May-2020	27-Apr-2021
Red Fox	*Vulpes*	26-Nov-2019	25-Nov-2019	19-Mar-2020
Striped skunk	*Mephitis*	4-Nov-2021	15-Apr-2020	NA
White-tailed deer	*Odocoileus virginianus*	19-Dec-2019	20-Nov-2019	18-Nov-2019

3.1.4 Species abundance

Mule deer were the most abundant of 12 wildlife species observed using the crossing structures, followed by white-tailed deer, elk, and coyotes (*Canis latrans*; Table 2). Several species were primarily observed at one site; badgers, coyotes, and moose predominantly used the North Yard underpass while mountain lions, raccoons, and white-tailed deer predominantly used the Flat Creek underpasses.

At North Yard, more observed reflections (cases where animals turned around before crossing through the underpass) occurred by eastbound animals while at both Flat Creek Crossings, more reflections occurred by westbound animals (Table 3). Many more animals hesitated or turned around upon approaching underpasses before eventually crossing- those animals are not shown the in the data as “reflections” but rather as “transmissions”. The apparent transmission rate (transmissions per camera-day) increased across years since construction (Figure 7), driven primarily by crossings of the most common species, mule deer.

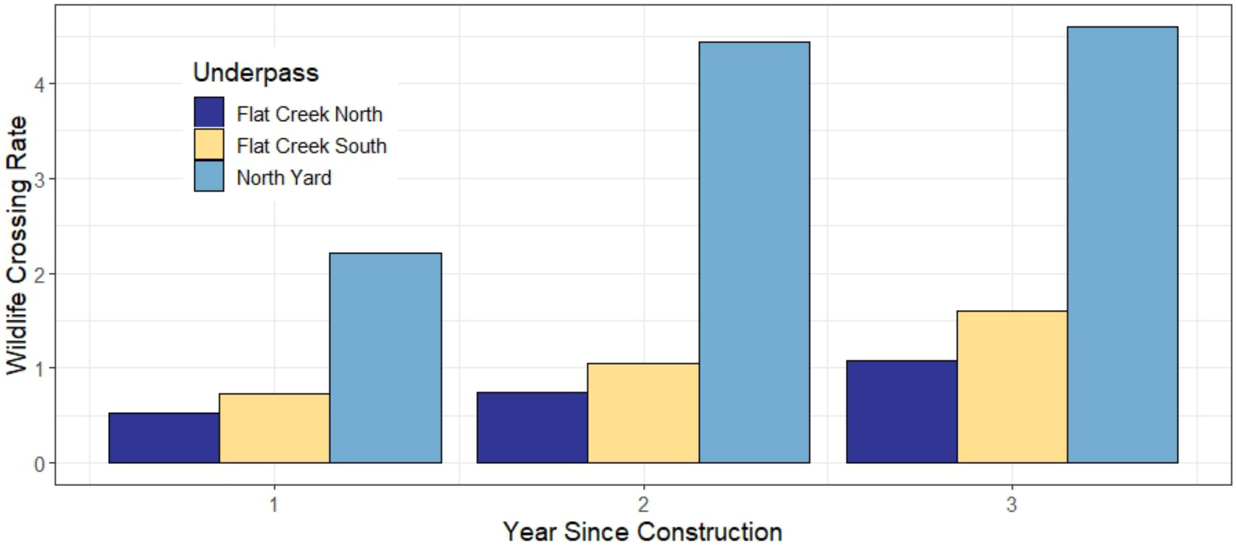


Figure 7. The rate of wildlife transmissions at each underpass location in each of the first three years post-construction, relative to the number of camera-days at that underpass in that year. These findings are driven primarily by mule deer.

Table 2. The total number of wildlife crossings ("transmissions") through US 89 Phase I underpasses between November 15, 2019 and 2022.

