Exploration of Opportunities to Address the Impacts of Roads and Traffic on Wildlife Around Rocky Flats National Wildlife Refuge

FINAL REPORT

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16. Abstract

Rocky Flats National Wildlife Refuge (“the Refuge”) in Colorado near Denver, Colorado, has a history (1952-1989) of producing components for nuclear weapons. The current goal for the area is “to restore and preserve the native prairie ecosystems, provide habitat for migratory and resident wildlife, conserve and protect habitat for Preble’s meadow jumping mouse, and provide research and education opportunities”. The grasslands of the Refuge are surrounded by busy roads to the west (Hwy 93, 18,000 AADT), north (Hwy 128, 4,200 AADT) and east (Indiana St. 7,000 AADT), and there are houses and associated roads on its southern boundary. Other open space with non-motorized trails and protected areas with predominantly grassland are to the west, north and east. Large ungulates, including mule deer, elk, and moose cross the roads. This results in large ungulate-vehicle collisions and the roads also represent a barrier to the movements of animals. Creek crossings under the roads are a concern as they are likely a barrier for species dependent on riparian habitat, including the Preble’s meadow jumping mouse. The objectives of the current project were to 1. Formulate measures that reduce collisions with large wild mammals, and 2. Formulate measures that improve connectivity across roads for large wild mammal species and one small mammal species in specific, the Preble’s meadow jumping mouse. We suggest large open span bridges at creek crossings (for deer, moose, black bear, mountain lion, and Preble’s meadow jumping mouse) and designated wildlife overpasses for elk and also for mule deer. The crossing structures may be combined with human co-use to connect the trails on the refuge with the trail system in the surrounding areas.

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STANDARD CONVERSION TABLE – ENGLISH TO METRIC				
Symbol	To convert from	Multiply by	To determine	Symbol
		LENGTH		
IN	inch	25.4	millimeters	mm
FT	feet	0.3048	meters	m
YD	yards	0.9144	meters	m
MI	miles	1.609344	kilometers	km
		AREA		
SI	square inches	645.16	square millimeters	mm^2
SF	square feet	0.09290304	square meters	m^2
SY	square yards	0.83612736	square meters	m^2
A	acres	0.4046856	hectares	ha
MI^2	square miles	2.59	square kilometers	km^2
		VOLUME		
CI	cubic inches	16.387064	cubic centimeters	cm^3
CF	cubic feet	0.0283168	cubic meters cubic	m^3
CY	cubic yards	0.764555	meters liters	m^3
GAL	gallons fluid	3.78541	liters	L
OZ	ounces	0.0295735	cubic meters	L
MBM	thousand feet board	2.35974		m^3
		MASS		
LB	pounds	0.4535924	kilograms	kg
TON	short tons (2000 lbs)	0.9071848	metric tons	t
		PRESSURE AND STRESS		
PSF	pounds per square foot	47.8803	pascals	Pa
PSI	pounds per square inch	6.89476	kilopascals	kPa
PSI	pounds per square inch	0.00689476	megapascals	Mpa
		DISCHARGE		
CFS	cubic feet per second	0.02831	cubic meters per second	$m^3/_s$
		VELOCITY		
FT/SEC	feet per second	0.3048	meters per second	m/s
		INTENSITY		
IN/HR	inch per hour	25.4	millimeters per hour	mm/hr
		FORCE		
LB	pound (force)	4.448222	newtons	N
		POWER		
HP	horsepower	746.0	watts	W
		TEMPERATURE		
˚F	degrees Fahrenheit	5 X (˚F – 32)/9	degrees Celsius	˚C
		DENSITY		
lb/ft^3	pounds per cubic foot	16.01846	kilograms per cubic meter	kg/m^3
		ACCELERATION		
g	freefall, standard	9.807	meters per second squared	m/s^2

TO CONVERT FROM METRIC TO ENGLISH, DIVIDE BY THE ABOVE CONVERSION FACTORS.

Summary

Rocky Flats National Wildlife Refuge ("the Refuge") in Colorado near Denver, Colorado, is part of the Colorado Front Range National Wildlife Refuge Complex and is managed by the U.S. Fish and Wildlife Service. The Refuge has a history (1952-1989) of producing components for nuclear weapons. The current goal for the area is "to restore and preserve the native prairie ecosystems, provide habitat for migratory and resident wildlife, conserve and protect habitat for Preble's meadow jumping mouse, and provide research and education opportunities". The Refuge officially opened to visitors in 2018 with trails for non-motorized recreation. A 1,300 acre legacy site in the center of the area continues to be monitored by the Department of Energy (DOE), and is closed to visitors. The grasslands of the Refuge are surrounded by busy roads to the west (Hwy 93, 18,000 AADT), north (Hwy 128, 4,200 AADT) and east (Indiana St. 7,000 AADT), and there are houses and associated roads on its southern boundary. Other open space with non-motorized trails and protected areas with predominantly grassland are to the west, north and east. Large ungulates, including mule deer, elk, and moose cross the roads. This results in large ungulate-vehicle collisions and the roads also represent a barrier to the movements of animals. Creek crossings under the roads are a concern as they are likely a barrier for species dependent on riparian habitat, including the Preble's meadow jumping mouse. The objectives of the current project are to 1. Formulate measures that reduce collisions with large wild mammals, and 2. Formulate measures that improve connectivity across roads for large wild mammal species and one small mammal species in specific, the Preble's meadow jumping mouse.

We first investigated where the highest concentrations of large mammal-vehicle crashes and large mammal carcasses were along Hwy 93 and Hwy 128 through a hotspot analysis. The highest concentrations of large mammal-vehicle collisions were just north of mile reference posts 9 and 11 along Hwy 93, and around mile reference post 2 along Hwy 128, and along Indiana St. south of the junction with Hwy 128. Most of the collisions occurred between dusk and dawn, especially between 8 and 11 pm. We also summarized the presence and movement of 2 wildlife species: elk and Preble's meadow jumping mouse. In 2022 there were about 350 elk on the Refuge. GPS-collared elk from the herd cross Hwy 128 regularly, but only cross Hwy 93 only occasionally. GPS-collared elk from the herd that resides mainly west of Hwy 93 (Plainview herd) were not observed crossing Hwy 93 into the Refuge or into the area north of Hwy 128. These movement data suggest that elk mostly stay away from the main roads; they are mostly confined to the meshes within the road network with the highways being partial or near complete barriers. The elk also seem to spend most of their time on the legacy site in the center of the Refuge where the public is not allowed and where human disturbance is lowest. The Refuge also includes designated critical habitat for the Preble's meadow jumping mouse, but there have been no confirmed observations since 2003. The likely decline of Preble's meadow jumping mouse on the Refuge is potentially related to changes in water management on the Refuge after industrial use stopped and human-made water retention ponds were removed. In addition, hotter and dryer conditions over the years may have further contributed to a reduction in suitable habitat, and the potential disappearance of the species from the Refuge. Nonetheless, habitat restoration along riparian corridors, as well as making creek crossings under highways more suitable for Preble's meadow jumping mouse may allow for re-establishment of the species.

To substantially reduce collisions with large wild mammals on the roads around the Refuge, we suggest installing wildlife fences. The fences should be combined with suitable crossing structures for species that would otherwise be isolated from surrounding areas. Elk and moose are the most demanding species in the area, and they require either large open span bridges or overpasses. At creek crossings or in areas with fill, consider large open span bridges. Structures along creeks can be expected to be "in the correct location" for white-tailed deer, moose, black bear, mountain lion, bobcat, and Preble's meadow jumping mouse. The bottomless nature of a bridge also means that the soil and stream characteristics under the bridge can be similar to upstream and downstream from the crossing. Higher clearance (height) of the structure allows for more light and moisture inside the structure and would allow for vegetation (e.g. grasses, shrubs) to grow which would be an important habitat requirement for Preble's meadow jumping mouse. Additional cover can be provided inside the structure through either natural material (e.g., root wads, tree branches, or rocks) or artificial material (e.g. concrete blocks with openings). Note that these underpasses would be multifunctional crossing structures as their location, type and dimensions are influenced by both hydrology and wildlife movements. However, the location, type and dimensions are not optimal or suitable for all wildlife species. Elk may still be hesitant to using large overspan bridges in drainages with limited visibility, and we suggest 3 wildlife overpasses for this species; one across each of the 3 main roads around the Refuge (Hwy 93, Hwy 128, and Indiana St.). Based on the movements of GPS-collared elk, a potential overpass location along Hwy 93, could be just north of Coal Creek (around mile reference post 11.3), where there is small roadcut. Along Hwy 128, consider an overpass between mile reference post 1.4 and 3.2, potentially around mile reference post 3.0 where there is a roadcut. Along Indiana St., consider an overpass around 0.8 miles or 1.3 miles south of the junction with Hwy 128 where there are roadcuts. Mule deer may use large open span bridges at creeks as well as overpasses.

The location and design of designated wildlife crossing structures are optimized for the target species. However, it is worthwhile to explore the potential for multi-functional crossing structures for which the location, type, and dimensions of the structures would not only be influenced by wildlife. Overspan bridges at creek crossings, when implemented, are already an example of a multifunctional crossing structure. They are influenced by both hydrology and wildlife. However, it is also possible to design multifunctional underpasses and overpasses that are also influenced by non-motorized trails, especially near urban centers where demand for such trail systems is high. The Refuge and the surrounding lands already have a system of trails for non-motorized recreational use by people from the greater Denver area. Similar to wildlife, people using non-motorized trails have trouble crossing busy roads. It is not only potentially dangerous, but it also affects the otherwise tranquil experience of being on the trails. In the case of the Refuge, elk have somewhat adapted to human presence and disturbance by concentrating in the center of the Refuge where the public does not have access. Most of the elk (and mule deer) crashes occur at night, further indicating that road crossings already happen predominantly at night. In this context, multifunctional overpasses for elk and people may be an option as moving connectivity for large ungulates towards the dark hours has already happened given the human presence and disturbance in the area. The combined interests of wildlife connectivity and a safer and better-connected network of non-motorized trails could increase public support and associated funding for the construction of multifunctional crossing structures.

1 Introduction

1.1 Background

Rocky Flats National Wildlife Refuge ("the Refuge") is a 5,237-acre area about 20 miles northwest of Denver, Colorado, is part of the Colorado Front Range National Wildlife Refuge Complex and is managed by the U.S. Fish and Wildlife Service. (Figure 1). While historic use included hunting by native Americans (prior to the 1800s), ranching (late 1800s until well into 1900s), and the production of nuclear weapons (1952-1989), the current goal is "to restore and preserve the native prairie ecosystems, provide habitat for migratory and resident wildlife, conserve and protect habitat for Preble's meadow jumping mouse, and provide research and education opportunities" (Clark et al. 2006, U.S. Fish and Wildlife Service 2022a). Cleanup of waste associated with the production of nuclear weapons was conducted between 1989-2005. Through the *Rocky Flats National Wildlife Refuge Act of 2001*, the site was established as a National Wildlife Refuge, and the USFWS has been managing the area since 2005. The Refuge officially opened to visitors on the 15th of September, 2018 with trails for non-motorized recreation. A 1,300 acre legacy site in the center of the area continues to be monitored by the DOE, and is closed to visitors.

Medium-sized and large mammal species on the Refuge or surrounding areas include mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), elk (*Cervus canadensis*), moose (*Alces americanus*), black bear (*Ursus americanus*), coyote (*Canis latrans*), mountain lion (*Puma concolor*), American badger (*Taxidea taxus*), and North American porcupine (*Erethizon dorsatum*). There have been observations of Preble's meadow jumping mouse (*Zapus hudsonius preblei*) on the Refuge in the past, but there have been no confirmed observations in many years (Personal Communication, Alison Michael, Colorado Department of Transportation's Liaison at the USFWS, retired). Nonetheless, seemingly suitable habitat for this species remains.

The goal of this project is to contribute to the knowledge of potential future measures along roads around the Refuge aimed at:

- Improving human safety through fewer collisions with large wild mammals.
- Reducing animal-vehicle collisions, especially for large wild mammals.
- Improving habitat connectivity for large wild mammal species and one small mammal species in specific, the Preble's meadow jumping mouse.

The objectives are to:

- Formulate measures that reduce collisions with large wild mammals.
- Formulate measures that improve connectivity across roads for large wild mammal species and one small mammal species in specific, the Preble's meadow jumping mouse.

