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Use and Effectiveness of Wildlife Crossing Structures with Short Sections of Wildlife Fencing

Elizabeth Rose Fairbank
The University of Montana

USE AND EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES WITH SHORT SECTIONS OF WILDLIFE FENCING IN WESTERN MONTANA

By:

ELIZABETH ROSE FAIRBANK

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Approved by:

Sandy Ross, Dean of The Graduate School
Graduate School

Vicki Watson PhD, Chair
Environmental Studies
University of Montana

Marcel P. Huijser PhD
Western Transportation Institute
Montana State University

Jonathan Graham PhD
Department of Mathematical Science
University of Montana

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Use and effectiveness of wildlife crossing structures with short sections of wildlife fencing in western Montana.

Chairperson: Vicki Watson, PhD

Our growing transportation infrastructure in the United States has many direct and indirect impacts to wildlife populations. Humans are also impacted by the interaction of roads and wildlife in terms of wildlife-vehicle collisions (WVC's); which annually result in: hundreds of human fatalities, tens of thousands of human injuries, and billions of dollars in property damage. In response to concerns for wildlife and human safety, road mitigation measures are becoming an increasingly important tool for transportation agencies to minimize the risks of WVC's. The construction of multiple wildlife crossing structures in combination with wildlife fencing have been shown to reduce WVC's by over 80% where extensive continuous wildlife fencing (covering many miles) has been implemented, and by 50-60% in areas where more limited fencing (covering 1-3 miles) has been implemented. In areas where land use is dominated by humans (agriculture, housing, access roads, etc.) such mitigation measures are not always possible or desirable. This results in a push towards more isolated crossing structures with little to no wildlife fencing to provide frequent road access and preserve landscape aesthetics. The effectiveness of isolated crossing structures with short sections of fencing (only a few hundred meters or less) is not well documented in terms of potential WVC reduction or wildlife use of the structures. In this study I investigate: the use of isolated crossing structures and fence ends by target species, the effect of fence length on at-grade crossings, and the ability of short sections of fencing to keep wildlife off the road. Overall, 82% of wildlife used the crossing structures for crossing as opposed to going around fence ends. Over the length of fence lengths sampled (3m-256m) there was no relationship between fence length and the number of crossings at fence ends. Deer were often foraging at fence ends, with nearly half of all foraging events occurring in the right of way (closer to the road than the fence is/would be). Overall, deer generally choose to use the crossing structures to get to the other side of the road, but they will still often be present in the right of way where they are not excluded with fencing. This indicates that while isolated crossing structures with short fencing may provide wildlife safe access to habitat on either side of the road, they may not provide the desired reduction in WVC's.

1. Introduction

As our population continues to grow in the United States, the number and width of roads also increases (USDOT 2011). Since 1980 an additional 183,000 miles of public roads have been constructed, an average of 6,500 miles of new roads each year (USDOT 2011). In the United States there are currently over 4.1 million centerline miles of public roads used by the 246 million registered vehicles (USDOT 2011). These roads have substantial impacts to the environment and wildlife, including but not limited, to habitat loss, degradation, and fragmentation, which can obstruct or impair critical daily, seasonal, and dispersal movements by wildlife (Clevenger et al. 2001, Hardy et al. 2007, Bond and Jones 2008; Huijser et al. 2008a & b, Beckman and Hilty 2010, among many others).

Roads also have a much more direct impact on wildlife: road mortality as a result of wildlife-vehicle collisions (hereafter WVC's). Besides the obvious impact to the individual animal, road mortality can also affect connectivity between populations on either side of the road, population size, population viability, and genetic variability, as well as representing a monetary loss (e.g. based on costs associated with the management of threatened or endangered species or the value of game animals to hunters) (Huijser et al. 2009, Ascensao et al. 2013). WVC's are not only dangerous to wildlife, they also result in serious risks to human safety and extensive property damage. In the United States there are an estimated one to two million large mammal-vehicle collisions each year, and the number continues to rise (Huijser et al. 2009). Annually, these wildlife-vehicle collisions result in hundreds of human fatalities, tens of thousands of human injuries, and billions of dollars in property damage (Huijser et al. 2008b; Huijser et al. 2009).

In response to these concerns, road mitigation measures are becoming an increasingly important tool for transportation agencies to minimize the risks of WVC's to human safety and wildlife populations (Beckman and Hilty 2010). The most promising mitigation method is the use of exclusion fencing (about 8 feet tall for common large ungulates such as white tailed deer (Odocoileus virginianus) and mule deer (Odocoileus hemionus)), combined with appropriately spaced wildlife crossing structures (such as culverts, underpasses, and overpasses). Crossing structures allow wildlife to cross over or under the road corridor without coming into contact with traffic (e.g. Clevenger et al. 2001, Dodd et al. 2007a&b, Huijser and McGowen 2010, van der Grift et al. 2013). Wildlife fencing keeps wildlife off the roads (thus reducing WVC's) and also funnels animals toward safe crossing opportunities that may be provided (Clevenger et al. 2001, Dodd et al. 2007a, Van der Grift et al. 2013). With appropriately spaced, appropriately located (based on local habitat), and appropriate type and dimensions of the structures, wildlife is less likely to breach the fence and access the fenced road corridor. So, safe crossing opportunities are not only good for habitat connectivity for wildlife, they also help further reduce WVCs (Huijser et al. 2008a). Wildlife crossing structures in combination with wildlife fencing have been shown to reduce WVC's with large mammals by over 80% in areas where extensive continuous wildlife fencing (covering many miles) has been implemented (Clevenger et al. 2001, Dodd et al. 2007a).