Species	**North Yard Transmissions**		**Flat Creek North Transmissions**		**Flat Creek South Transmissions**	
Direction	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
American badger	4	1	0	0	0	0
Coyote	137	101	3	1	2	1
Elk	89	132	33	30	18	28
American mink	0	0	0	0	0	1
Moose	11	13	0	1	0	0
Mountain lion	0	0	23	27	5	9
Mule deer	4754	4945	820	921	643	766
Muskrat	0	0	0	0	0	2
Raccoon	0	0	19	39	3	4
Red fox	34	19	12	14	1	7
Skunk	1	0	2	5	0	1
White-tailed deer	8	3	172	185	114	115
Directional Totals	**5038**	**5214**	**1084**	**1223**	**786**	**934**
Underpass Totals	**10252**		**2307**		**1720**	

Table 3. The total number of animals that "reflected" (approached the entrance to an underpass but turned around and did not cross through during that event) at US 89 Phase I underpasses between November 15 2019 and 2022.

Species	**North Yard Reflections**		**Flat Creek North Reflections**		**Flat Creek South Reflections**	
Direction	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbounc
American badger	0	0	1	0	0	0
Coyote	7	3	2	2	0	2
Elk	18	6	11	5	2	1
American mink	0	0	0	0	0	0
Moose	1	0	1	0	0	0
Mountain lion	0	0	0	0	0	1
Mule deer	274	228	41	99	19	109
Muskrat	0	0	0	0	0	0
Raccoon	0	0	1	0	0	0
Red fox	2	0	1	1	0	3
Skunk	0	0	2	0	0	0
White-tailed deer	0	0	6	3	13	8
Directional Totals	**302**	**237**	**66**	**110**	**34**	**124**
Underpass Totals	**539**		**176**		**158**	

3.1.4 Activity patterns

Common species showed seasonal patterns of activity at the underpasses (Figure 8). Elk exhibited greatest activity at the underpasses during the period when they are typically in the valley (late fall through spring), with an abrupt arrival in the fall, but a more dispersed departure in the spring. Mule deer showed peaks of activity during the summer and late fall, and white-tailed deer showed a peak in use over-winter through early spring. Mountain lions (*Puma concolor*), which frequented the Flat Creek underpasses in the first year post-construction but not after, showed a peak of activity in the winter and early spring while coyotes and foxes started regularly using the underpasses later during the monitoring period, and showed peaks of activity in the winter and fall.