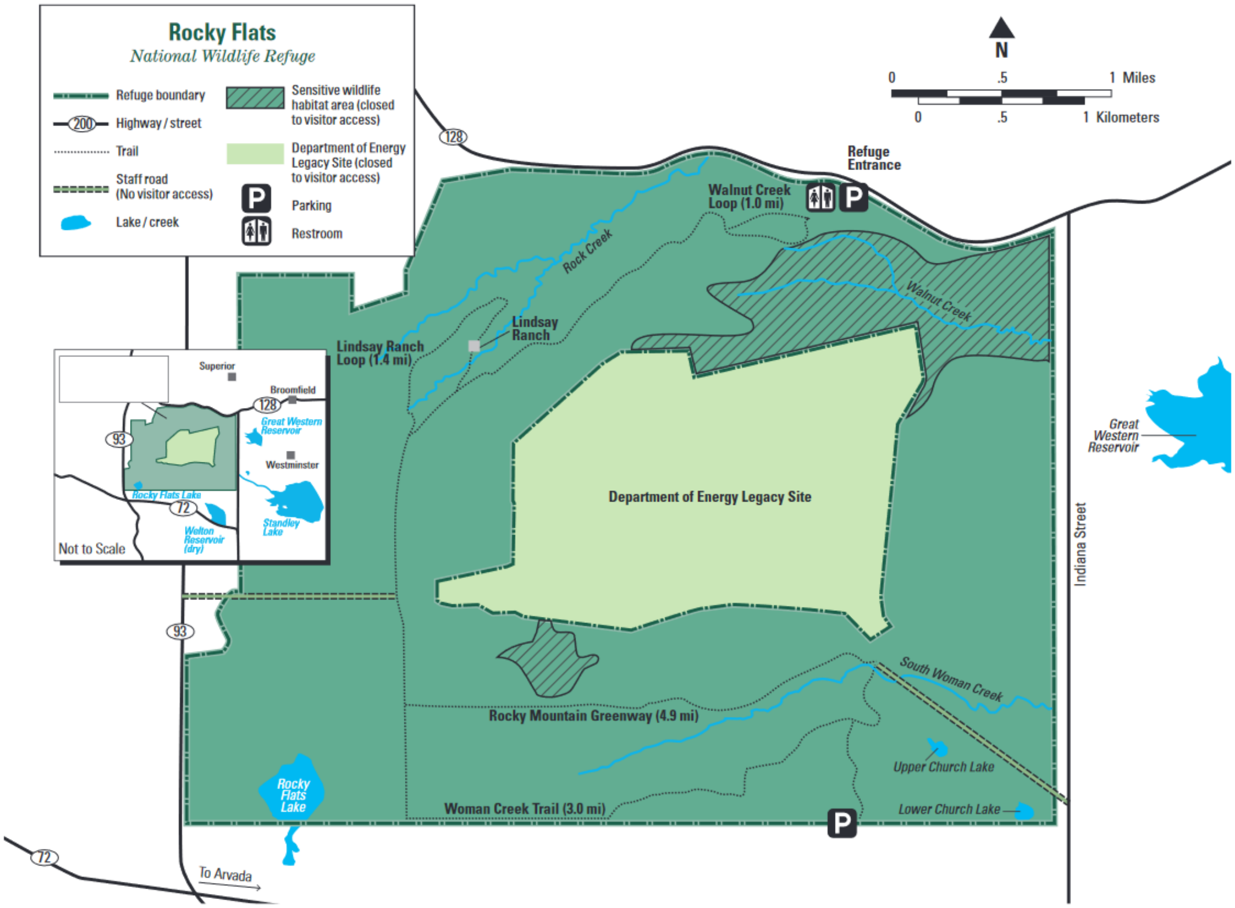

Figure 1: Map of Rocky Flats National Wildlife Refuge, northwest of Denver, Colorado.

1.2 Problem statement

The Refuge is surrounded by the following roads and other barriers:

- Hwy 93 to the west
- Hwy 128 to the north
- Indiana St. to the east
- Houses and associated roads to the south

Other open space and protected areas with predominantly grassland are to the west, north and east. Large ungulates, including mule deer, elk, and moose cross these roads, especially the ones to the west, north, and east of the Refuge. This results in large ungulate-vehicle collisions. The roads also represent a barrier to the movements of animals as they likely cross these roads less often compared to moving through the surrounding areas away from the roads. Creek crossings under the roads are a concern for species dependent on riparian habitat, including the Preble's meadow jumping mouse. The Preble's meadow jumping mouse depends on "well-developed riparian vegetation, relatively undisturbed adjacent grassland communities, and a nearby water source" (U.S. Fish and Wildlife Service 2018a). In this context, narrow culverts that lack riparian habitat, dry areas, and cover are likely unsuitable or marginal for this species. Because roads are considered a partial or complete barrier for the Preble's meadow jumping mouse (U.S. Fish and Wildlife Service 2018a), dry culverts, or culverts with dry ledges, and culverts that provide cover may result in better habitat connectivity than culverts that are filled with water and that have no cover. The Preble's meadow jumping mouse has been observed using culverts with ledges and ramps that connect them to the dry areas at the entrances of culverts, though observations were scarce (Meaney et al. 2007). Culverts (e.g. 10x4, 5x3 ft) under US Hwy 36 between Denver and Boulder (e.g. Marshallville Ditch, Goodhue ditch, Davidson ditch)) were specifically designed for Preble's meadow jumping mouse (Huijser & Gunson 2019). These culverts had natural substrate, and logs and branches for cover (Huijser & Gunson 2019).

Because of its history in producing components for nuclear weapons, there have been concerns about pollutants, including radioactive contaminants, on the Refuge (Clark et al. 2006). However, plutonium and americium form oxides and colloids that are transported as fine particles by wind and surface water, but they are not soluble in water (Clark et al. 2006). As a consequence, the clean-up focused on removing contaminated soil down to 1 meter below the surface and replacing it with fresh soil on top. Spread of the remaining radioactive contaminants is managed through preventing and reducing erosion due to wind and surface water (Clark et al. 2006). Therefore, having vegetation that covers the soil and not having anything disturbing the soil in the legacy area and exposing remaining contaminants is very important. The clean-up was completed in 2005. There have also been concerns about the health risk associated with hunting and consuming large ungulates that have spent time on the Refuge, and the risk of improving habitat connectivity for animals from the Refuge. Analyses of liver, muscle, lung, bone, and kidney tissue samples from resident Refuge deer in 2002 showed that only 17 of the more than 450 individual isotopic samples had actinide concentrations above method detection limits (Todd & Sattelberg 2005). Actinides are radioactive elements from Actinium (atomic number 89) to Lawrencium (atomic number 103, and they include plutonium and uranium. Of these 17 samples, only 2 had concentrations of an actinide isotope that exceeded thresholds for a 1×10^{-6} additional cancer risk following human ingestion of all edible tissues from an average-sized Refuge deer (Todd & Sattelberg 2005). The maximum calculated risk level was 4.733×10^{-6}, which is at the low end of the U.S. Environmental Protection Agency's acceptable risk range (Todd & Sattelberg 2005). Several tissue samples from a site not contaminated with actinides had detectable actinide concentrations comparable to the samples from the Refuge. This suggests that either: 1) The samples with detected actinide concentrations may be the result of measurement errors rather than an actual relatively high concentration of actinides, or 2) The concentration of actinides in deer tissue samples from the Refuge is similar to those of uncontaminated sites because they have similar background levels, and there is no heightened amount of actinides in the deer from the Refuge.

1.3 Goals, objectives, and tasks

The goal of this project is to contribute to the knowledge of potential future measures along roads around the Refuge aimed at:

- Improving human safety through fewer collisions with large wild mammals.
- Reducing animal-vehicle collisions, especially for large wild mammals.
- Improving habitat connectivity for large wild mammal species and one small mammal species in specific, the Preble's meadow jumping mouse.

The objectives are to:

- Formulate measures that reduce collisions with large wild mammals.
- Formulate measures that improve connectivity across roads for large wild mammal species and one small mammal species in specific, the Preble's meadow jumping mouse.

The tasks include:

1. Obtain data on:
    - Large mammal-vehicle collisions (crash data and carcass removal data for Hwy 93 to the west, Hwy 128 to the north, Indiana St. to the east.
    - Obtain data on large mammal movements alongside and across Hwy 93 to the west, Hwy 128 to the north, Indiana St. to the east. Large mammal species of interest include mule deer, white-tailed deer, elk, moose, black bear, and mountain lion.
    - Obtain data on historic and currently occupied habitat of Preble's meadow jumping mouse close to the highways and roads around the Refuge.

2. Conduct field reviews and meet stakeholders:
    - Meet with representatives of USFWS, Colorado Parks & Wildlife, and CDOT about their perspective on human safety, biological conservation, and wildlife movement across transportation infrastructure around the Refuge.
    - Inspect the road sections that are of greatest interest to mitigation around the Refuge, either because of large mammal-vehicle collisions or existing or desired connectivity for large mammals and Preble's meadow jumping mouse. Creek crossings (Coal Creek, Rock Creek, Walnut Creek, Woman Creek) are of specific interest.
    - Inspect existing mitigation measures (e.g. culverts) for Preble's meadow jumping mouse along US Hwy 36 between Boulder and Denver, and interview stakeholders and/or researchers with regard to the effectiveness of these mitigation measures.

3. Analyses
   - Identify relatively high frequency collision road sections for large mammal-vehicle collisions on the roads around the Refuge.
   - Identify important movement areas for large mammals across the roads around the Refuge. This can be based on existing movements, historic movements, or policy, or a combination of these perspectives.
   - Identify important historic or current habitat for Preble's meadow jumping mouse close to the roads around the Refuge.

4. Reporting
   - Report on the findings of the analyses.
   - Advice on mitigation measures aimed at reducing large mammal-vehicle collisions and at providing or maintaining connectivity for large mammals and Preble's meadow jumping mouse for the roads around the Refuge.

2 Crash and carcass data

2.1 Introduction

If collisions with large mammals need to be reduced because of a concern for human safety, data are needed on the locations where these types of collisions occur. Along most roads in North America there are two types of large animal-vehicle collision data that can help identify the "worst" road sections:

- Crash data: These data are typically collected by law enforcement personnel. For a crash to be entered into the database there is often a threshold (e.g. the estimated vehicle repair cost is at least US $1,000 and/or there are human injuries and human fatalities) (Huijser et al. 2007).
- Carcass data: These data are typically collected by road maintenance crews when they remove carcasses of large mammals that are on the road or that are very visible from the road in the right-of-way and that are an immediate safety hazard or a distraction to drivers (Huijser et al. 2007). Note that carcass data are sometimes also collected or recorded by others, e.g. by personnel from natural resource management agencies, researchers, or the general public.

Both types of collision data tend to relate to large mammals only, and they can include both wild species and domesticated species (livestock or feral species). For North America, common large wild ungulates, especially white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*) and moose (*Alces americanus*) are the most numerous species in the crash and carcass data. Therefore, common large wild ungulates tend to drive the identification and prioritization of road sections where mitigation measures may be considered based on human safety. Medium-sized and small-sized mammals and other species groups such as amphibians, reptiles and birds are usually inconsistently recorded, or not recorded at all, by law enforcement or maintenance personnel (Huijser et al. 2007). Furthermore, crash data typically represent only a fraction (14-50%) of the carcass data, even if both data sets relate to large mammals only (Tardif and Associates Inc. 2003; Riley & Marcoux 2006; Donaldson & Lafon 2008). Finally, the carcass data are far from complete as well; animals that are not very visible from the road in the right-of-way may not be removed and do not get recorded. Wounded animals that make it beyond the right-of-way fence before they die are also usually not recorded at all. Carcass counts underestimate the number of large mammals that are hit, and Lee et al. (2021) calculated a correction factor of 2.8.

If one chooses to reduce direct road mortality of wildlife species, regardless of the possible impacts for human safety, the concern can relate to any species, not just common large mammal species. This means that the species can be large or small, and the species may be common or rare. There may be emphasis on reducing mass mortality (e.g. amphibians or reptiles), regardless of whether a species is endangered or threatened, or whether it has reduced population persistence in an area. There can also be emphasis on reducing direct road mortality, or reducing the probability of direct road mortality, for rare species, including species that have not yet been recorded as road mortality. This may especially apply to species for which direct road mortality is or can be suppressing their population survival probability in an area. Oftentimes, traditional crash and carcass data are not suited to identify and prioritize the road sections where action should be considered first for small or rare species. Additional data collection may be warranted for small or rare species or species groups in specific areas. One may also conduct spatial analyses based where mitigation measures may be warranted based on suitable habitat or potential population viability, regardless of whether the habitat is currently occupied by the concerning species.