While continuous wildlife fencing over relatively long road sections combined with wildlife crossing structures can result in a substantial reduction in WVC's and substantial wildlife use of crossing structures, such mitigation measures are not always possible or desirable (Clevenger et al. 2001, Dodd et al. 2007a, Huijser et al. 2012). Such long sections of fencing can increase the barrier effect of roads if insufficient crossing structures are provided. This concern applies especially to species with smaller home ranges or those that are less mobile, making some land managers hesitant about applying extensive fencing (Jaeger and Fahrig 2004, Dodd et al. 2007a, Bissonette and Adair 2008, Huijser et al. 2008a). Additionally, much of the landscape in North America is heavily used by people (agriculture, houses, access roads, etc.), resulting in a push towards more isolated crossing structures with little to no wildlife fencing to provide frequent road access for people and preserve landscape aesthetics (many people are opposed to 8ft tall fencing and gates or cattlegaurds near their homes and businesses) (Huijser et al. 2012).

The effectiveness of more isolated crossing structures with short sections of fencing is not well documented in terms of potential WVC reduction or wildlife use of the structures, as wildlife may be hesitant to travel through crossing structures when other crossing opportunities exist (i.e. when road access is not blocked with fencing) (Ward 1982, Huijser et al. 2012). In Montana, monitoring of four road segments with multiple crossing structures tied together by 1-3 miles of wildlife fencing has shown a 50-60% reduction of WVC's within these sections (Huijser et al. 2013; MDT unpublished data). These road sections with more limited fencing (a few miles of road length at most) show substantially less WVC reduction (50-60%) when compared to studies with more extensive fencing (≥80% reduction), and could imply that with even shorter sections of fencing (only a few hundred meters or less), or no fencing, WVC reduction can likely be expected to be even lower.

While wildlife fencing can be effective in reducing WVC's, it has also been found to create the potential for WVC hotspots centered around the fence ends (Clevenger et al. 2001, McCollister and van Manen 2010). This fence end effect may impact only a small percentage of the fenced area in places where extensive wildlife fencing exists; however, it begins to have increasingly more influence on the effectiveness of the fencing in reducing WVC's as fence lengths decrease. That is, a larger percentage of the fenced section will be impacted by the fence end effect if only a few hundred meters of fencing exists as opposed to areas with many miles of fencing. This may be one factor influencing the lower WVC reduction observed in the studies with more limited fencing, and begs the question of how effective even shorter sections of fencing (a few hundred meters of less) can be at reducing WVC's when such a large portion of the fencing is likely to be impacted by the fence end effect.

In this study I ask the following questions about isolated crossing structures with short sections of wildlife fencing (covering <800m of the road):

1.) What proportion of large mammals (especially white-tailed deer) uses the suitable crossing structures to get to the other side of the road vs. crossing at-grade at the fence ends?
2.) What effect does fence length (<400m measured from the crossing structure to fence end) have on crossing structure use and at-grade crossings at fence ends?

3.) How effective are isolated crossing structures with short sections of fencing at keeping animals out of the roadway?

In order to address these questions, I monitored 10 large-mammal underpasses with varying short lengths of wildlife fencing (up to 400m from the crossing structure) and recorded large mammal road crossings through each crossing structure and across the road (at-grade).

2. Methods

2.1 Study Area

The study area is the U.S. Highway 93 road corridor in western Montana. Study sites are located within Flathead, Lake, Missoula, and Ravalli Counties and include the Flathead Indian Reservation. The landscape is characterized by the many mountain ranges, wide valleys, rivers, and drainages present in this northern Rockies region.

The road corridor extends north to south primarily through wide valley bottoms (the Flathead Valley north of Missoula, and the Bitterroot Valley south of Missoula) and is bounded to the east by the Swan, Mission, Rattlesnake Divide, and Sapphire Mountain Ranges and to the west by the Salish and Bitterroot Mountain Ranges. These glaciated valleys surround the Flathead and Bitterroot Rivers and are traversed by numerous drainages and spotted with glacial lakes, ponds, creeks, and wetlands. Climate in the region is dominated by Pacific maritime systems, and habitats range from agricultural lands, shrub and grassland, and wetland and riparian areas in the valley bottoms, to subalpine habitats at higher elevations. These habitats support a diversity of wildlife including many large mammals such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus),* elk (*Cervus elaphus*), moose (*Alces*

alces), black bear (*Ursus americanus*), grizzly bear (*Ursus arctos*), and mountain lion (*Puma concolor*). Land-use adjacent to the road corridor is heavily impacted by humans and includes agriculture, urban development, and residential use. Land ownership falls under private, tribal, state and federal holdings (Hardy et al. 2007).

Figure One: Study area in western Montana showing US 93 road corridor and crossing structure locations(red dots).