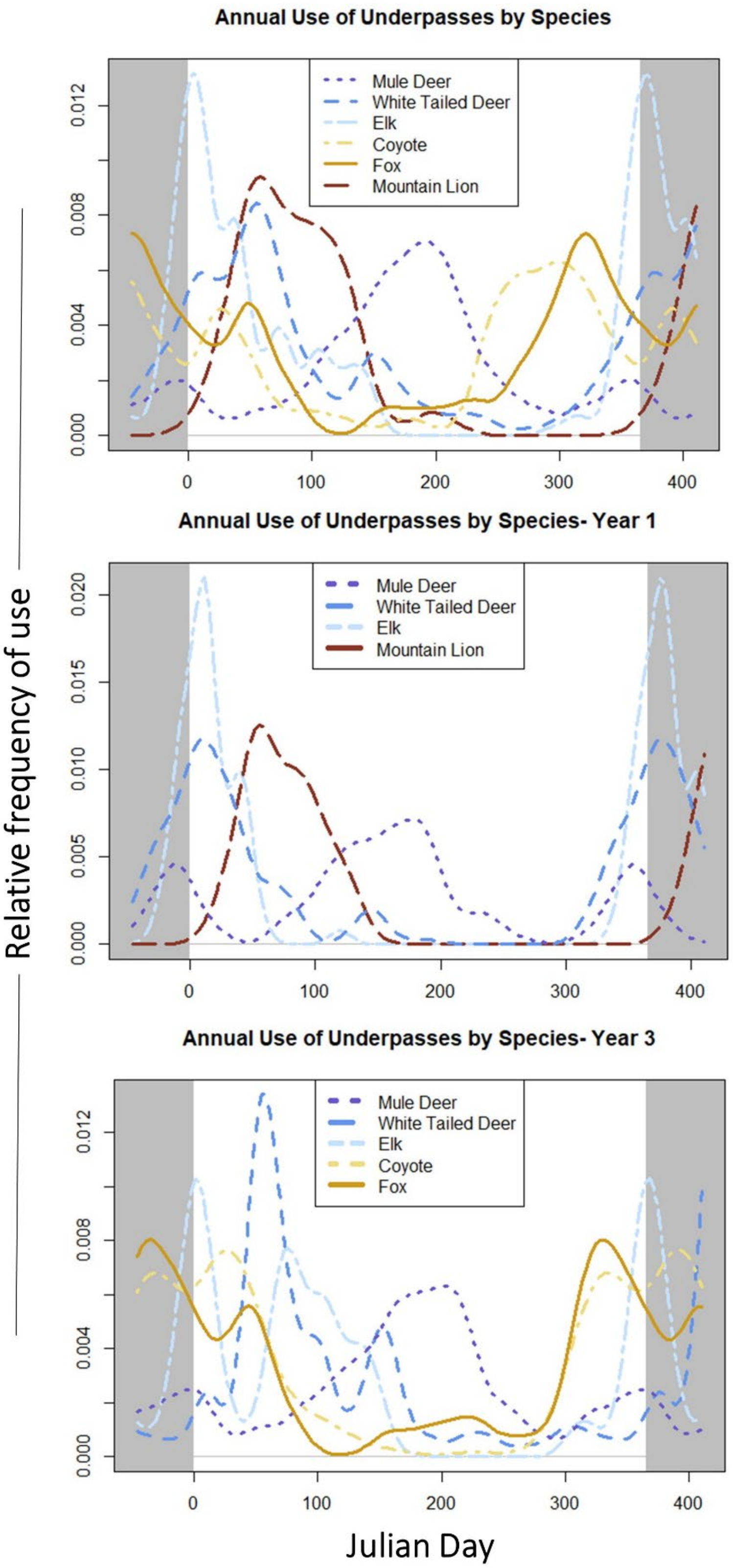


Figure 8. Annual timing of underpass use for the most common species with data combined across underpasses. Patterns of annual use changed for some species between the first and third years post-construction.

3.2 Part II: Wildlife Vehicle Collisions

For the six years prior to completion of the wildlife infrastructure associated with Phase I of the South Jackson Project (wildlife crossing structures and wildlife fencing), there was an average of 93.5 ungulate collisions per year between Jackson and Hoback Junction, mostly mule deer. With data from November 2013 through April 2022 (including 30 months post-construction), there were an average of 54 ungulate collisions per year in the same stretch (Figure 9), representing a 42 percent reduction between Jackson and Hoback Junction. The largest declines in collisions were in the Phase I project area, even when collisions that occurred within 500m of the ends of the fences were attributed to the project area, providing evidence of the efficacy of the infrastructure changes in reducing collisions. The section of road south of the project area was undergoing construction and collision mitigation work during the latter portion of the monitoring period (Phase II) and also experienced a reduction in collisions (Figure 9-B, yellow color), while the area north of the Phase I project area experienced collision rates comparable to the previous five-year average (Figure 9-B purple color). We estimated that 2 fewer collisions with elk, and 40 fewer with deer and pronghorn annually between Jackson and Hoback on US 89 amounted to an annual average savings of $411,089 (2023 US dollars, cost data from Huijser et al. 2009, Figure 10) attributable to infrastructure changes. Collision reduction strictly within the project area accounted only for 40 percent of this savings.

The magnitude of the collision reduction effect depended on whether collisions that occurred within 500m of fence ends were attributed to the project area or excluded. When fence end collisions were disregarded, collision reduction was calculated to be 75 percent in the project area; when collisions within 500m of fence ends were included, project area collision reduction was 56 percent. Collisions at fence ends at the South end of the project area saw a 20 percent reduction in the years after phase I project completion, attributed to collision mitigation infrastructure associated with Phase II of the project that was being installed during this period. There were no changes in collisions within 500m of the fence ends at the North end of the project area.

Despite the reductions in collisions, there were still 16 ungulate collisions that occurred within the fenced right-of-way of the project area (not including collision that occurred at fence ends) in the first 30 months after construction (~6 collisions/year). These collisions represent the incomplete barrier created by wildlife fencing.