2.2 Crash data

Animal-vehicle crash data were obtained for Hwy 93, Hwy 128, and Indiana St. and for Indiana St. (source: Chuck Attardo, Colorado Department of Transportation). The researchers selected records for the most recent 10-year period for which data were available (2011- 2020) and that related to the following road sections (Figure 2):

1. Hwy 93
    a. Start mile reference post: 7.2 (Junction with Hwy 72, Coal Creek Canyon Rd.).
    b. End mile reference post: 11.9 (Junction with Hwy 128).
    c. Length: 4.7 miles.
2. Hwy 128
    a. Start mile reference post: 0.0 (Junction with Hwy 93).
    b. End mile reference post: 4.2 (Junction with Indiana St.).
    c. Length: 4.2 miles.
3. Indiana St. (no mile reference posts present, description based on crossroads)
    a. Start: Junction with Hwy 128.
    b. End: Junction with Canelas Parkway.
    c. Length: 3.5 miles.

Figure 2: The highway sections with mile reference posts and crossroads included in the animal-vehicle crash data analyses.

Along Hwy 93, deer and elk crashes were most abundant between mile reference posts 9.1-9.5 and between 10.7 and 11.3 (Figure 3). Along Hwy 128, deer and elk crashes were most abundant at mile reference post 2.0 and 3.9 (Figure 4). Along Indiana St., deer and elk crashes were most abundant south of the junction with Hwy 128 (Figure 5).

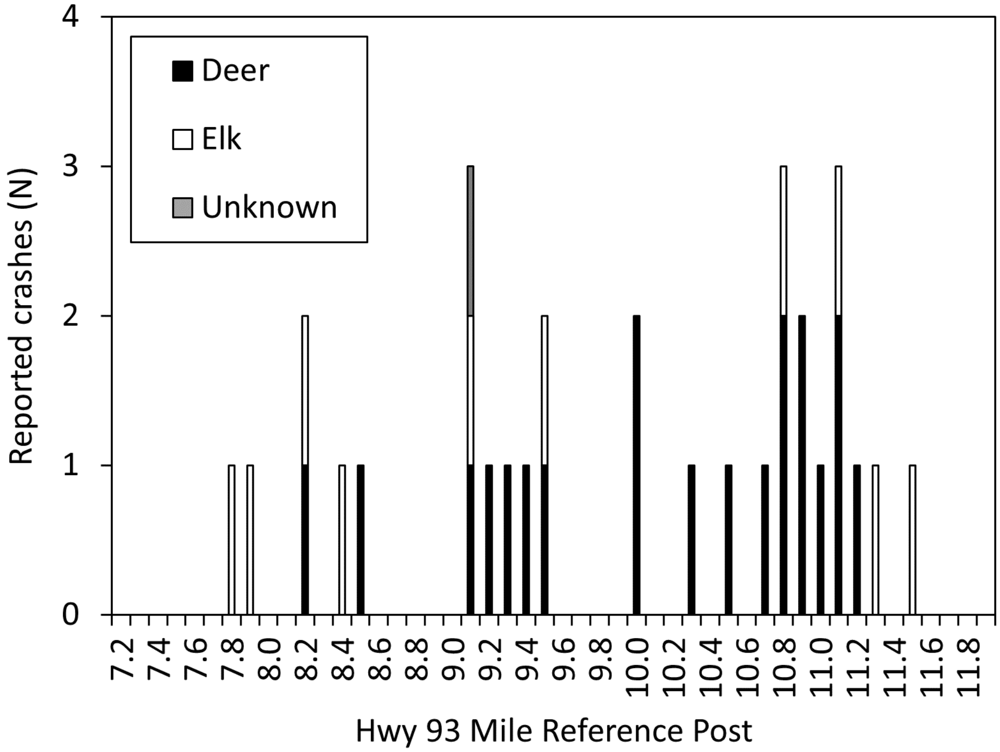

Figure 3: The number of reported crashes with animals along Hwy 93 between mile reference post 7.2 (Junction with Hwy 72, Coal Creek Canyon Rd.) and 11.9 (Junction with Hwy 128).

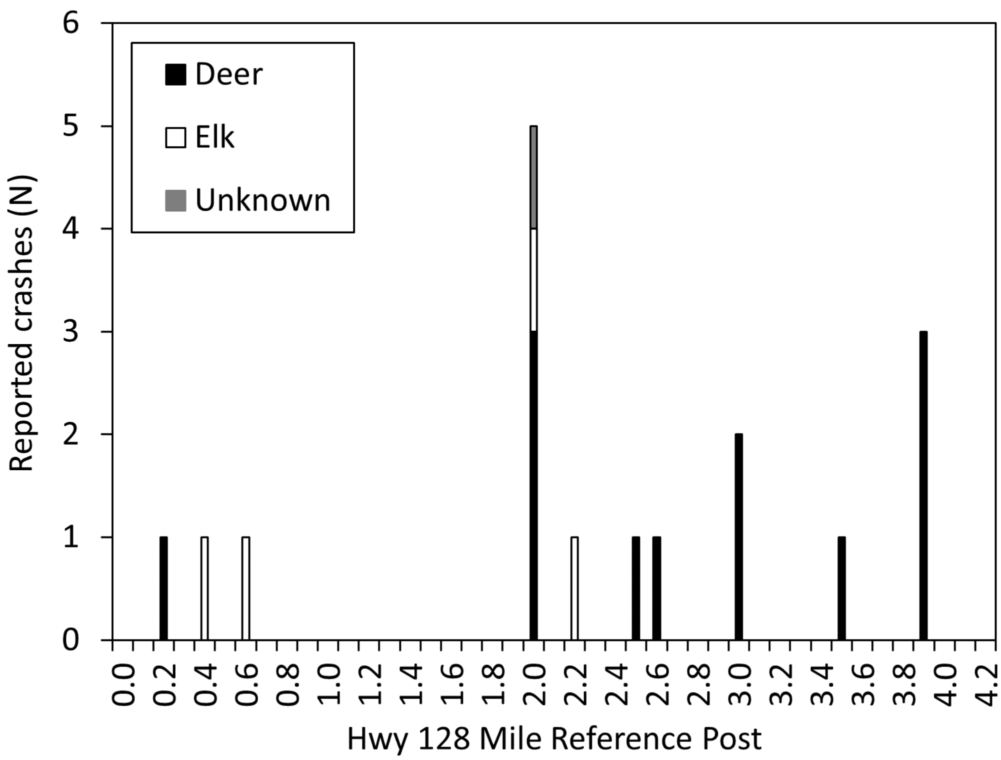

Figure 4: The number of reported crashes with animals along Hwy 128 between mile reference post 0.0 (Junction with Hwy 93) and 4.2 (Junction with Indiana St.).

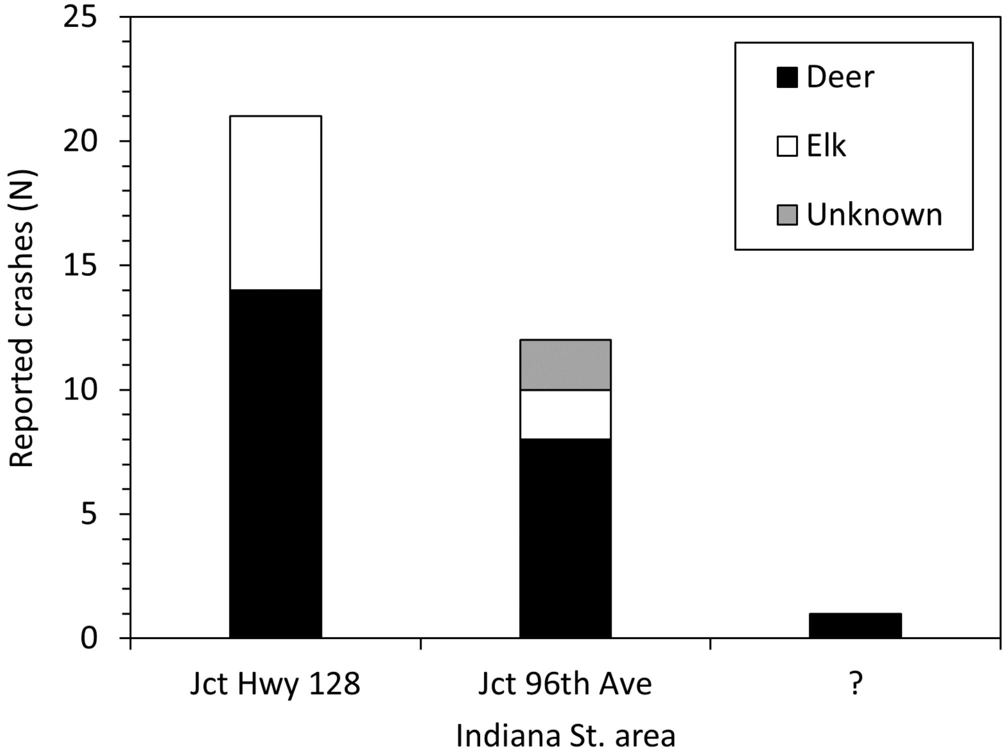

Figure 5: The number of reported crashes with animals along Indiana St. in 2 areas: South of Junction with Hwy 128 (north end), and around the Junction with W 96th Avenue (south end).

We investigated where the highest concentrations of large mammal-vehicle crashes were along Hwy 93 and Hwy 128 through a hotspot analysis. Large mammal-vehicle crashes along Indiana St. could not be included as the location of the observations was not spatially precise. The hotspot analysis was based on a Kernel density analysis using ArcGIS 10.6.1 (ESRI 2018) for point features of large mammal-vehicle crash locations using a 25 m cell size (82 ft × 82 ft). A 25 m cell size is relatively fine scale but still accommodates for some spatial inaccuracies in GPS coordinates. The Kernel density analysis calculates the density of crashes in a neighborhood around each cell and is based on the quartic kernel function described by Silverman (1986). We set the neighborhood search radius at 1,000 m (0.62 mi). On a straight road this means that large mammals crashes that are up to about 1,000 m away are included in the density analysis for each cell. To help interpret the results of the Kernel density analyses and identify hotspots, we displayed the raster output using a heat map classification with varying densities of crashes. We used percentage breaks to create five categories (<5%, 5-<25%, 25-<50%, 50-<75%, and 75–100%) that display the areas with the highest densities of crashes (<5%) to areas with the lowest densities (75-100%). The highest concentrations of large mammal-vehicle crashes were just north of mile reference posts 9 and 11 along Hwy 93, and around mile reference post 2 along Hwy 128 (Figure 6).