From 2004-2012 the Montana Department of Transportation (MDT) reconstructed portions of US 93 to allow for higher traffic volumes. The reconstructed road corridor is comprised of sections of divided and undivided 4-lane highway, 3 lane (one middle turn lane) highway, and undivided two lane highway. During reconstruction, MDT added 60 fish and wildlife crossing structures (between Polson and Hamilton), as well as extensive wildlife fencing on both sides of the road along selected road sections (Huijser et al. 2013; Cramer et al 2013). Many crossing structures are tied together with continuous wildlife fencing, while other structures have either no fencing or short sections of fencing that do not connect to another crossing structure. Extensive monitoring of animal movements through crossing structures is ongoing; however, little to no data is available about the pros and cons of wildlife crossing structures with either no wildlife fencing or short wildlife fencing in terms of human safety (reduce at-grade crossings) and habitat connectivity (allow for safe wildlife crossings) (Huijser et al. 2013; Cramer et al. 2013).

To date the US 93 reconstruction and monitoring project is the most extensive wildlife-sensitive design project in North America. Other examples of large-scale mitigation efforts in North America include: I-75 (Alligator Alley) in south Florida (24 crossing structures over 40 mi; Foster & Humphrey 1995), the Trans-Canada Highway in Banff National Park in Alberta, Canada (24 crossing structures over 28 miles (phase 1, 2 and 3A); Clevenger et al. 2002), State Route 260 in Arizona (17 crossing structures over 19 miles; Dodd et al. 2007a), and I-90 at Snoqualmie Pass East in Washington State (about 30 crossing structures planned over 15 miles; WSDOT 2007).

2.2 Study Design

Wildlife crossings at crossing structures and at-grade at fence ends were recorded with infrared remote sensing cameras (Reconyx Hyperfire PC900). Study sites were chosen based on meeting both of the following criteria:

1.) Underpass suitable for passage by large mammals. Underpasses selected had approximate dimensions of at least 3.5m high and between 7m and 30m wide (width is equal to road length in this context). Underpass types included concrete and metal arch culverts, and small open span bridges.

AND

2.) Existing short sections of wildlife “wing” fencing at each corner of the underpass. One crossing structure (Bass Creek North) had barrier walls extending <10m from each corner of the underpass, this was counted as short fencing. Fence lengths did not to exceed 400m from each corner of the underpass (combined length of the two fence sections on either side of the underpass on the same side of the road=<800m). This is based on the average home range size of a whitetail deer (0.5-1.2 km^2 in western Montana, minimum radius=400m) (Foresman 2012). Theoretically both the crossing structure and all fence ends are accessible to animals whose home range is centered at the crossing structure.

From June 2012-October 2013, ten sites were identified and monitored, each consisting of an isolated crossing structure (underpass) with short sections of wildlife fencing extending from each corner of the structure. A total of 10 underpass and 40 fence-end locations were sampled over the course of the study (see Table 1 and Figure 2 below). Wildlife cameras were placed at the entrance of each crossing structure and at all four fence ends in order to measure the proportion of large mammals (primarily white-tailed deer) using the crossing structure versus crossing at-grade (see Figure 2 below).

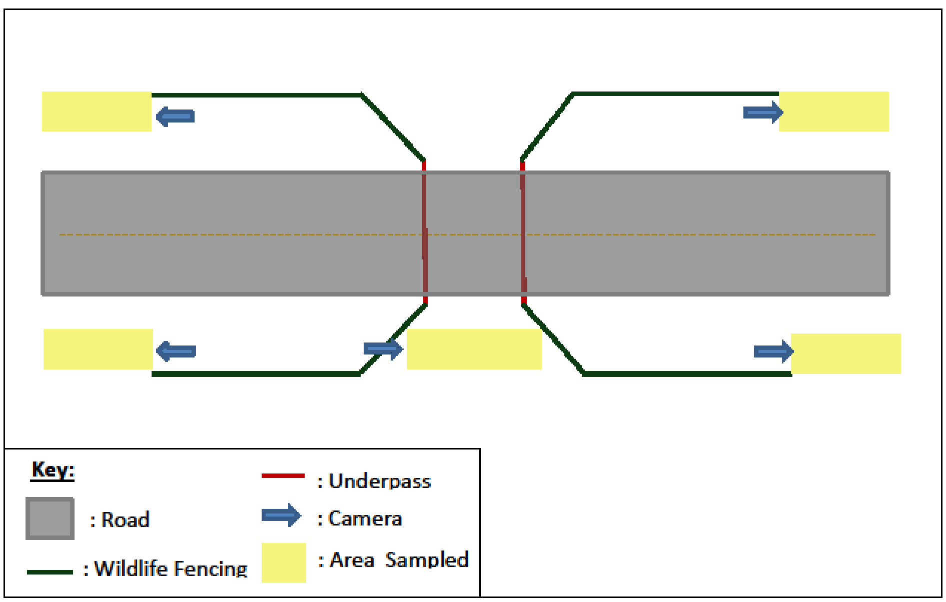

Figure 2. Study Design: Isolated underpass with limited fencing showing camera placement.