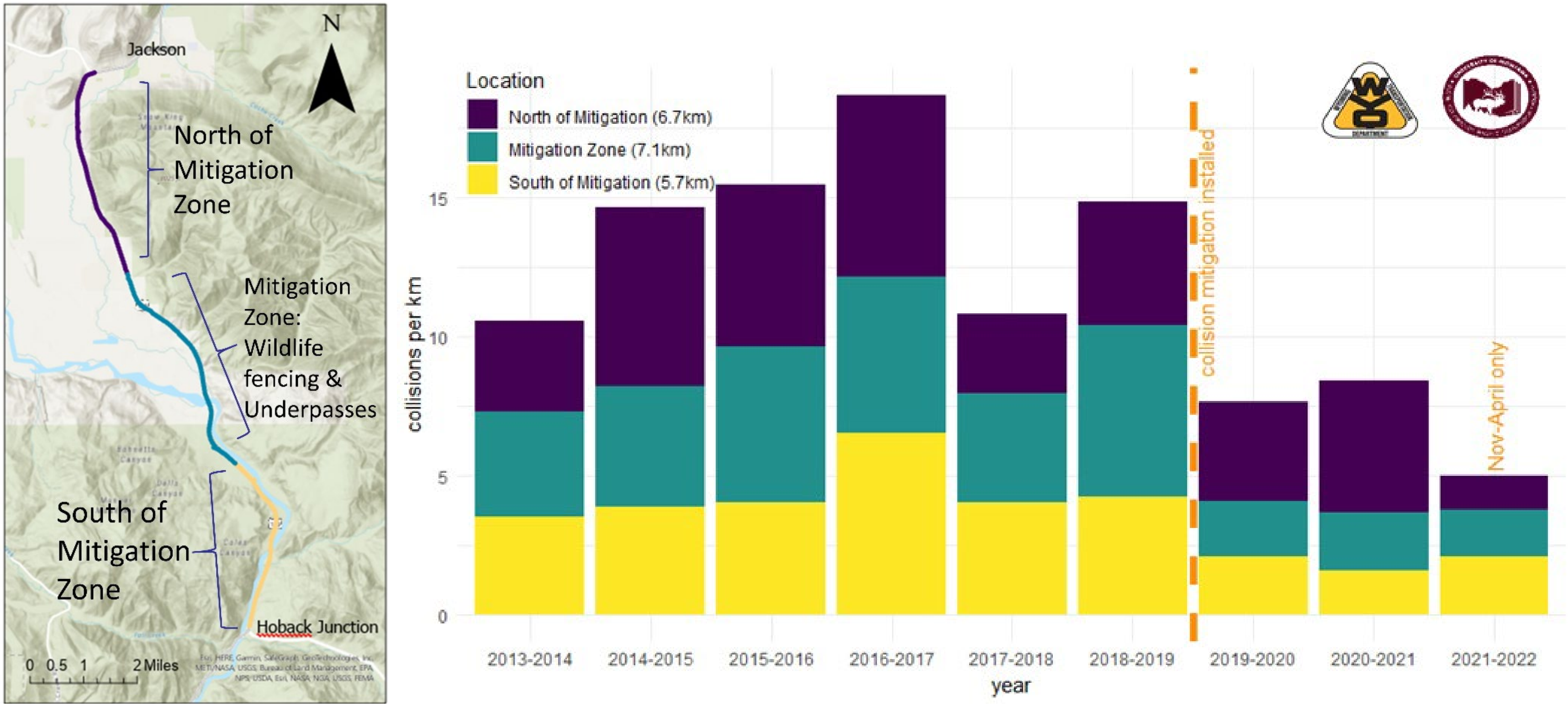


Figure 9. Ungulate collision rate from Nov 2014- April 2022 on Highway 89 between Jackson and Hoback Junction, where bars in the graph (top to bottom) are organized in in the same order as the map (North to South). Collisions that occurred with 500m of the end of the study area ("Mitigation Zone") were attributed to the "Mitigation Zone". Collision data compiled by Jackson Hole Wildlife Foundation.