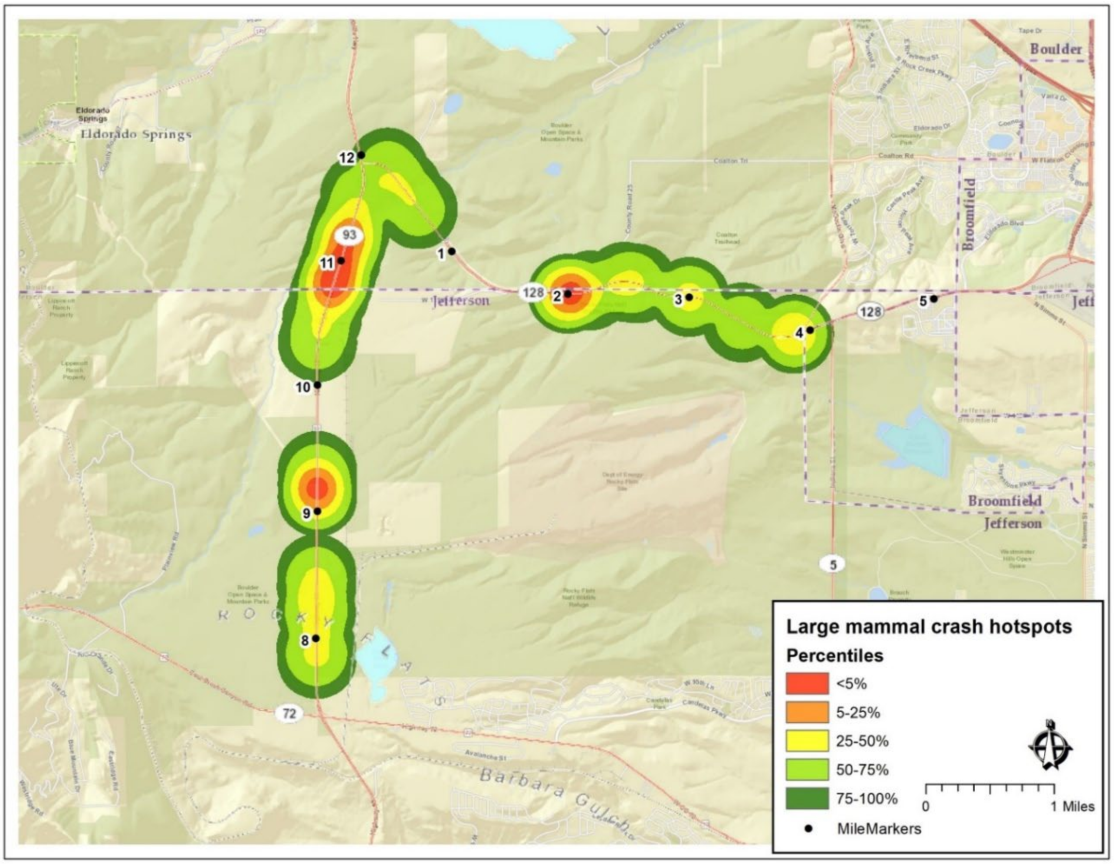

Figure 6: Kernel density hotspot percentiles for large mammal-vehicle crashes for Hwy 93 and Hwy 128 (2011–2020).

Deer and elk crashes predominantly occurred during the dark hours, especially between 8 and 11 pm (Figure 7).

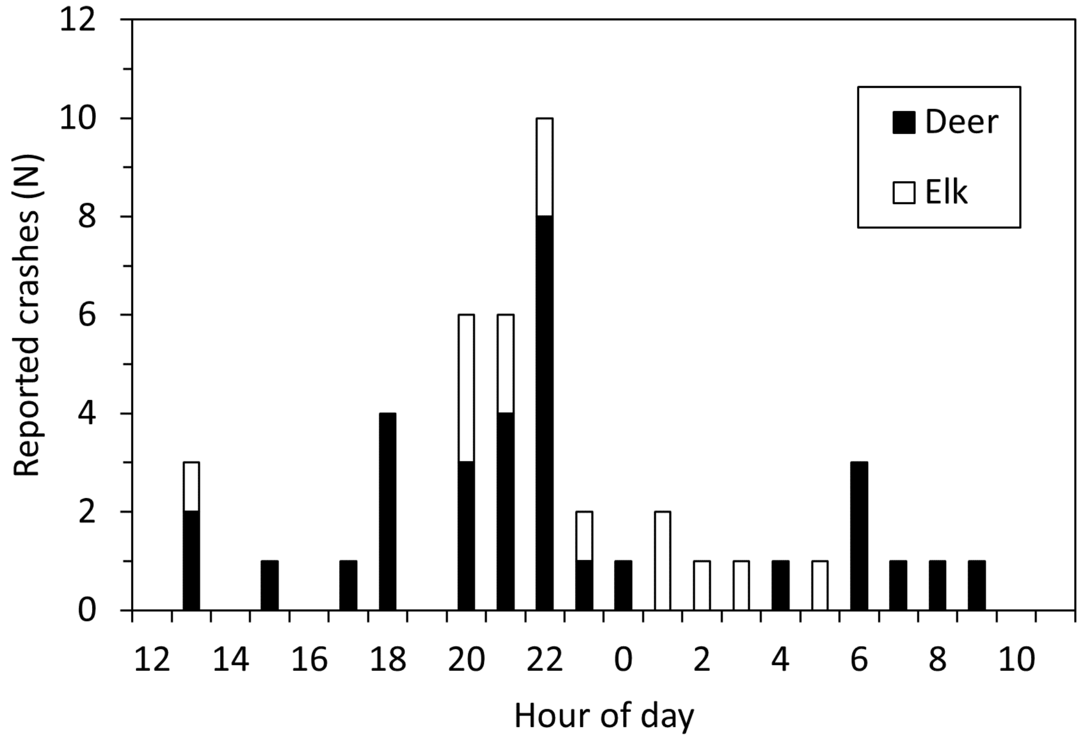

Figure 7: Deer and elk crashes by the hour of day (2011–2020). 20 = between 8 and 9 pm.

2.3 Carcass data

Carcass removal data were obtained for Hwy 93 and Hwy 128 (source: Jeff Peterson, Colorado Department of Transportation). Carcass removal data were not available for Indiana St. The researchers selected records for the years that carcass data were available for both roads (2002-2022) and that related to the following road sections:

1. Hwy 93
    a. Start mile reference post: 7.2 (Junction with Hwy 72, Coal Creek Canyon Rd.).
    b. End mile reference post: 11.9 (Junction with Hwy 128).
    c. Length: 4.7 miles.
2. Hwy 128
    a. Start mile reference post: 0.0 (Junction with Hwy 93).
    b. End mile reference post: 4.2 (Junction with Indiana St.).
    c. Length: 4.2 miles.

Along Hwy 93, deer and elk carcasses were most abundant at mile reference post 10.0 and between 11.0 and 11.2 (Figure 8). Along Hwy 128, the number of recorded carcasses was low and deer and elk crashes did not have a particular concentration (Figure 9).

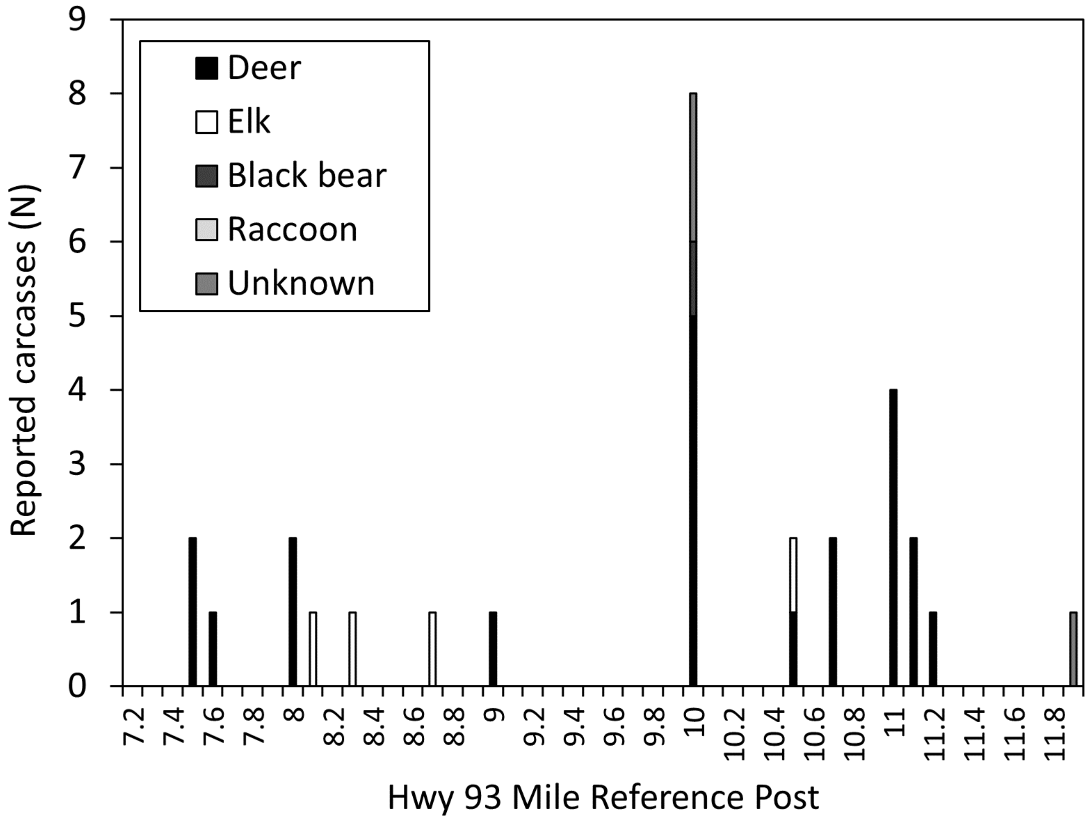

Figure 8: The number of reported carcasses with animals along Hwy 93 between mile reference post 7.2 (Junction with Hwy 72, Coal Creek Canyon Rd.) and 11.9 (Junction with Hwy 128).

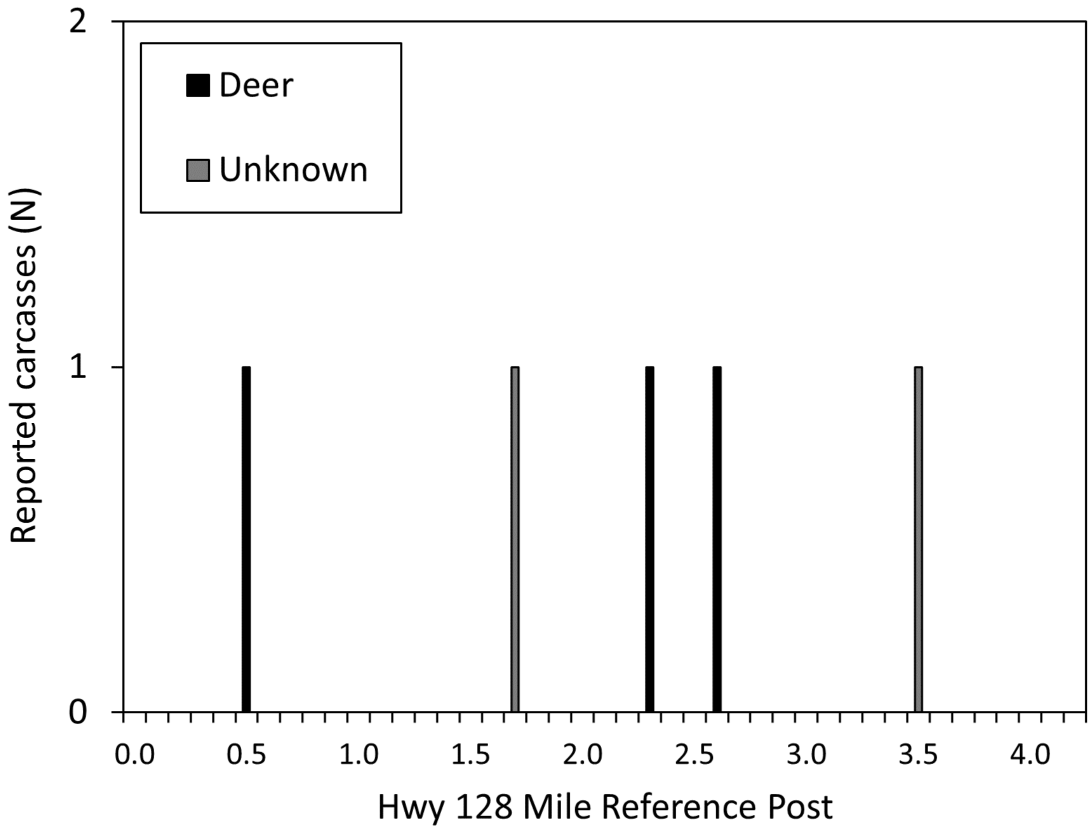

Figure 9: The number of reported carcasses with animals along Hwy 128 between mile reference post 0.0 (Junction with Hwy 93) and 4.2 (Junction with Indiana St.).

We investigated where the highest concentrations of large mammal-vehicle carcasses were along Hwy 93 and Hwy 128 through a hotspot analysis, similar to the analysis described for crashes. Large mammal-vehicle carcasses along Indiana St. were not available. The highest concentration of large mammal carcasses was along Hwy 93 from just south to just north of mile reference post 11.0 (Figure 10).