Five to six cameras equipped with SD Cards and lithium batteries were used at each site (1-2 at the underpass depending on its width and 1 at each fence end, see Figure 2 above). At fence end locations a stake was placed in the ground 10m from the fence end, and only crossings that occurred within 12m of the fence end were recorded. Cameras remained at each location until 14 full days (24 hours per day) of data were collected from all cameras on the same dates (meaning that if one camera failed or became full early then all cameras would need to stay out until the same 14 days were successfully recorded by all cameras at the site). Cameras were placed at an approximate height of ~1m in order to capture large mammal movements. Cameras were set to take 10 photos in rapid succession (in <10sec) each time they were triggered, with zero lag time in between events.

Fence lengths were measured by plotting the GPS coordinates of the crossing structures and fence ends in Google Earth (<5m accuracy), then measuring from each corner of the crossing structure (excluding the opening of the structure) to its associated fence end, measuring along the road. Fence length refers to the length of road that is fenced rather than the length of the actual fence which may zigzag.

Table 1. Underpasses monitored, and the length of fencing extending from each corner.

Crossing Structure	Year Built/Type of Structure	Fence End	Fence Length (meters)
Highway 206	2008 Culvert	N.E.	138
		N.W.	145
		S.E.	256
		S.W.	253
Post Creek 1	2006 Culvert	N.E.	30
		N.W.	82
		S.E.	81
		S.W.	36
Post Creek 2	2006 Culvert	N.E.	51
		N.W.	43
		S.E.	73
		S.W.	32
Post Creek 3	2006 Culvert	N.E.	46
		N.W.	98
		S.E.	82
		S.W.	91
Mission Creek	2006 Bridge	N.E.	141
		N.W.	130
		S.E.	158
		S.W.	176
Sabine Creek	2006 Culvert	N.E.	198
		N.W.	155
		S.E.	27
		S.W.	34
Bass Creek North	2005 Bridge	N.E.	3
		N.W.	5
		S.E.	4
		S.W.	7
Bear Creek South	2012 Bridge	N.E.	101
		N.W.	141
		S.E.	58
		S.W.	58
Mill Creek	2011 Bridge	N.E.	95
		N.W.	82
		S.E.	81
		S.W.	90
Blodgett Creek	2008 Bridge	N.E.	45
		N.W.	77
		S.E.	30
		S.W.	187

2.3 Analysis

A record was created for each individual large mammal movement event captured by the cameras at all locations. Each of the events could have one of four outcomes regarding whether or not the animal crossed or attempted to cross the road at either the crossing structure or the fence ends. The possible event outcomes include:

- **Yes (crossing):** If an animal entered or exited the crossing structure or ROW and did not come back within 3 minutes, it is considered a crossing. At fence ends, crossings were only counted if they occurred within 12m of the fence end. The images for fence ends across from one another were viewed at the same time to ensure that if the same crossing event was captured on more than one camera (i.e. seen both entering and exiting the roadway), it would be counted as only one crossing event, not two. Whether the event captured the entry or exit from the ROW, or both, was noted for all fence end crossings.
- **No crossing:** The animal was seen walking by the crossing structure or fence end but made no attempt to cross. Generally walking parallel to the road corridor.
- **Aborts (unsuccessful crossing attempt):** The animal approaches or begins to enter the crossing structure or ROW but comes back within 3 minutes.
- **Unknown:** The animal's movement is in a direction such that they may or may not have made a crossing however it is unclear based on the camera images.

Additionally, for each fence end event I recorded whether or not the animal ever entered or was present in the ROW (i.e. closer to the road than where the fence is). I also noted if they were foraging and whether the foraging occurred inside or outside the ROW.

In order to examine the effect of fence length on the proportional use of each underpass ($\frac{\#\ of\ crossings\ at\ UP}{Total\ \#\ of\ crossings\ at\ site\ (UP+4\ FE's)}$)and each of its four associated fence ends($\frac{\#\ of\ crossings\ at\ FE}{Total\ \#\ of\ crossings\ at\ site}$), I used a weighted linear regression analysis where the independent variable is fence length and the dependent variable is the proportional use of each fence end. Each point is weighted by the total number of crossings at its location (meaning crossings through structure + crossings at all four fence ends, with no double counts for crossings at fence ends).

3. Results

A total of 997 large mammal movements (events) were captured by all cameras during the study (see Table 2). Of these events, 727 (73%) resulted in an animal crossing the road corridor at either an underpass or a fence end. Over 99% of the large mammal crossings recorded (721 of the 727) were made by white-tailed deer, the remaining 6 crossings were made by bear species.

3.1 Proportional Use of Underpasses and Fence Ends:

The proportional use of each underpass varied among the 10 crossing structures sampled (min=24%, max=92%, avg=71%), however all of the heavily weighted sites (where the overall number of crossings is highest) show ≥ 84% of large mammals recorded using the underpass for crossing the road corridor. The proportional use of each individual fence end ranged from 0-50% of the sites total crossings, with an average of 8% (see Fig. 3 below) . Across all locations combined, 599 of the 727 recorded crossings (82% [C.I. 95%; ± 3%]) occurred at underpasses, with the remaining 18% of animals crossing at-grade at the fence ends.