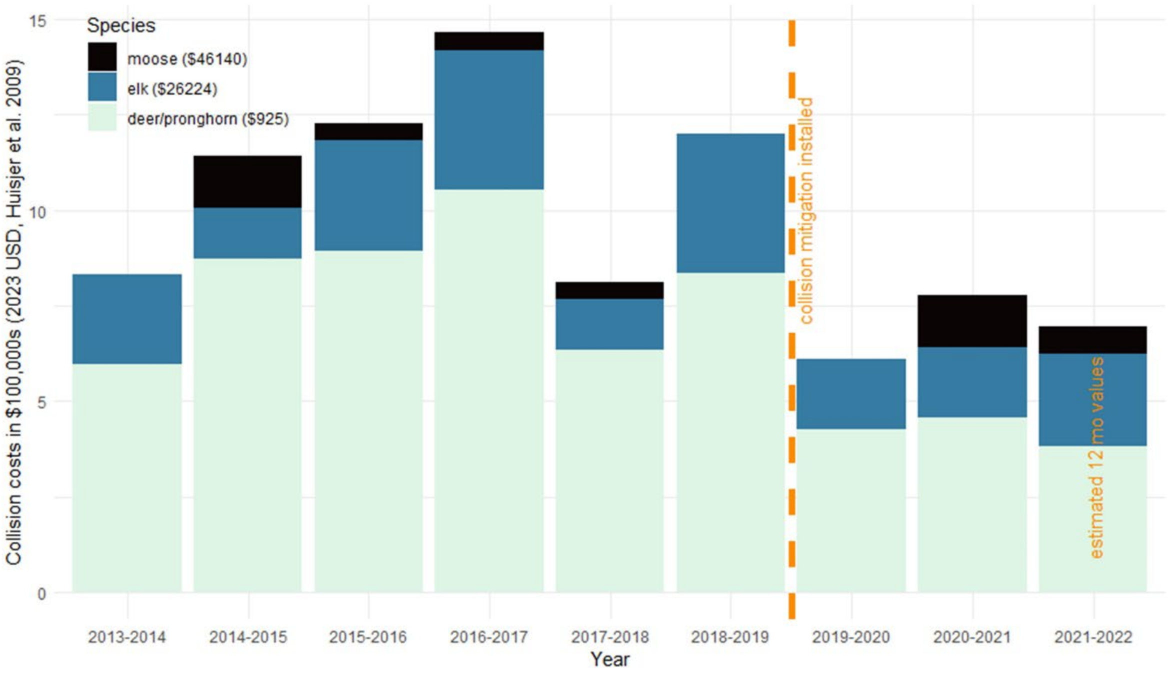


Figure 9. Collision costs from ungulate collisions that occurred on Highway 89 between Jackson and Hoback Junction (2023 USD, based on Huijser et al. 2009). Annual savings stem from avoided vehicle repairs, human injury and other costs.

CHAPTER 4: DISCUSSION AND RECOMMENDATIONS

4.1 Species Composition and Use

The North Yard underpass location saw far more use than the Flat Creek location. We suspect that part of this high use by elk and mule deer was driven by proximity of this particular underpass to winter feeding grounds off of South Park Loop Rd. The Flat Creek underpass was seasonally frequented by does with fawns of both mule and white-tailed deer, we suspect due to the location of this underpass along the Flat Creek riparian corridor; in contrast, we infrequently observed fawns using the North Yard underpass. Mean group size of mule deer at the North Yard underpass was also double that at the Flat Creek location.

The peak of activity of mountain lions in the first year at Flat Creek occurred during a relative lull in activity by large ungulate species both seasonally and diurnally (Specht, unpublished analyses). Whether this separation in the timing of use by lions and potential ungulate prey represents avoidance would require more detailed information about individual animal movement to evaluate. Black bears and pronghorn were not observed using or approaching either underpass, though both species were observed approaching the road near the locations of these wildlife crossing structures prior to their construction (personal communication, Jackson Hole Wildlife Foundation). It has been observed that pronghorn will preferentially use overpasses rather than underpasses (Sawyer et al. 2016) to cross roads, perhaps explaining their lack of use of an the underpasses. Black bears are known to use underpasses throughout North America (Sawaya et al. 2014). However black bears and pronghorn infrequently show up in collision records for Highway 89 from Jackson to Hoback Junction (Jackson Hole Wildlife Foundation 2023), so we suspect that their absence from use of the underpasses reflects their general lower abundance in this particular area of the valley floor.