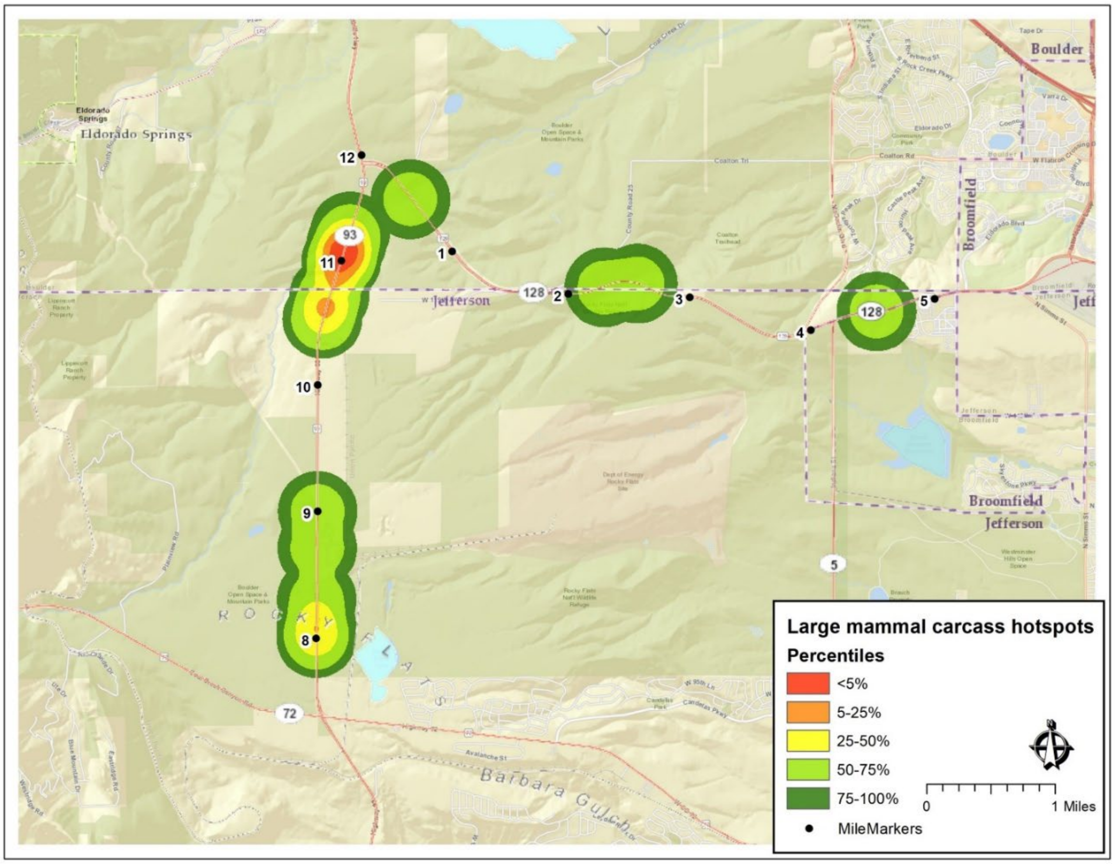

Figure 10: Kernel density hotspot percentiles for large mammal carcasses for Hwy 93 and Hwy 128 (2002–2022).

3 Wildlife movement data

3.1 Introduction

In addition to considering mitigating road sections where relatively many animals are hit and killed by vehicles, one may also choose to reduce the barrier effect of roads and traffic for animals. This is especially relevant for wild species whose movements are not or should not be controlled or limited by people, and for species who would "benefit" from improved connectivity. In general, small and isolated populations have lower population viability than populations that are large and well connected. Reducing the barrier effect of roads and traffic can therefore improve population persistence for a species in an area. It is important to realize that the road sections where the barrier effect may need to be mitigated most urgently, are not necessarily the same road sections where direct road mortality occurs most frequently. In fact, improved connectivity across roads may also be needed where there is no evidence of direct road mortality at all, potentially because the barrier effect is so substantial that animals do not even attempt to cross the road. Nonetheless, reducing the barrier effect on such locations may lead to a larger effective population size because it is better connected thus has a higher population survival probability. Furthermore, improving connectivity across roads may not only be based on the current distribution and movements of animals. It may also be based on conservation efforts that aim to restore habitat and movement corridors across the wider landscape, and on the dispersal of individuals that move to far away areas. Dispersing animals may strengthen the viability of small and isolated populations, but they may also colonize or recolonize areas that are not currently occupied by that species at all. Besides improved population persistence, habitat connectivity across roads may also be required for species that have seasonal migration. This may involve small-scale movements (e.g., hundreds of meters for certain amphibian species that move between winter habitat and breeding habitat) or large-scale movements (e.g. dozens or even hundreds of kilometers for certain ungulate species). In some cases, there may be substantial direct road mortality where roads bisect such seasonal migration corridors, but that is not necessarily the case.

Here we summarize existing knowledge about the presence and movements of two species in and around the Refuge; elk (Figure 11) and Preble's meadow jumping mouse.

Figure 11: Elk herd on Rocky Flats National Wildlife Refuge.

3.2 Elk

Over the last years the size of the elk herd on the Refuge was between 200-250 animals (U.S. Fish and Wildlife Service 2022b). However, after the Marshall fire on 30 December 2021, elk from north of Hwy 128 joined the elk on the Refuge and the number of elk on the Refuge grew to about 350 animals in 2022, which is above the management objective (U.S. Fish and Wildlife Service 2022b). Maps showing the locations of GPS-collared elk in and around the Refuge were obtained (source: Joe Halseth, Colorado Parks and Wildlife). The collars were on a 12-hour location interval (3 am, 3 pm) and the lines connect subsequent locations but do not necessarily reflect the true travel path of the animals.

GPS-collared elk from the herd that resides mainly in the Refuge cross Hwy 128 regularly, but cross Hwy 93 only occasionally (Figure 12). GPS-collared elk from the herd that resides mainly west of Hwy 93 (Plainview herd) were not observed crossing Hwy 93 into the Refuge or into the area north of Hwy 128 (Figure 13). These movement data suggest that elk mostly stay away from the main roads; they are mostly confined to the meshes within the road network with the highways being partial or near complete barriers. The elk also seem to spend most of their time on the legacy site in the center of the Refuge where the public is not allowed and where human disturbance is lowest.

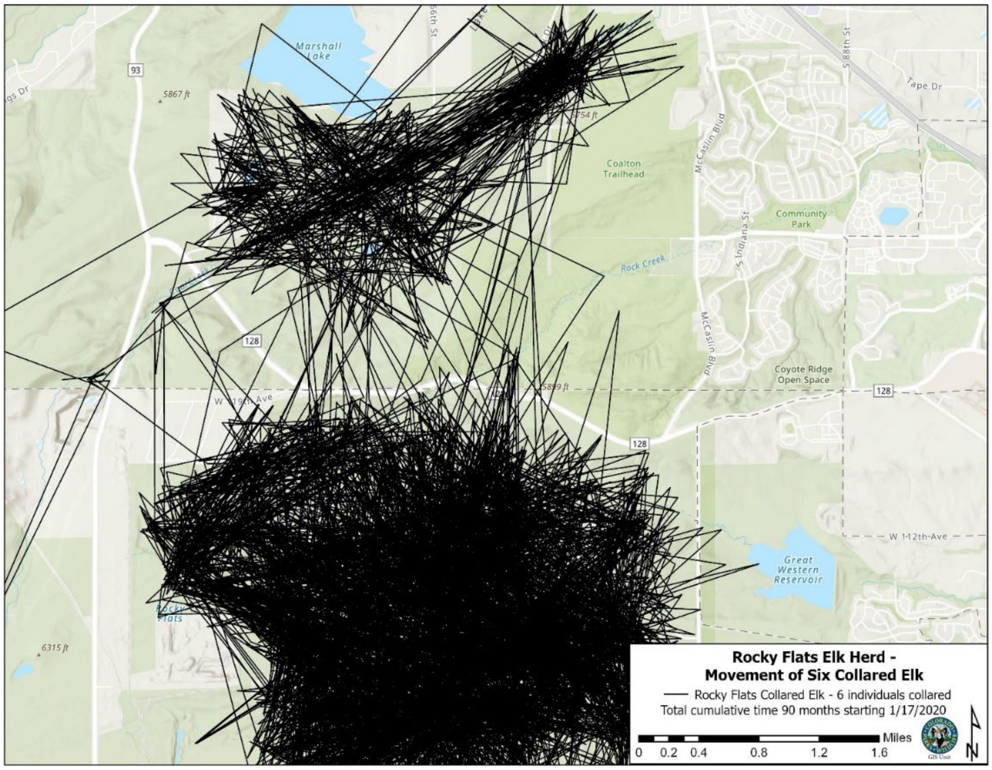

Figure 12: Locations and movements of GPS-collared elk from the Rocky Flats National Wildlife Refuge herd (Source: Joe Halseth, Colorado Parks and Wildlife).

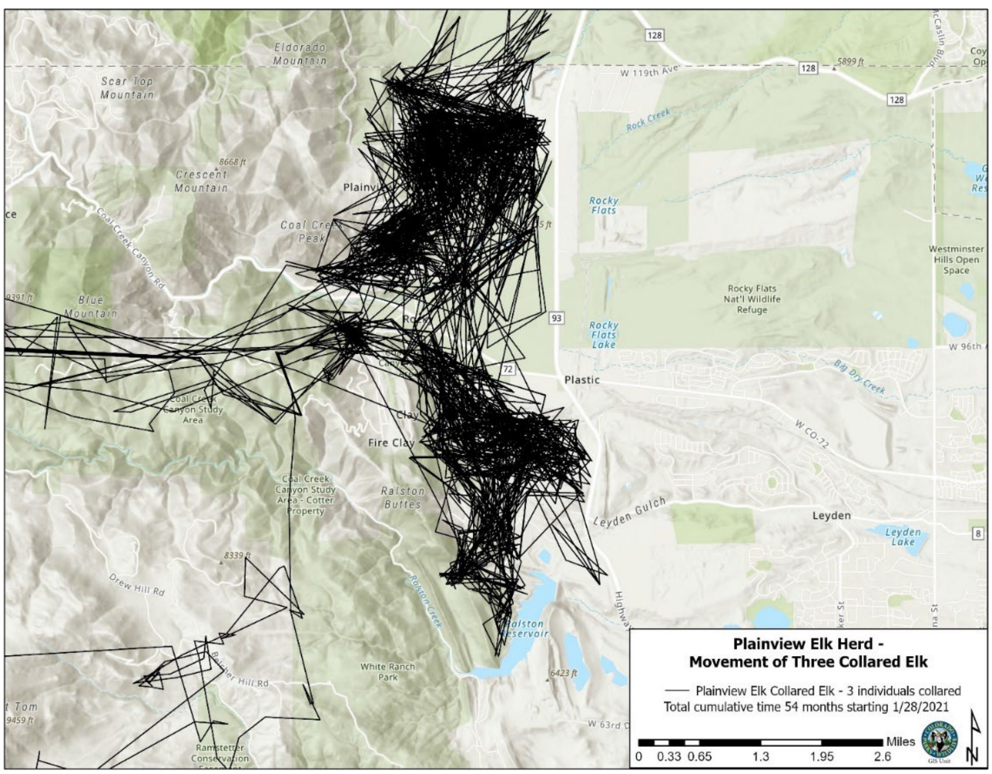

Figure 13: Locations and movements of GPS-collared elk from the Plainview herd (Source: Joe Halseth, Colorado Parks and Wildlife).

3.3 Preble's meadow jumping mouse

The Refuge includes designated critical habitat for the Preble's meadow jumping mouse. Critical habitat equals designated stream drainages plus 120 meters outward on each side. While there have been observations of Preble's meadow jumping mouse on the Refuge in the past, there have been no confirmed observations since 2003 (U.S. Fish and Wildlife Service 2018b). Small mammal surveys in 2014, 2015, 2016, and 2017 did not detect any Preble's meadow jumping mouse on the Refuge, although this may be because of relatively low sampling effort (U.S. Fish and Wildlife Service 2018b).

The likely decline of Preble's meadow jumping mouse on the Refuge is potentially related to changes in water management on the Refuge after industrial use stopped and human-made water retention ponds were removed (Personal Communication, Alison Michael, Colorado Department of Transportation's Liaison at the USFWS, retired). In addition, hotter and dryer conditions over the years may have further contributed to a reduction in suitable habitat, and the potential disappearance of the species from the Refuge (Personal Communication, Alison Michael, Colorado Department of Transportation's Liaison at the USFWS, retired). Nonetheless, habitat restoration along riparian corridors, as well as making creek crossings under highways more suitable for Preble's meadow jumping mouse may allow for the species to increase their population size on the Refuge again through population growth, recolonization, or both (Trainor et al. 2007, Personal Communication, Alison Michael, Colorado Department of Transportation's Liaison at the USFWS, retired). Habitat restoration would include wetter conditions, including having water in the creek, and taller grasses and more woody vegetation along the creeks, e.g. through the exclusion of livestock from the riparian corridors (Trainor et al. 2007, 2012). Note that Preble's meadow jumping mouse can move over long distances and has also been observed in culverts under roads (Meaney et al. 2007). "A radio-collared mouse at Rocky Flats National Wildlife Refuge was observed moving 764 feet from its point of original capture in Rock Creek perpendicularly into a tributary in a 24-hour period (Personal communication, Thomas Ryon, National Renewable Energy Laboratory through Personal Communication, Alison Michael, Colorado Department of Transportation's Liaison at the USFWS, retired).