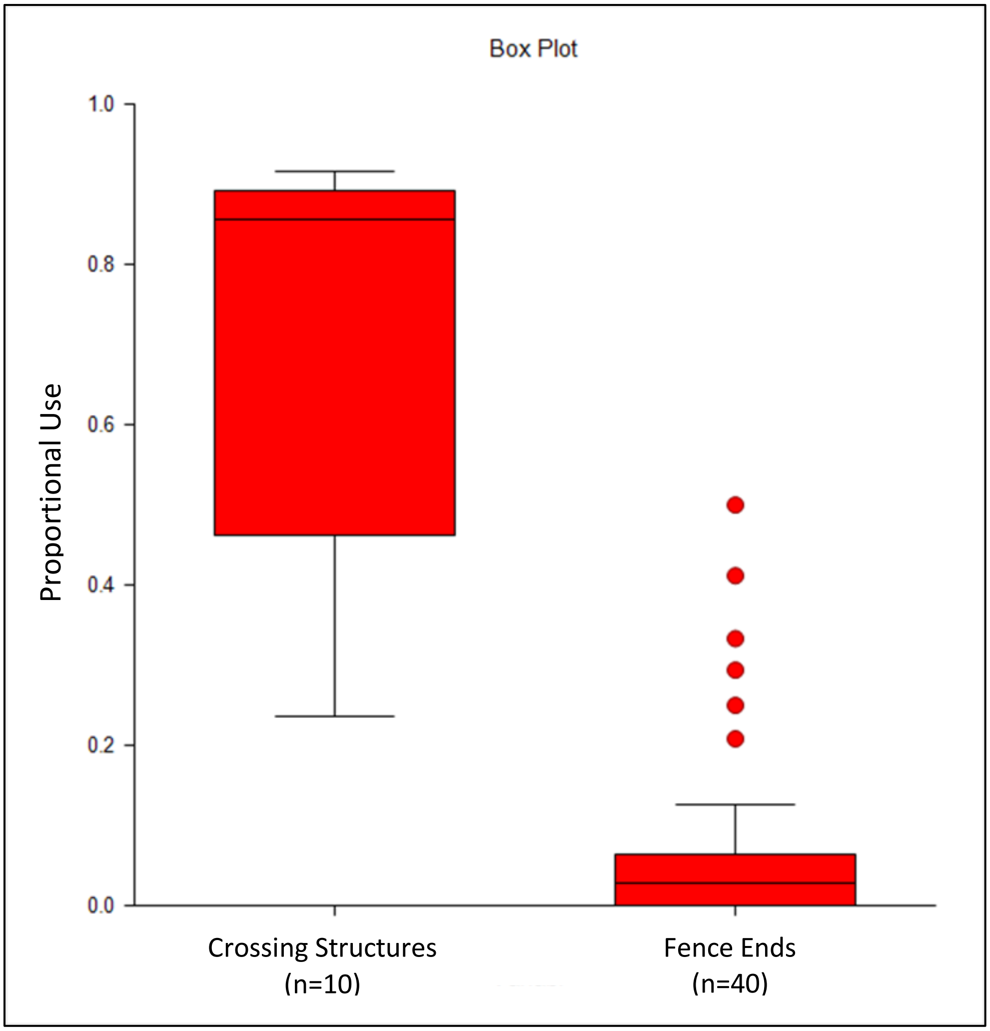

Figure 3: Box Plot showing the proportional use of each underpass and fence end location.

Table 2. Use of underpasses and associated fence ends by large mammals (99% white-tailed deer).

Crossing Structure	Total Crossings	Proportional Use of Underpass	Fence End	Fence Length (meters)	Proportional Use of Fence End
Highway 206	94	87%	N.E.	138	5%
			N.W.	145	5%
			S.E.	256	3%
			S.W.	253	0%
Post Creek 1	104	88%	N.E.	30	0%
			N.W.	82	0%
			S.E.	81	7%
			S.W.	36	5%
Post Creek 2	167	92%	N.E.	51	5%
			N.W.	43	0%
			S.E.	73	1%
			S.W.	32	2%
Post Creek 3	170	84%	N.E.	46	6%
			N.W.	98	6%
			S.E.	82	2%
			S.W.	91	2%
Mission Creek	27	89%	N.E.	141	7%
			N.W.	130	4%
			S.E.	158	0%
			S.W.	176	0%
Sabine Creek	17	24%	N.E.	198	41%
			N.W.	155	6%
			S.E.	27	29%
			S.W.	34	0%
Bass Creek North	3	67%	N.E.	3	0%
			N.W.	5	0%
			S.E.	4	33%
			S.W.	7	0%
Bear Creek South	81	90%	N.E.	101	4%
			N.W.	141	2%
			S.E.	58	2%
			S.W.	58	1%
Mill Creek	24	50%	N.E.	95	4%
			N.W.	82	0%
			S.E.	81	21%
			S.W.	90	25%
Blodgett Creek	40	35%	N.E.	45	3%
			N.W.	77	13%
			S.E.	30	0%
			S.W.	187	50%

3.2 Effect of Fence Length on At-Grade Crossings:

Using a linear regression analysis weighted by the total number of crossings at each site (underpass and four associated fence ends, see Table 2), I plotted the proportional use of each of the 40 fence ends as a function of the length of wildlife fencing associated with it (see Fig. 4 below). A majority of all fence end data points, and all of the heavily weighted fence end data points, show less than 7% proportional use of each fence end by large mammals. Proportional use remains steady across the range of fence lengths sampled (min=3.2m, max=256.70m, All fence lengths listed in Table 1).