4.2 Detection probability and closed capture models

Camera studies advise placing cameras at crossing structure entrances, facing the direction of movement (e.g. Jumeau et al. 2017). In our study area, both underpasses occurred in locations frequented by humans participating in recreational activities due to their placement along popular biking, hiking and river routes. As such, we secured cameras to bridge infrastructure to reduce the chance of cameras being tampered with. Some cameras were, nonetheless, tampered with (e.g. angled in different directions). Initially, cameras were angled such that the trigger zones (in the bottom 2/3 of a photo) did not intersect all animal movement pathways, resulting in missed detections of crossing events. Changes to the camera angle, and the addition of cameras to the Northeast and Northwest corners of the North Yard underpass improved detection of crossing events. Nevertheless, cameras were not ideally placed to observe reflections, as animals had to nearly enter the underpass in order to be detected. Furthermore, animals that initially “reflected” from the underpass but ultimately crossed within the same event were considered “transmissions” instead of reflections. Reflections are, therefore, only represented as an ultimate outcome in our findings, though animals might “reflect” multiple times before crossing.

The two-camera monitoring design offered distinct benefits to this study. First, the two-camera system offered redundancy in monitoring when one camera was not operating—only during one stretch was an underpass completely unmonitored. Second, the two-camera system provided an opportunity to determine whether crossing events with an “unknown” outcome from one camera were actually transmissions when animals were detected on both cameras. Third, the two camera system provided the capacity to look at camera set up and other variables influencing whether crossing events were detected through treatment of the two cameras as a “capture-recapture” system. Additionally, this detection model allowed proof of concept that the two camera approach could be used to estimate the number of missed crossing events.

We tabulated that only 43 percent of crossing events were detected on cameras on both sides of crossing structures. Closed population models for mule deer, similarly, showed that event detection at each underpass were mediocre, resulting in part from long stretches where not all cameras were operational at a crossing structure, driving the low overall detection rates across the study period, even once camera setup created the potential for high detection probability. We also anecdotally observed that detection was hampered at cameras with greater vegetation growth (e.g. Flat Creek SW, Figure 8) during the last summer of the monitoring period (2022). Regardless of camera position or the number of cameras monitoring a crossing, larger groups of animals were more likely to be detected. This is likely driven by the greater number of opportunities for camera-triggering events with larger animal groups.

Figure 10. An example of vegetation growth at the Flat Creek SW camera location between spring 2020 (left; 7 months post-construction) and summer 2022 (right; 32 months post-construction). The increase in vegetation made detection of moving animals less reliable.

We found a positive relationship between temperature and detection rates. This effect was opposite of our expectation; we anticipated that lower ambient temperatures would create greater temperature differentials between the ambient environment and animal body temperatures, leading to greater trigger rates of infrared camera sensors in colder weather. However, the greater activity of mule deer at underpasses during the summer months, when temperatures are warmer likely drives this effect, suggesting that the effect is more likely reflecting availability for detection rather than the process of detection itself. We have yet to determine an independent covariate that could serve to represent temporal animal density so as to allow temperature to function as a detection variable. These findings suggest that mule deer crossing events that went undetected were most likely to be characterized by small group sizes.

We pursued the use of closed population models for three reasons: (1) to evaluate the camera set up and understand the conditions that underpin the best monitoring outcomes in an effort to provide recommendations for subsequent project phases and similar monitoring effort elsewhere; (2) to recover information about undetected crossing events, given incomplete camera monitoring in hopes of more completely reporting the number of animals using the underpass; and (3) providing the basis for characterizing underpass use while accounting for imperfect detection and better link underpass use information to population information (Hardy et al. 2003). The closed capture modelling approach proved useful in understanding detection probability of our camera set up (1), but less useful for understanding characteristics of undetected crossing events or linking to population information (2, 3). More specifically, the models allowed us to estimate number of missed crossing events, but did not allow us to estimate the number of animals that crossed since we could not estimate characteristics of missed crossing events, such as group size or timing. This is because we do not have covariate values for the crossing events that went undetected (e.g. we do not know when they occurred). This is unlike other applications of data augmentation modelling approaches, such as those applied to estimating diversity, wherein sites without detections were still specifically surveyed and thus covariate data collected (Kéry and Royle 2009).Ultimately, looking closely at animals crossing through underpasses is unlikely to allow a link to processes describing population connectivity without corresponding data that link individuals using the crossings to populations. However, the location of this study in the Jackson Hole area provides a unique and ideal setting for pursuing these linkages through collaboration, due to the number of collared and marked animals in the system; indeed, some collared animals were observed using the underpasses.