4 Existing conditions

4.1 Introduction

The Refuge is surrounded by roads to the west, north, and east, and has developments just beyond its southern boundary (Figure 14). Hwy 93 has an estimated Annual Average Daily Traffic Volume (AADT) of about 18,000 vehicles, Hwy 128 about 4,200 vehicles, and Indiana St. about 7,000 vehicles (Michael Baker International 2016, CDOT 2023). There are several water bodies in the area that are likely important to ungulates, especially during the dry summer months (Figure 14). The area mostly consists of dry grassland with some shrubs and trees along some of the creeks (Figure 15, 16).

Figure 14: Map of Rocky Flats National Wildlife Refuge showing highways and associated mile reference points, creek crossings and water bodies.

Figure 15: Rocky Flats National Wildlife Refuge mostly consists of dry grasslands. This image was made from just east of the center of the Refuge, looking east towards Indiana St. and Great Western Reservoir.

Figure 16: Shrubs and trees along Rock Creek, near the Lindsay Ranch buildings.

4.2 Creek crossings

The roads surrounding the Refuge cut across the following creeks:

- Woman Creek (Hwy 93, mile reference post 8.40).
- Coal Creek (Hwy 93, mile reference post 10.95).
- Coal Creek (Hwy 128, mile reference post 0.47).
- Rock Creek (Hwy 128, mile reference post 2.54).
- Walnut Creek (Indiana St., 0.62 mile south of junction with Hwy 128).
- South Woman Creek (Indiana St., 2.25 mile south of junction with Hwy 128).

These existing crossing structures were visited in November 2022 and photographed (see following sections). There was limited monitoring of two of these structures with a wildlife camera (Source: Will Keeley, City of Boulder, Open Space and Mountain Parks). Wild mammal species observed at these 2 structures included:

- Coal Creek (Hwy 93, mile reference post 10.95): coyote and bobcat.
- Rock Creek (Hwy 128, mile reference post 2.54): coyote, bobcat, mink, striped skunk, raccoon, fox squirrel, rock squirrel, cottontail sp., and black bear.

4.2.1 Woman Creek (Hwy 93, mile reference post 8.40)

The crossing for Woman Creek along Hwy 93 (mile reference post 8.40) consists of a double culvert (Figure 17, 18).

Figure 17: Double culvert, Woman Creek (Hwy 93, mile reference post 8.40), east side, outflow.

Figure 18: Double culvert, Woman Creek (Hwy 93, mile reference post 8.40), east side, outflow.

4.2.2 Coal Creek (Hwy 93, mile reference post 10.95)

The crossing for Coal Creek along Hwy 93 (mile reference post 10.95) consists of a divided box culvert (Figure 19, 20, 21).

Figure 19: Surroundings, Coal Creek (Hwy 93, mile reference post 10.95), east side, looking south.

Figure 20: Divided box culvert, Coal Creek (Hwy 93, mile reference post 10.95), west side, inflow.

Figure 21: Surroundings, Coal Creek (Hwy 93, mile reference post 10.95), east side, outflow.

4.2.3 Coal Creek (Hwy 128, mile reference post 0.47)

The crossing for Coal Creek along Hwy 128 (mile reference post 0.47) consists of a divided box culvert (Figure 22, 23).

Figure 22: Divided box culvert, Coal Creek (Hwy 128, mile reference post 0.47), south side, inflow.

Figure 23: Divided box culvert, Coal Creek (Hwy 128, mile reference post 0.47), north side, outflow.

4.2.4 Rock Creek (Hwy 128, mile reference post 2.54)

The crossing for Rock Creek along Hwy 128 (mile reference post 2.54) consists of a box culvert (Figure 24, 25).

Figure 24: Surroundings, Rock Creek (Hwy 128, mile reference post 2.54), south side, looking east.

Figure 25: Surroundings, Rock Creek (Hwy 128, mile reference post 2.54), south side, inflow.

4.2.5 Walnut Creek (Indiana St., 0.62 mile south of junction with Hwy 128)

The crossing for Walnut Creek along Indiana St. (0.62 mile south of junction with Hwy 128) consists of a round culvert (Figure 26, 27, 28, 29).

Figure 26: Surroundings, Walnut Creek (Indiana St., 0.62 mile south of junction with Hwy 128),west side, looking south.

Figure 27: Surroundings, Walnut Creek (Indiana St., 0.62 mile south of junction with Hwy 128), west side, inflow.

Figure 28: Outflow structures, Walnut Creek (Indiana St., 0.62 mile south of junction with Hwy 128), east side, outflow.

Figure 29: Riprap at outflow, Walnut Creek (Indiana St., 0.62 mile south of junction with Hwy 128), east side, outflow.

4.2.6 South Woman Creek (Indiana St., 2.25 miles south of junction with Hwy 128)

The crossing for South Woman Creek along Indiana St. (2.25 miles south of junction with Hwy 128) consists of a round culvert (Figure 30, 31, 32).

Figure 30: Riprap at inflow, South Woman Creek (Indiana St., 2.25 mile south of junction with Hwy 128), west side, inflow.

Figure 31: Riprap inside culvert, South Woman Creek (Indiana St., 2.25 mile south of junction with Hwy 128), west side, inflow.

Figure 32: Riprap at outflow, South Woman Creek (Indiana St., 2.25 mile south of junction with Hwy 128), east side, outflow.

4.3 Fences

There are right-of-way fences or livestock fences along the highways, both on the side of the Refuge, and the other side of the highways (Figure 33, 34). These fences are not designed to keep large wild ungulates off the highway, but they can cause injuries, and even entanglement or death of large wild ungulates. Should the fences be required to keep livestock off the road, then they are likely more detrimental to wildlife then needed as wildlife friendly livestock fence designs are available (see e.g., Paige 2015).

Figure 33: Right-of-way fence, Hwy 93, east side, near mile reference post 8.4.

Figure 34: Right-of-way fence, Hwy 93, east side, near mile reference post 11.3.

4.4 Wildlife warning signs

There are several standard wildlife warning signs along the roads surrounding the Refuge (Figure 35, 36).

Figure 35: Elk warning sign, southbound on Indiana St., about 0.1 mile from the junction with Hwy 128.

Figure 36: Deer warning sign, northbound on Indiana St., about 2.6 mile from the junction with Hwy 128.

4.5 Non-motorized trail system

There is a non-motorized recreational trail system on the Refuge (Figure 37). These trails connect, or could connect, to non-motorized trails on the other side of Hwy 93, Hwy 128, Indiana St., and to trails south of the Refuge. Specifically, there is a proposal to connect the trails with a bridge above the traffic across Indiana St., just south of Great Western Reservoir (CPR 2017). In addition, an underpass is proposed to connect the trails on either side of Hwy 128.

Figure 37: Trailhead along the southern edge of Rocky Flats National Wildlife Refuge, near W 95th Ln.

5 Effective mitigation measures

5.1 Introduction

This chapter describes effective mitigation measures aimed at:

- Improving human safety through fewer collisions with large wild mammals.
- Reducing animal-vehicle collisions, especially for large wild mammals.
- Improving habitat connectivity for large wild mammal species and one small mammal species in specific, the Preble's meadow jumping mouse.

While dozens of mitigation measures have been described, implemented, or evaluated for their effectiveness, large mammal fences in combination with wildlife crossing structures are the most robust and effective mitigation measure to both reduce collisions with large and small animal species and maintain or improve connectivity for wildlife (Huijser et al. 2021). However, it is important to be aware of the different functions of fences vs. the function of crossing structures:

Fences

- The primary function of wildlife fences is to keep the target species off the road (Huijser et al. 2016). In the case of large wild mammals this improves human safety. In addition, all animal species, regardless of their size, can benefit through having fewer animals killed or injured on the road, if the fence is a barrier to them.
- Since fences alone would result in an absolute or near-absolute barrier for the target species and other species for which the fence acts as a barrier, fences are typically combined with safe crossing opportunities for wildlife, especially wildlife crossing structures (underpasses and overpasses). In this context, the secondary function of wildlife fences is to guide or funnel wildlife species to these crossing structures (Dodd et al. 2007, Gagnon et al. 2010).

Crossing structures

- The function of wildlife crossing opportunities (i.e. underpasses or overpasses) is to provide safe crossing opportunities for the species the crossings are designed for. The connectivity across roads may be rooted in the need to provide access to food, water, or shelter on a near daily basis, to address genetic or demographic needs for selected species, to allow for seasonal migration (e.g. for some large ungulates), to allow for dispersal to promote colonization or recolonization of areas nearby or further away, or to allow for ecosystem processes in general (biotic and abiotic parameters) to continue across the road, including those associated with climate change (e.g. Kramer-Schadt et al. 2004; Clevenger & Huijser 2011; Sawaya et al. 2013; 2014; Lister et al. 2015; Sawyer et al. 2012, 2016; Jarvis et al. 2019). Note that crossing structures without fences do not necessarily reduce direct road mortality for wildlife (Rytwinski et al. 2016).

Fences and wildlife crossing structures are almost always implemented together, regardless of whether the primary objective is to reduce animal-vehicle collisions or to reduce the barrier effect of roads and traffic for wildlife. However, the road sections where the measures are implemented are very much dependent on the primary objectives, and if they relate to reducing collisions and direct road mortality, or improving connectivity for selected wildlife species. If the objective is to improve human safety, the road sections need to have a relatively high concentration of collisions, typically with common large ungulates. If the objective is to improve connectivity, the selected road sections need to be where connectivity is needed most, e.g. to connect or reconnect small fragmented populations or to allow for recolonization. This implies that if the objective is to improve connectivity, that direct road mortality does not have to be present or substantial. Moreover, the target species does not even have to be currently present in the adjacent areas. In other words, crossing structures may also be required for population persistence in areas where the target species now has low abundance or where it is currently entirely absent.

It is important to be aware of the limitations of existing crossing structures that were not built for wildlife versus designated wildlife crossing structures. While designated wildlife crossing structures should be located where connectivity for wildlife is needed most, existing structures that were not built for wildlife are not necessarily located where connectivity for wildlife is needed most. Nor are such existing crossing structures necessarily of the right type (e.g. overpass vs. underpass) or dimensions given the target species, and there are typically limits to potential modifications to existing structures to improve the suitability for the target species.

In conclusion, fences and wildlife crossing structures are almost always implemented together, regardless of whether the primary objective is to reduce animal-vehicle collisions or to reduce the barrier effect of roads and traffic for wildlife. However, the road sections where the measures are implemented are very much dependent on the primary objective, and they may include road sections where the target species is not hit or no longer hit, and where the target species may have low population density or where it is currently not present at all.

5.2 Fences and other barriers

Fence characteristics for the large mammal species (i.e. larger than a coyote) that are present in or around the Refuge are summarized in Table 1. Should smaller species such as coyote, bobcat or American badger also be included in the list of target species, chain-link fence material is recommended. For coyote and American badger, a dig barrier, 1 ft dug into the ground, is also required (Huijser et al. 2022).

Table 1: Indicative fence characteristics for selected potential wild large mammal target species in in Rocky Flats National Wildlife Refuge and surroundings. Note that fence height may have to be adjusted if the fence is positioned on a slope. Based on Huijser et al. 2022.

Target species	Fence height	Posts	Fence material	Dig barrier	Overhang	High tensile top wire[1]
White-tailed deer, mule deer, elk, moose	8 ft (2.4 m)	Wood	Mesh-wire	No	No	Yes
Black bear[2]	10 ft	Metal	Chain-link	Yes	Yes	Yes
Mountain lion[3]	10 ft	Metal	Chain-link	Yes	Yes	Yes

[1] Especially recommended in areas with trees where a tree may fall on the fence.
[2] Black bears can climb wooden posts and insert their feet in large mesh size of mesh-wire fence. Tall fence, metal posts, fence material with small mesh size (e.g. chain-link), fence overhang, and dig barriers are recommended. Strands of electrified wire can further increase functionality of the barrier. Alternatively, strands of electrified wire, e.g. one at 3-4 ft and one near the top, can be combined with an 8 ft fence, but data on effectiveness are not available.
[3] Mountain lions are good climbers and jumpers. Very tall fences, metal posts, small mesh sizes, and overhang are recommended.