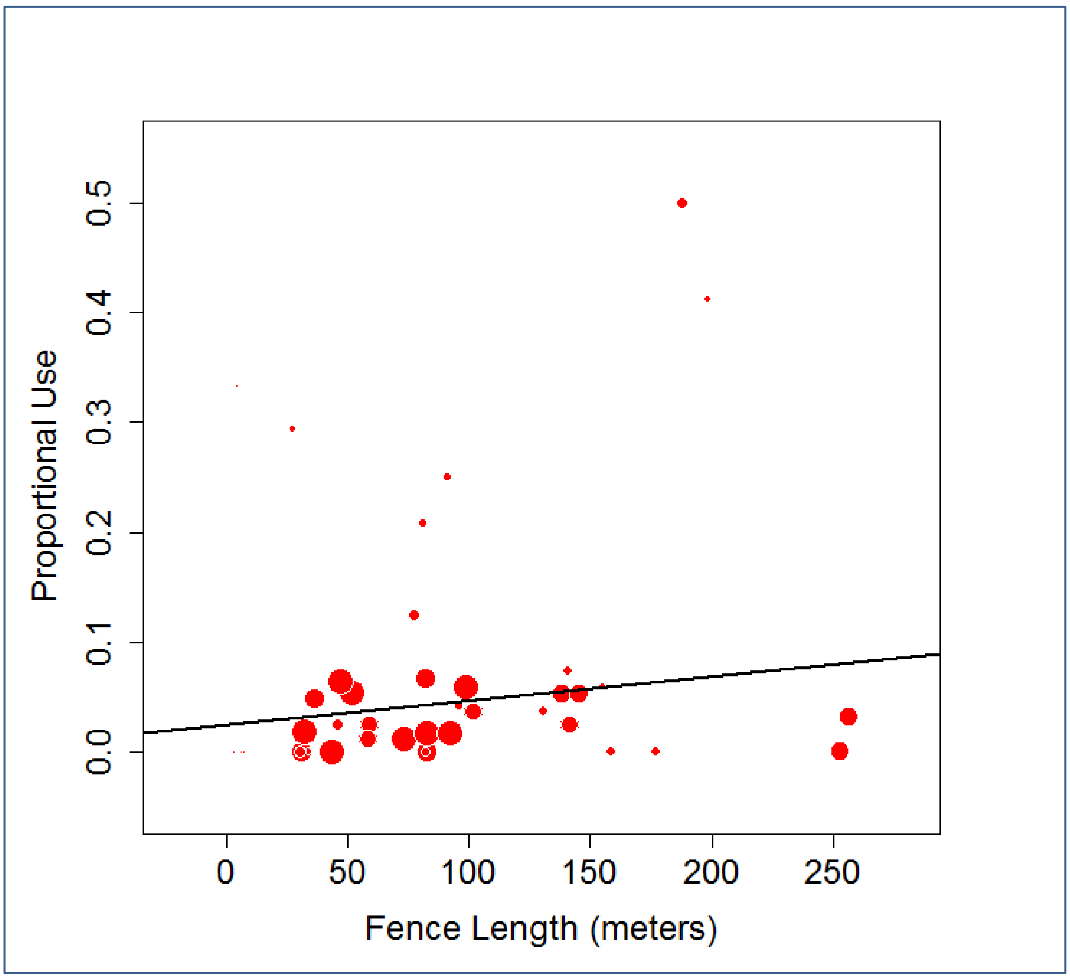

Figure 4: Bubble plot showing the proportional use of each fence end location for crossing as a function of fence length. Bubble size is proportional to the weight (total number of crossings at location [underpass and fence ends]) of each data point. N=40; R^2=0.0297; P=0.2878; slope=0.0002.

3.3 Wildlife Behavior at Fence Ends:

A total of 640 large animal movements (64%) were recorded at underpasses, with 599 (94%) resulting in a crossing. The remaining 357 events (36%) occurred at fence ends, with 164 animals (46% of all FE events) entering the ROW, and 128 (36%) of all fence end events resulting in a crossing. Deer were seen foraging in 126 (35%) of the fence end events, with 62 deer seen foraging within the fenced ROW (closer to the road than where the fence would be).

4. Discussion:

Overall this study found that 82% of all recorded crossings occurred at underpasses and only 18% at the fence ends. With 599 crossings occurring through the underpasses, this is an encouraging sign that these isolated crossing structures (in combination with short sections of fencing) are receiving substantial use by the target species and may promote connectivity of wildlife habitat on both sides of the road.

The variation in proportional underpass use across sites could be attributed to small sample sizes at some locations (see Table 2), as well as differences in the local landscapes. The five sites with the highest number of total crossings (n>81) all showed ≥84% use of the underpass as opposed to associated fence ends. The four sites that showed <70% proportional use of the underpass all had sample sizes of 40 total crossings or less and so could be drastically impacted by random events. These sites may be less indicative of the actual proportion of deer that land managers should expect to use underpasses vs. fence ends at other similar isolated structures with short sections of fencing. Differences in the surrounding landscape and the structural attributes of crossing structures could also play an important role in the proportion of large mammals expected to use crossing structures.