4.3 Collisions

When fence-end collisions are not considered, the reduction in collisions within the project area (75 percent) approaches the substantial reductions achieved in fencing and crossing structure projects in other locations (e.g. 80 percent Clevenger 2001, 97 percent Gagnon et al. 2015, 80 percent Huijser et al. 2016). Even when fence-end collisions are considered, the reduction in collisions amounts to considerable annual savings to society, amounting to over $1 million in the first 2.5 years after project completion. Nevertheless, animals still accessed the roadway in locations where fencing was interrupted for vehicle access, fence gates were mistakenly left open or other opportunities for roadway access occurred. We expect this savings to grow with time as these “leaky locations” are identified and mitigated. Additionally, the distance fenced in the first project phase (~5km) has seen variable success in collision reduction in other locations (Huijser et al. 2016); as additional phases of the project are completed, extending the length of the fence line and providing additional crossing structures, we expect the rates of collision reduction to continue to improve, as higher rates are more consistently observed for longer fences. Finally, savings from collision reduction will accrue with time as more animals locate and use the wildlife crossing structures and the annual mitigation of collisions accrues savings.

4.4 Recommendations

We recommend that periodic maintenance inspections occur to identify areas of fencing or gates that may need repair to minimize animal attempts at accessing the roadway. Retaining a non-porous barrier to road access will help animals locate crossing structures and is critical to achieving the collision mitigation potential of the infrastructure investment.

We recommend maintaining the two-camera monitoring system where possible for the benefits described in section 3.3.2. Additionally, we recommend using camera angles which maximize the overlap between the trigger zone of the cameras and the animal movement pathways, such as those implemented after April 2021, as this adjustment improved detection probability at all crossings. At particularly wide crossing structures, we recommend deploying 4 cameras (one at each corner), so that all animal pathways through the crossing structure are monitored and, in particular, that there are likely to be at least three cameras running at all times. Specifically, at the wide North Yard crossing, we found that probability of detecting a crossing event on at least one camera reached desirable values of detection probability (>0.85) only once three cameras were being used.

The addition of more crossing structures within the same broader landscape should provide an opportunity to examine how the landscape context and structural characteristics of the different crossings facilitate use by different wildlife communities. At this point, we recommend that a model (or models) to look at patterns of animal underpass use relative to characteristics of crossing structures and the landscape context would be best formulated as a model with a response variable expressing the occurrence or rate of crossing events by a given species in a given week. We recommend using a week as a time frame because relevant temporal covariates are likely to be more similar within a week than across weeks, and summarizing at the scale of weeks will remove some amount of random temporal variation in movement. A response variable expressing the rate (number of animal crossings per week) will allow examination of why volume of crossings may differ between crossing structures and will be more dependent on the density of animals in that particular location at that particular time of year. A response variable expressing occurrence of crossing events would mask some of the influence of animal density in a certain area (e.g. more ungulates closer to feeding grounds) if that density cannot readily be modelled by the covariates. We recommend against using a binomial response model wherein each individual detected animal is assigned a 1 if they traversed the underpass and a 0 if they “reflected” since the monitoring approach under detects animals that reflect and would lead to a strongly unbalanced dataset. Similarly, occupancy models will be hard to utilize to examine relationships between use and site characteristics because closure at any period greater than the species-specific time to independence period should not be assumed, so a temporal replicate would have to be too short to be meaningful. If interspecific interactions are of interest, covariates should be specifically formulated to address hypotheses (e.g. include rate variable across all carnivores in a deer model instead of pursuing a multi-species model).

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