5.3 Crossing structures

Different species are more or less likely to use certain types and dimensions of wildlife crossing structures. For a crossing structure type and dimension to be considered suitable for a species, the likelihood that the structure will be used by an animal that approaches a structure should be "high". While there are no established minimum norms for acceptance, selecting a structure type and dimensions that have a high acceptance rate (perhaps at least 70-80%) for the target species seems logical. In this context it is important to remember that having observed "use" by a species does not mean that it is defensible to claim that that that structure type and its associated dimensions are "suitable", as a structure with a very low acceptance rate still has some "use". By definition, a crossing structure that is "suitable" for the target species is much more likely to be found effective in reaching objectives related to the connectivity than a crossing structure that may be "used" but that may not have a high acceptance rate. Data on acceptance (and thus suitability) are not common (but see e.g. Purdum 2013; Huijser et al. 2019; Denneboom et al. 2021). Instead, we summarize the suitability of different types of crossing structures and dimensions based on data analyzed by the authors, supplemented by their interpretation of the literature and their opinion (Table 2, 3). The approach slope of a crossing structure likely also influences the acceptance of a structure by wildlife. While data on this parameter are not available, the authors of this report suggest a very gradual approach to an underpass and overpass (perhaps 10-15% at a maximum). This may be especially relevant in open and flat landscapes compared to landscapes with lots of cover and topography. Gradual approaches may impact natural vegetation in the surroundings. However, the vegetation on the approaches may be restored after construction, and the disturbance is only once. The structure itself may only have a lifespan of 75-80 years (Huijser et al., 2009). Therefore, the soil and vegetation on top of an overpass or at an underpass may be disturbed each time the structure is replaced.

Table 2: Crossing structure types and dimensions.

Safe Crossing Opportunity type	**Indicative dimensions (as seen by the animals)**	**Image**
Wildlife overpass	50-70 m wide	

Safe Crossing Opportunity type	Indicative dimensions (as seen by the animals)	Image
Open span bridge	12-30 m wide, ≥5 m high	
Large mammal underpass	7-8 m wide, 4-5 m high	
Medium mammal underpasses	0.8-3 m wide, 0.5-2.5 m high	
Small-medium mammal pipes	0.3-0.6 m in diameter	

Table 3. Suitability of different types of mitigation measures for selected large and small mammal species (for 2-3 lane highways [25-35 m (82-115 ft)] wide road without median) (Based on Huijser et al. 2022).

● Recommended/Optimum solution; (●) Likely, but no data, ⭘ Likely marginal or somewhat possible if adapted to species' specific needs; ⊗ Not recommended; ? Unknown, more data required; — Not applicable (Clevenger & Huijser 2011, O'Brien et al. 2013, Ford et al. 2017, 2022, Huijser et al., preliminary data; Clevenger, unpublished data).

	Wildlife overpass	Open span bridge	Large mammal underpass	Medium mammal underpass	Small-medium mammal pipes
Mountain lion	●	●	●	⊗	⊗
Deer spp.	●	●	●	⊗	⊗
Elk	●	●	⭘	⊗	⊗
Moose	●	●	⭘	⊗	⊗
Black bear	●	●	●	⊗	⊗
Badger	●	●	●	●	●
Grey fox	●	●	●	●	●
Porcupine	●	●	●	?	⊗
Raccoon	●	●	●	●	?
Red fox	●	●	●	●	●
Skunks	●	●	●	●	?
Squirrels	●	●	●	⊗	⊗

Crossing structure specifications for culverts at three ditches that were also intended to provide connectivity for Preble's meadow jumping mouse were based on engineering plans from the Colorado Department of Transportation (repository in Huijser & Gunson, 2019). The culverts are shown in Figure 38, 39, and 40. As for as the authors of this report know, there are no data on use or potential effectiveness of these structures for Preble's meadow jumping mouse. However, from the images it is evident that there is no cover, let alone live vegetation inside these culverts. Much larger structures (greater width and height) that would allow light and moisture to come in the underpasses would likely result in riparian vegetation, at least near the entrances of the underpasses.

Figure 38: Culvert at Davidson Ditch (Hwy 36, mile reference post 40.8).

Figure 39: Culvert at Goodhue Ditch (Hwy 36, mile reference post 41.2).

Figure 40: Culvert at Marshallville Ditch (Hwy 36, mile reference post 41.5).

5.4 Spatial scale of mitigation measures

Many mitigation measures are not implemented at a sufficiently large spatial scale (Huijser & Begley 2022). In some cases, the habitat may be homogeneous and extensive and occur for more than several miles alongside a road. For mitigation measures to be effective, barriers should extend along the entire habitat, and at least cover the full length of known roadkill hotspots, animal crossing areas, and adjacent buffer zones (Ward 1982; Huijser et al. 2015). The length of the buffer zone is at least partially influenced by the home range size of the target species. For white-tailed deer in North America 1 km long buffer zones have been suggested (starting from each end of the hotspot) (Huijser et al. 2008). When designing wildlife fencing (in combination with safe crossing opportunities for wildlife) consider implementing the fencing over at least 3 miles (5 kilometers) of road length rather than at shorter road sections (Huijser et al. 2016). Note that fences may need to be implemented over long distances if the objective is to reduce the overall number of collisions rather than just reduce the number of collisions in the fenced road section and move them to an adjacent road section (Huijser & Begley 2022).

5.5 Spacing crossing structures

The appropriate spacing of wildlife crossing structures can be determined in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes (e.g. water flow). It is good practice to design structures that are primarily needed for hydrology in such a way that they can also function for wildlife. However, only providing wildlife crossing opportunities in low and wet areas means that no connectivity is provided for species that depend on high and dry habitat. Thus, a possible strategy is to identify the different ecosystems and habitat types (not just streams, rivers or wetlands) and ecosystem processes that permeability needs to be provided for and then provide appropriate mitigation measures in each of those ecosystems or habitat types.
- Allowing a wide variety of species, or selected targets species, to change their spatial distribution drastically, for example in response to climate change.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (including allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements (e.g. mule deer, pronghorn or elk) as this can be seen as a component of the biological integrity of an ecosystem.
- Allowing individuals of selected target species that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is substantially permeable to those species, at least for the individuals that live close to the road.

A further complication is that individuals that disperse, that display seasonal migration, or that live in the immediate vicinity of a road may display differences in behavior with regard to where and how they move through the landscape, how they respond to roads, traffic, and associated barriers (e.g. wildlife fencing), and their willingness to use safe crossing opportunities. For example, dispersing individuals may grow up far away from the areas adjacent to roads and may shy away from human disturbances and human made features, they may not move through habitat the way we might expect them to, and they typically travel long distances, much further and quicker compared to resident individuals. Safe crossing opportunities may not be encountered by dispersing individuals as they are new in the area and are not familiar with their location, and when confronted with a road or associated wildlife fence they may return or change the direction of their movement before they encounter and use a safe crossing opportunity. Furthermore, if dispersing individuals do encounter a safe crossing opportunity, they may be more hesitant to use it compared to resident individuals that not only know about their location, but that also have had time to learn that it is safe to use them. Since dispersal can be a relatively rare phenomenon, one may not be able to afford to have a dispersing individual fail to cross the road. Therefore, even though dispersers travel much further than resident individuals, safe crossing opportunities for dispersers may not allow for a greater distance between safe crossing opportunities compared to safe crossing opportunities for resident individuals.

Full scale population viability analyses can be very helpful to compare the effectiveness of different configurations of safe crossing opportunities. However, there is also a simpler approach that bases the distance between safe crossing opportunities on the diameter of the home range of the species concerned (Figure 41). In theory, this allows individuals that have the center of their home range on the road to have access to at least one safe crossing opportunity. However, individuals that may have had their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (Figure 42). Finally, this approach assumes homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat quality may vary greatly, causing variations in density and home range size of individuals and irregular shaped home ranges. Species that have smaller home ranges need the crossing structures to be closer together than species with large home ranges.

This approach does not necessarily result in viable populations for every species of interest, and that not every individual that approaches the road and associated wildlife fence, will encounter, and use a safe crossing opportunity. In addition, the approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the approach chosen is consistent, practical, can be based on available data, and is likely to result in considerable permeability of the road corridor and associated wildlife fencing for a wide array of species.

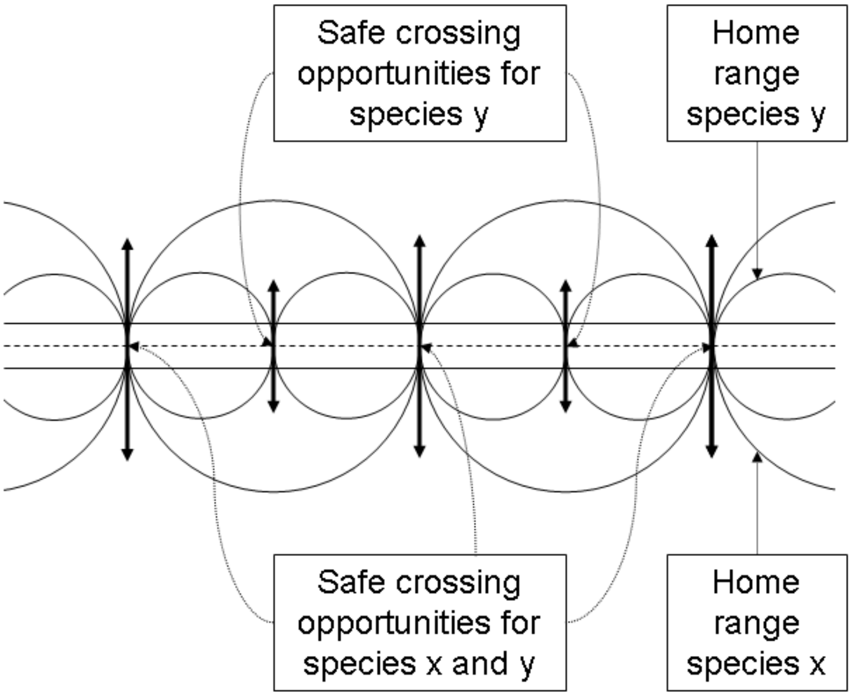

Figure 41. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

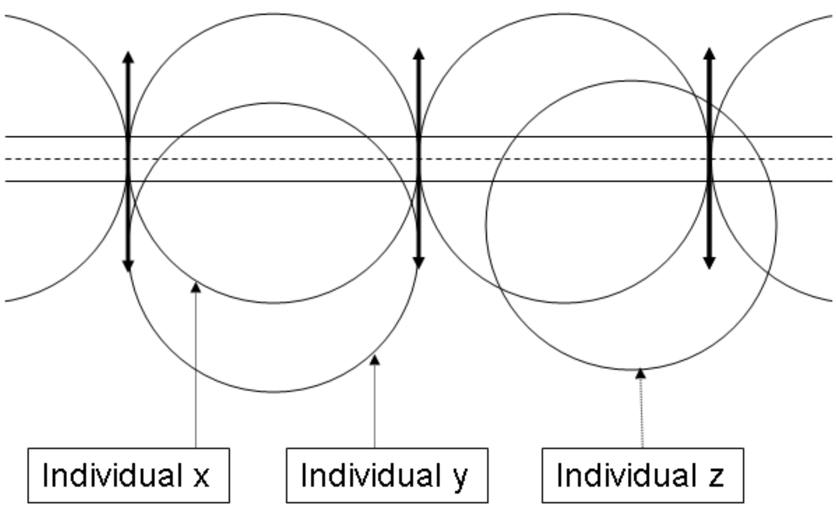

Figure 42. Schematic representation of home range for an individual (x) that has the center of its home range on the center of the road (access to two safe crossing opportunities), an individual (y) that has the center of its home range slightly off the center of the road exactly in between two safe crossing opportunities (no access to safe crossing opportunities), and an individual (z) that has the center of its home range slightly off the center of the road but not exactly in between two safe crossing opportunities (access to one safe crossing opportunity).