At the outset of this study I hypothesized that there would be a negative relationship between fence length and the proportional use of each fence end, meaning that as fence length increased the proportional use of the fence end for crossing would decrease. However over the range of fence lengths from 3m to 256m, there was no significant relationship between fence length and the proportional use of each fence end. Proportional use of each fence end remained steady at <10% across fence lengths sampled. Fence ends receiving >10% proportional use all occurred at sites with low sample sizes (≤40 total crossings). The fence end that received the highest proportional use (50%, Blodgett Creek SW) is located within a known WVC hotspot identified by Cramer et al. 2013 (see Cramer et al. 2013-Figure 5, milepost 50-51). Additionally, a deer carcass was present within 20m of this fence end upon camera setup. This suggests that there are specific site conditions at this location that make the animals cross at-grade.

Although most of the crossings occurred at underpasses, many deer were present around fence ends (n=357) and over 1/3 of all deer present at the fence ends made a crossing. Additionally, almost half (46%) of all deer present at fence ends entered or were present within the fenced ROW at some time during the event. This indicates that although deer may generally choose to cross the road corridor using the crossing structure, they will still be present in the ROW where they are not excluded. Deer were seen foraging in over 35% of fence end events, with nearly half of all foraging events occurring within the fenced ROW. This poses an interesting challenge to land managers in that the forage available in the ROW may act as an attractant to ungulate species, causing them in enter the fenced ROW even when they may have no intention of actually crossing the road.

Once an animal enters the ROW, it becomes at risk of road mortality due to a WVC. Animals in the ROW are also a risk to human safety and increase the likelihood of WVC's. This effect is further magnified when the animal enters the fully fenced road section (where fencing is present on both sides of the road), where it is then trapped in the road corridor and the only direction it can run if so inclined is towards the road and potentially toward oncoming traffic.

While short sections of wildlife fencing in combination with suitable crossing structures may result in substantial use of the safe crossing provided, this may not provide the desired reduction in WVC's. Because deer will still be inclined to enter the fenced ROW for reasons other than just crossing the road, short sections of fencing may frequently allow for animals to be present within the road corridor, thereby imposing considerable risk of potential WVC's. Fence end mitigation measures may be a very important tool for land managers to try to reduce WVC's where only short sections of fencing are available or possible.

Fence end mitigation measures can work in two ways. First, they can help keep animals which do enter the ROW from entering the fully fenced sections, where they are at higher risk for WVC's due to being trapped between wildlife fencing on both sides of the road. Second, they can slow traffic and/or alert drivers to areas where animals are likely to be near the road. Some fence end mitigation measures include:

- Boulder fields between the fence end and the road (as well as in the median where applicable) to deter ungulates from wandering into the fenced ROW. The boulder field may be 50-100m long along the roadway and should extend from the edge of the pavement up to the fence in order to preclude ungulates from navigating around them (for complete specifications and photos see Huijser et al. 2008a).
- Road related measures such as wildlife warning signs, slow speed zones, or the installation of traffic calming devices (such as speed bumps or rumble strips) near fence end locations may help to reduce WVC's, although the effectiveness of these measures is not well documented (Clevenger et al. 2001, Huijser et al. 2008a).

Although there are many factors at play in the effectiveness of various types of crossing structures and fencing regimes, this study provides valuable insight into wildlife behavior at and around isolated wildlife underpasses and their associated fence ends. More long term research is needed to allow for higher sample sizes and greater certainty, especially at sites where total crossing numbers are low. Overall this study indicates that isolated underpasses with short sections of fencing can still receive substantial use by large mammals and may be a useful tool for reducing the barrier effect of roads and providing habitat connectivity for large mammals. However, my literature review, in combination with the wildlife behavior observed at fence ends in this study, suggest that short sections of fencing may be far less effective in reducing WVC's than longer sections of fencing (covering several miles), as deer will frequently enter the ROW where the fencing ends. More extensive fencing or other additional fence end mitigation measures may be necessary to minimize the fence end effect and effectively reduce the risk of WVC's.

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References:

Ascensão, F., Clevenger, A., Santos-Reis, M., Urbano, P., & Jackson, N. (2013). Wildlife–vehicle collision mitigation: Is partial fencing the answer? An agent-based model approach. Ecological Modelling, 257, 36-43.

Beckman, J.P. and J.A. Hilty. 2010. Connecting wildlife populations in fractured landscapes. In Beckman, J.P., Clevenger, A.P., Huijser, M.P. and J.A. Hilty (Eds.), *Safe Passages: Highways, Wildlife, and Habitat Connectivity* (pp.3-16). Washington D.C., USA: Island Press.

Bissonette, J.A., and W. Adair. 2008. "Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings." *Biological Conservation* 141:482-488.

Bissonette, J.A., and P.C. Cramer; National Cooperative Highway Research Program. 2008. "Wildlife and Roads: A resource for mitigating the effects of roads on wildlife using wildlife crossings such as overpasses, underpasses, and crosswalks." Available from the internet: http://www.wildlifeandroads.org/decisionguide/2_1_6.cfm

Bond, A.R., and D.N. Jones. 2008. "Temporal trends in use of fauna-friendly underpasses and overpasses." *Wildlife Research* 35:103-112.

Clevenger, A. P., Chruszcz, B., & K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* 29(2), 646-653.