Another way to decide on "appropriate distance" between safe crossing opportunities is to evaluate what the spacing is for wildlife crossing structures on other wildlife highway mitigation projects. The average spacing for large mammal crossing structures in Montana (US Hwy 93 North and South), I-75 in Florida, SR 260 in Arizona, Banff National Park in Canada, and ongoing reconstruction on I-90 in Washington State is 1.2 mi (1.9 km) (range for the average spacing of structures in these individual areas is 0.5-1.8 mi (0.8-2.9 km)). However, the 1.2 mi (1.9 km) spacing is simply what people have done elsewhere, and it is not necessarily based on what may be needed ecologically, and the requirements for the target species in one area may be different from what is needed in another area.

Yet another way to decide on "appropriate distance" between safe crossing opportunities is to allow for all "meshes" within the road network to be accessible to the target species. This would result in each mesh being linked to at least one other mesh with an appropriate type and dimension of a crossing structure for the target species.

6 Recommendations

For wildlife fences to effectively reduce the number of collisions with large wild ungulates in a fenced road section, the fenced road section would need to be at least 3 miles long. However, for wide roaming species, including elk, there is still a risk of “moving” collisions to nearby road sections rather than really reducing the number of collisions in the area. Therefore, to achieve a substantial reduction in the collisions with large ungulates, especially elk, the entire length of Hwy 93, Hwy 128 and Indiana St. should be fenced (on both sides of the roads). Consider also placing a fence along the southern border near the houses to reduce the likelihood of human wildlife- conflicts and to reduce the likelihood of animals moving through the area with houses to cross at a fence- end. crossing

If wildlife fences are installed along the boundaries of the Refuge, they should be combined with suitable crossing structures for species that would otherwise be isolated from surrounding areas. Elk and moose are the most demanding species in the area, and they require either large open span bridges or overpasses (see Chapter 5) (Figure 43, 44). At creek crossings or in areas with fill, consider large open span bridges. For moose consider a minimum width of 40 ft (12 m) width and a minimum height of 15 ft (4.5 m) (Clevenger and Huijser 2011). Structures along creeks can be expected to be “in the correct location” for white-tailed deer, moose, black bear, mountain lion, bobcat, and Preble’s meadow jumping mouse. The bottomless nature of a bridge means that the soil and stream characteristics under the bridge can be similar to upstream and downstream from the crossing. Higher clearance (height) of the structure allows for more light and moisture inside the structure and would allow for vegetation (e.g. grasses, shrubs) to grow which would be an important habitat requirement for Preble’s meadow jumping mouse. Additional cover can be provided inside the structure through either natural material (e.g., root wads, tree branches, or rocks) or artificial material (e.g. concrete blocks with openings). Based on historical observations of Preble’s meadow jumping mouse (U.S. Fish and Wildlife Service 2018b), the following creek crossings seem most important to this species: Indiana St. at Walnut Creek, followed by Hwy 128 at Rock creek, and Indiana St. and Hwy 93 at Woman Creek. Though technically not on the Refuge, the creek crossings for Coal Creek (both along Hwy 93 and Hwy 28) can also be considered important to the potential recovery of Preble’s meadow jumping mouse on the Refuge as they would also provide access to the mesh within the road network that the Refuge is situated within. Note that these underpasses would be multifunctional crossing structures as their location, type and dimensions are influenced by both hydrology and wildlife movements. However, the location, type and dimensions are not optimal or suitable for all wildlife species. These recommendations are largely consistent with David Evans and Associates, Inc. (2018) and Kintsch et al. 2022.

Figure 43. Multifunctional underpass, The Netherlands. The underpass is for hydrology and wildlife.

Figure 44. Multifunctional underpass, Hwy 3, Crowsnest Pass, Alberta, Canada. The underpass is for hydrology and wildlife. Note how the substrate and stream dynamics are unaffected by the structure and how light and moisture reaches the entire area under the bride allowing for natural vegetation in the riparian and terrestrial zones.

Elk may still be hesitant to using large overspan bridges in drainages with limited visibility, and the authors of this report suggest 3 wildlife overpasses for this species; one across each of the 3 main roads around the Refuge (Hwy 93, Hwy 128, and Indiana St.) (Figure 45). It may well be that connectivity for large ungulates, including mule deer and elk, across Hwy 128 and Indiana St. is important for access to water as the GPS-collar data for elk show regular crossings across these roads. Hwy 93 has the highest traffic volume of the 3 roads (see Chapter 4) which seems to have resulted in a substantial barrier for large mammals, especially elk, already (see Chapter 3). Restoring connectivity for elk across Hwy 93 would allow for more natural and longer distance movements of the elk herd on the Refuge, and also allow for more contact with the Plainview herd west of Hwy 93. It is best to situate overpasses designed for elk at or near where elk are known to come close to the roads and where they cross the roads. A roadcut would be a convenient topographic feature that would make the approaches more gradual and that would reduce the amount of soil that would need to be moved. Based on the movements of GPS-collared elk, a potential overpass location along Hwy 93, could be just north of Coal Creek (around mile reference post 11.3), where there is small roadcut (Figure 46). Along Hwy 128, consider an overpass between mile reference post 1.4 and 3.2, potentially around mile reference post 3.0 where there is a roadcut (Figure 47). Along Indiana St., consider an overpass around 0.8 miles or 1.3 miles south of the junction with Hwy 128 where there are roadcuts (Figure 48, 49). Mule deer may use large open span bridges at creeks as well as overpasses (Sawyer et al. 2016).

Figure 45. Wildlife overpass, primarily for pronghorn (Antilocapra americana) (46 m (150 ft) wide), on the Path of the Pronghorn, Trapper's Point, US Hwy 191, near Pinedale, Wyoming, USA.

Figure 46. The roadcut along Hwy 93, around mile reference post 11.3.

Figure 47. The roadcut along Hwy 128, around mile reference post 3.0.

Figure 48. The roadcut along Indiana St., about 0.8 miles south of the junction with Hwy 128.

Figure 49. The roadcut along Indiana St., about 1.3 miles south of the junction with Hwy 128.

The location and design of designated wildlife crossing structures are optimized for the target species. However, it is worthwhile to explore the potential for multi-functional crossing structures for which the location, type, and dimensions of the structures would not only be influenced by wildlife. Overspan bridges at creek crossings, when implemented, are already an example of a multifunctional crossing structure. They are influenced by both hydrology and wildlife. However, it is also possible to design multifunctional underpasses and overpasses that are also influenced by non-motorized trails, especially near urban centers where demand for such trail systems is high (van der Ree & van der Grift 2015). The Refuge and the surrounding lands already have a system of trails for non-motorized recreational use by people from the greater Denver area. Similar to wildlife, people using non-motorized trails have trouble crossing busy roads. It is not only potentially dangerous, but it also affects the otherwise tranquil experience of being on the trails.

Non-motorized human co-use can reduce wildlife use of crossing structures (Clevenger & Waltho 2000), but depending on the species, wildlife use of the structures can also be positively associated with human co-use (review in van der Ree & van der Grift 2015 et al. 2015). However, in multi-functional landscapes, the species that are still present can be expected to have adapted to a certain degree of human presence and disturbance. While wildlife use may remain similar when combined with human co-use, there may still be a shift where wildlife now primarily use the structure during the night when people are absent (van der Ree & van der Grift 2015). In those situations, wildlife use of crossing structures may continue to reach connectivity targets, especially when the multifunctional crossing structures are specifically designed for wildlife and human co-use. Examples of such design characteristics include (review in van der Ree & van der Grift 2015) (Figure 50, 51, 52, 53, 54):

1. A wider structure than a structure that is only for wildlife. The extra width should be at least the space taken by the recreational trail and the noise and visual barrier in between the trail and the wildlife zone (see one of the next points). If negative impacts spill further into the wildlife zone, additional width is recommended. If the target species include species that are sensitive to human presence and disturbance, increase the width even further.
2. Have external screens on the outer edges of the structure to reduce noise and light from vehicles on the structure. This not only reduces disturbance in the wildlife zone, but it also reduces disturbance along the trail for people, and potentially for horses in case of equestrian uses.
3. The recreational zone should be a narrow but well-maintained trail, located towards one of the 2 edges of the structure.
4. Fencing, earth berms and vegetation (e.g. shrubs) in between the trail and the wildlife zone can reduce human impacts radiating from the recreational path towards the portion of the structure that is designated for wildlife. Such barriers discourage people from leaving the trail and also reduce visual and audio disturbances in the wildlife zone. These internal barriers are especially important if the target species are sensitive to human presence and disturbance.

If the target species is rare, threatened, highly sensitive to human presence, or potentially dangerous to people, human co-use of a wildlife crossing structure should probably be avoided. In these cases, it may be better to design two separate structures; one for wildlife and one for a non-motorized trail.

Figure 50. Multifunctional underpass under A28 motorway near Hilversum, The Netherlands. The trail for non-motorized human use is on the far-right side. A berm with root wads, small trees and shrubs in the center separates the trail from the wildlife zone further to the left. Beyond the black screen on the far left there is a 2-lane road.

Figure 51. Multifunctional overpass across a 2-lane road and railroad tracks with a trail for non-motorized recreation on the left side, Natuurbrug Zanderij Crailoo, The Netherlands. The trail has a berm with trees and shrubs to reduce human presence and disturbance in the wildlife zone that is further to the right. The habitat on top of the overpass is dry and sandy grassland and heathland.

Figure 52. Multifunctional overpass across a 2-lane road and railroad tracks with a trail for non-motorized recreation, Natuurbrug Zanderij Crailoo, The Netherlands. The trail has a berm with trees and shrubs on the left-hand side to reduce human presence and disturbance in the wildlife zone that is further to the left. There is also a berm with trees and shrubs to the right of the trail, reducing visual and noise disturbance from vehicles towards the trail.

Figure 53. Horseback riders on a trail on a multifunctional overpass across a 2-lane road and railroad tracks. The trail is for non-motorized recreation. Natuurbrug Zanderij Crailoo, The Netherlands. The trail has a berm with trees and shrubs on the right-hand side to reduce human presence and disturbance in the wildlife zone that is further to the right. There is also a berm with trees and shrubs to the left of the trail, reducing visual and noise disturbance from vehicles towards the trail.

Figure 54. Bicyclists on a trail on a multifunctional overpass. The trail is for non-motorized recreation. Soest, The Netherlands. The trail has a fence and a berm with trees and shrubs on the left-hand side to reduce human presence and disturbance in the wildlife zone that is further to the left.

In the case of the Refuge, elk have somewhat adapted to human presence and disturbance by concentrating in the center of the Refuge where the public does not have access. Most of the elk (and mule deer) crashes occur at night (see Chapter 2), further indicating that road crossings already happen predominantly at night. In this context, multifunctional overpasses for elk and people may be an option as moving connectivity for large ungulates towards the dark hours has already happened given the human presence and disturbance in the area. The combined interests of wildlife connectivity and a safer and better-connected network of non-motorized trails could increase public support and associated funding for the construction of multifunctional crossing structures. An overpass for a non-motorized trail has already been suggested across Indian St. around mile reference post 1.3 (City and County of Broomfield 2016, FHWA 2023). This connector would be important to the local network of trails as well as the Rocky Mountain Greenway (RMG) that would connect the Refuge, Rocky Mountain Arsenal National Wildlife Refuge, Two Ponds National Wildlife Refuge in Arvada, and Rocky Mountain National Park (City and County of Broomfield 2016). This location would likely also be suited for a wildlife overpass for elk (see earlier).

Should no wildlife crossing structures are provided, then there probably should also be no wildlife fences that would make the Refuge into an island, isolated from its surroundings. If no crossings would be provided, consider replacing right-of-way or standard livestock fences with wildlife friendly livestock fences on both sides of the highway if the landowners or managers agree (Paige et al. 2015). If the fences are not needed to keep livestock of the road, it is possible to consider removing the wires and leaving only the posts to delineate the right-of-way boundary. While wildlife friendly livestock fences or removing wires is likely to reduce the likelihood of wildlife injuries and fatalities when crossing fences, they do not reduce the barrier effect of the roads and traffic. This means that Hwy 93 would continue to be a near absolute barrier and that the barrier effect of Hwy 128 and Indiana St. would continue to grow with expected increases in traffic volume. Increased barrier effect of Hwy 128 and Indiana St. may gradually reduce access to water for large mammals, including elk. This may have consequences for their continued presence on the Refuge.

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