Clevenger, A.P., Chruszcz, B. Gunson, K., and J. Wierzchowski. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks-Movements, mortality, and mitigation. Final report to Parks Canada. Banff, Alberta, Canada.

Cramer, P. C. and J. A. Bissonette. 2005. Wildlife crossings in North America: The state of the science and practice. In *Proceedings of the 2005 International Conference on Ecology and Transportation*, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006. 442-447.

Cramer, P.C., Hamlin, R., Gunson, K.E., and M. Greenwood. 2013. Montana US Highway 93 South Wildlife Crossings Research 2012 Annual Report. Prepared for the Montana Department of Transportation. Available from the internet: http://www.mdt.mt.gov/other/research/external/docs/research_proj/us93_wildlife/progress_jan13.pdf

Cserkész, T., Ottlecz, B., Cserkész-Nagy, Á., & Farkas, J. 2013. Interchange as the main factor determining wildlife–vehicle collision hotspots on the fenced highways: spatial analysis and applications. *European Journal of Wildlife Research* 1-11.

Dodd, N.L., Gagnon, J.W., Boe, S., and R.E. Schweinsburg. 2007a. Role of fencing in promoting underpass use and highway permeability. In *Proceedings of the 2007 International Conference on Ecology and Transportation*, edited by C. Leroy Irwin, Debra Nelson, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2007.

Dodd, N. L., Gagnon, J. W., Manzo, A. L., and R.E. Schweinsburg. 2007b. Video surveillance to assess highway underpass use by elk in Arizona. *The Journal of Wildlife Management* 71(2), 637-645.

Foresman, K.R. 2012. Mammals of Montana. Second Edition. Missoula, Montana: Mountain Press Publishing Company.

Foster, M. L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23(1): 95-100.

Hardy, A. R., Fuller, J., Huijser, M. P., Kociolek, A., and M. Evans. 2007. Evaluation of wildlife crossing structures and fencing on US Highway 93 Evaro to Polson -- Phase I: Preconstruction data collection and finalization of evaluation plan final report." FHWA/MT-06-008/1744-2, Montana Department of Transportation, Helena, Montana, USA. 210 pp. Available from the internet: http://www.mdt.mt.gov/research/projects/env/wildlife_crossing.shtml

Huijser, M. P., McGowen, P. T., Clevenger, A. P., & R. Ament. 2008a. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. Available from the internet: http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm

Huijser, M. P., McGowen, P., Fuller, J., Hardy, A., Kociolek, A., Clevenger, A. P., Smith, D., and R. Ament. 2008b. Wildlife-vehicle Collision Reduction Study. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. 232 pp. Available from the internet: http://www.tfhrc.gov/safety/pubs/08034/index.htm

Huijser, M. P., Duffield, J. W., Clevenger, A. P., Ament, R. J., & P.T. McGowen. 2009. Cost–benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. *Ecology and Society* 14(2), 15.

Huijser, M.P. and P.T. McGowen.2010. Reducing wildlife-vehicle collisions. In Beckman, J.P., Clevenger, A.P., Huijser, M.P. and J.A. Hilty (Eds.), *Safe Passages: Highways, Wildlife, and Habitat Connectivity* (pp.51-74). Washington D.C., USA: Island Press.

Huijser, M.P., Purdam, J.P. and W. Means. 2012. US 93 Post-construction wildlife-vehicle collision and wildlife crossing monitoring and research on the Flathead Indian Reservation between Evaro and Polson, Montana: Annual Report 2012. Western Transportation Institute College of Engineering Montana State University, Bozeman, Montana, USA. 31pp. Available from the internet: http://www.mdt.mt.gov/other/research/external/docs/research_proj/wildlife_crossing/phaseii/annual_2012.pdf

Jaeger, J. A., & Fahrig, L. (2004). Effects of road fencing on population persistence. Conservation Biology, 18(6), 1651-1657.

Lesbarrères, D., & Fahrig, L. (2012). Measures to reduce population fragmentation by roads: what has worked and how do we know?. Trends in ecology & evolution, 27(7), 374-380.

McCollister, M. F., & Van Manen, F. T. (2010). Effectiveness of Wildlife Underpasses an Fencing to Reduce Wildlife-Vehicle Collisions. Journal Of Wildlife Management, 74(8), 1722-1731.***

USDOT: Federal Highway Administration, Office of Highway Policy Information. 2011. “Our Nation's Highways: 2011”. Available from the internet: http://www.fhwa.dot.gov/policyinformation/pubs/hf/pl11028/chapter1.cfm#fig14

van der Grift, E. A., van der Ree, R., Fahrig, L., Findlay, S., Houlahan, J., Jaeger, J. A., ... and Olson, L. (2013). Evaluating the effectiveness of road mitigation measures. Biodiversity and Conservation, 22(2), 425-448.

Ward, A. L., “Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. “ Transportation Research Record Vol. 859 (1982) pp. 8-13.

WSDOT. 2007. Snoqualmie Pass east folio. Washington Department of Transportation, Olympia, Washington State, USA .2 pp. Available from the internet: http://www.wsdot.wa.gov/NR/rdonlyres/F8067230-75B1-4CB6-907D-0299F4E17F97/0/I90SnoqPassEastFolio_03_2007.pdf